KJ College of Engineering and Management Research, Pune

3rd International Conference on



ICITET-2025

12TH & 13TH JUN 2025

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Dr. Suhas Khot

Editor
Prof. Gayatri S. Patil
Dr. Neha S. Shahare
Dr. Atul B. Pujari
Dr. Sunita Deshmukh
Dr. Vivek B. Korde

3rd International Conference

on

"Innovative Trends in Engineering and Technology (ICITET-2025)"

June 12th -13th, 2025

Editor

Prof. Gayatri S. Patil

Dr. Neha S. Shahare

Dr. Atul B. Pujari

Dr. Sunita Deshmukh

Dr. Vivek Korde

Organized and Published By

KJ's Educational Institute

K J College of Engineering and Management Research, Pune

ISBN Number: 978-93-343-2006-0

ISBN: 978-93-343-2006-0

Preface

It gives me immense pleasure to welcome you to the "3rd International Conference on "Innovative Trends in Engineering and Technology" (ICITET-2025) held from [12-13th June 2025], organized by KJCOEMR, Pune under the theme "Innovative Trends". This international gathering brings together scholars, researchers, industry professionals, and academicians from across the globe to share innovative ideas, present their research findings, and engage in fruitful discussions on emerging trends and challenges in the field.

The conference proceedings serve as a valuable record of the knowledge exchanged during this event and showcase the diversity and depth of contributions received. We are proud to include a wide range of peer-reviewed papers that reflect the latest advancements, theoretical insights, and practical applications across multiple disciplines.

We sincerely thank all the authors for their high-quality submissions, the reviewers for their critical insights and timely feedback, and the session chairs for ensuring the smooth flow of discussions. A special note of appreciation goes to our organizing committee and volunteers whose hard work and dedication made this event possible.

We hope this conference fosters meaningful collaborations and inspires future research and innovation. Thank you for being a part of this journey.

Warm regards,

Prof.Gayatri S. Patil, HoD, Mechanical Engg

Dr. Neha S. Shahare, HoD, ACT Engg.

Dr.Atul B. Pujari, HoD, Civil Engg.

Dr.Sunita Deshmukh, HoD, VLSI D&T Engg.

ISBN: 978-93-343-2006-0

Message from the President

It is with great pride and pleasure that I extend a warm welcome to all participants of the "3rd International Conference on "Innovative Trends in Engineering and Technology" (ICITET-2025), hosted by KJ college of Engineering Management and Research, Pune from 12-13th June 2025. This prestigious international conference marks a significant milestone in our institution's ongoing commitment to academic excellence, research innovation, and global collaboration.

The theme of this 3rd conference resonates deeply with the current global challenges and opportunities in the [Computer/ E&Tc / Electrical / Mechanical / Civil /Engineering Science and AI]. By bringing together distinguished researchers, academicians, professionals, and students from diverse regions and disciplines, we aim to foster an enriching environment of knowledge exchange, critical thinking, and collaborative discovery.

The conference proceedings reflect the intellectual vibrancy and scholarly rigor of this event. They are a testament to the collective efforts of all contributor's authors, reviewers, session chairs, and organizers whose dedication has made this conference a success. I am confident that the ideas and innovations shared here will leave a lasting impact and inspire new directions in research and practice.

On behalf of KJ college of Engineering Management and Research, Pune, I thank you for your participation and wish you a rewarding and intellectually stimulating experience.

Warm regards,

Hon. Shri. Kalyan Jadhav
Founder President, KJEI, Pune

ISBN: 978-93-343-2006-0

Message from the Patron

It gives me immense pleasure to welcome all distinguished guests, researchers, academicians, industry experts, and participants to the 3rd International Conference on Innovative Trends in Engineering and Technology (ICITET-2025), organized by K J College of Engineering and Management Research, Pune, India on 12th and 13th June 2025.

In the era of rapid technological advancement and global integration, this conference serves as a dynamic platform for exchanging novel ideas, showcasing cutting-edge research, and fostering collaboration among global minds. It reflects our institution's commitment to academic excellence, innovation, and knowledge-driven growth.

I am confident that the insights and discussions during this two-day event will lead to meaningful outcomes and open new avenues for interdisciplinary research and technological development.

I congratulate the organizing committee for their dedication and wish the conference grand success.

Dr. Suhas S. Khot

Principal and Patron of Conference

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ISBN: 978-93-343-2006-0

IOT Based Child Security System Designed For School Bus

Associate Prof.Lakshmiprabha
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail: laxmi-prabha.balaji@dypiemr.com

Sakshi Jadhav
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail:sanjanasj13@gmail.com

Siya Rawani
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail:rawanisiya3@gmail.com

Shrushti Kumbhar
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail:megha-kumbhar1005@gmail.com

ABSTRACT:

This project focuses on the development of an IoT-based child security system designed to enhance the safety and monitoring of school-going children during transportation. The system enables real-time tracking and notification of school bus locations, aiming to improve both student security and the efficiency of the transportation process.
The core of the system is built around the ESP32 microcontroller, equipped with built-in Wi-Fi and Bluetooth capabilities. It incorporates a GPS module for live location tracking and an RFID reader for the first level of student identity verification during boarding and deboarding. To further strengthen security, an ESP32-CAM module is configured with Telegram to transmit real-time images as a second verification method. Additional hardware includes switches for START and SOS functions, along with a GSM module to send alerts and notifications during emergencies or abnormal situations.
A user-friendly mobile and web application developed using MIT App Inventor allows parents and school administrators to monitor the bus's movement in real time. The application displays individual student entry and exit times along with the corresponding locations. For backend support, Firebase is integrated as a cloud database to manage and store student timestamps, bus activity logs, and emergency alerts.

The system leverages C-based libraries within the Arduino IDE for seamless communication between the ESP32, GPS, RFID, GSM, and Firebase modules.

KEYWORDS:

IoT, Student Safety, RFID, GPS Tracking, ESP32, Real-Time Monitoring, School Bus Security, Firebase, Mobile Application, Image Verification, GSM Alerts, MIT App Inventor, Child Tracking System, ESP32-CAM, Cloud-Based Monitoring

1.INTRODUCTION

In today's fast-paced world, ensuring the safety of school children during transportation has become a growing concern for both parents and educational institutions. With increasing incidents of negligence and safety breaches during school bus commutes, there is a pressing need for a smart and efficient solution that can monitor and manage student security in real time.
This project introduces an IoT-based child security system specifically designed for school buses. By combining modern communication technologies with intelligent hardware, the system offers real-time tracking of the school bus, verification of student entry and exit, and immediate alert notifications in case of emergencies. The solution integrates key components such as the ESP32 microcontroller, GPS module for live location tracking, RFID readers for student authentication, and an ESP32-CAM for visual verification using image transmission via Telegram.
To enhance accessibility and transparency, the system is supported by a mobile and web application built using MIT App Inventor. This interface allows parents and school authorities to view live bus locations, student boarding and deboarding times, and receive instant alerts. Additionally, Firebase is used as a cloud platform to store and manage all data, including timestamps and emergency records, ensuring secure and organized information handling.
By utilizing C-based libraries within the Arduino IDE for component communication, the system ensures smooth operation and optimized performance. This innovative approach not only strengthens child safety but also improves the reliability and accountability of school transport services.

2.PROBLEM STATEMENT

Despite the increasing use of technology in education and transportation, the safety of children during their commute to and from school remains a major concern for parents and school authorities. Traditional school bus systems often lack real-time monitoring, proper verification of student entry and exit, and immediate response mechanisms in case of emergencies. This lack of visibility and control can lead to delayed communication, misplaced children, and inefficient transport management. There is a need for a smart, automated, and reliable system that can track the school bus in real time, verify each student's presence at every stop, and provide instant notifications to both parents and school administrators. The system should also be capable of handling emergency alerts, storing data securely, and ensuring easy access through user-friendly mobile and web applications.

3. OBJECTIVES

To develop a real-time tracking system that monitors the live location of school buses using GPS and displays it on mobile and web platforms accessible to parents and school authorities.

1. **To implement a dual-level student verification mechanism** using RFID tags for initial identification and an ESP32-CAM module for image-based verification via Telegram.
2. **To provide instant notifications and alerts** to parents and school administrators using GSM technology in case of emergencies or unauthorized events.
3. **To maintain accurate records of student boarding and deboarding** times and locations using RFID and cloud-based data storage through Firebase.
4. To design a user-friendly application using MIT App Inventor for real-time access to student activity, bus status, and emergency alerts.
5. **To integrate and synchronize all hardware modules** using C-based libraries within the Arduino IDE for reliable system performance and data flow.
6. **To enhance school transport safety and efficiency** by automating student monitoring and reducing manual errors or miscommunication.

4.LITERATURE REVIEW

With the advancement of Internet of Things (IoT) technologies, various smart systems have been developed to enhance safety and monitoring in transportation, especially in the domain of child security. Several researchers and developers have proposed solutions that focus on real-time tracking, automated attendance, and emergency alert mechanisms for school buses.

Previous studies have explored the use of **RFID-based attendance systems**, where students carry RFID tags that are scanned during entry and exit. These systems have proven effective in reducing manual errors and maintaining digital records. However, most of these solutions lack real-time tracking and do not integrate image verification, limiting their reliability in critical situations.

Research involving **GPS-enabled tracking systems** has demonstrated the importance of live location updates for parents and school authorities. These systems enhance transparency and allow quicker response in case of route deviations or delays. However, many of these implementations do not link the location data with individual student verification, making it difficult to confirm who is present on the bus.

Some existing projects have introduced **GSM modules** for alert messages and updates. While effective for basic notifications, these systems often suffer from integration issues and do not offer multi-layered verification or cloud-based data management.

Recent developments have shown a shift towards **IoT-based integrated platforms** that combine multiple modules such as RFID, GPS, GSM, and cloud services. These systems are more robust, offering both tracking and verification features. The integration of **ESP32 microcontrollers and Firebase** has emerged as a powerful combination due to its low cost, wireless communication capability, and real-time database management.

In conclusion, while past research has addressed individual aspects of child safety in school transportation, there remains a gap in comprehensive systems that combine **real-time location tracking, dual-layer student verification, emergency alerting, and cloud-based data storage**—all accessible via user-friendly mobile and web applications. This project aims to fill that gap with a fully integrated IoT solution tailored for school bus security.

5. SYSTEM ARCHITECTURE AND DESIGN

The system architecture of the IoT-Based Child Security System for School Bus is designed to ensure seamless communication between hardware components, cloud services, and user interfaces. It is structured into three main layers: Hardware Layer, Communication & Processing Layer, and Application Layer.

5.1 HARDWARE LAYER

THIS LAYER CONSISTS OF ALL THE PHYSICAL DEVICES INSTALLED ON THE SCHOOL BUS:

ESP32 Microcontroller: Acts as the central control unit, handling data from all sensors and modules.
RFID Reader: Used for the first-level student verification by scanning RFID cards during boarding and deboarding.
GPS Module: Provides real-time location data of the bus.
ESP32-CAM Module: Captures images of students for second-level verification and sends them through Telegram.
GSM Module: Sends emergency alerts and location-based SMS notifications to parents and school authorities.
Switches: Used for system start/stop control and emergency SOS signaling.

5.2 COMMUNICATION & PROCESSING LAYER

THIS LAYER IS RESPONSIBLE FOR PROCESSING DATA AND MANAGING COMMUNICATION BETWEEN THE BUS HARDWARE AND THE CLOUD:

Wi-Fi/Bluetooth (via ESP32): Transfers data from the microcontroller to the cloud database and communication services.
Firebase Cloud Database: Stores student entry/exit timestamps, bus location updates, emergency alerts, and verification logs.
Telegram Bot Integration: Used to send images captured by the ESP32-CAM for additional security validation.

5.3 APPLICATION LAYER

This is the user interaction layer for both parents and school

administrators:
MIT App Inventor-Based Mobile App: Allows users to track the bus in real time, view student boarding/deboarding details, and receive alerts.
Web Application: Provides similar functionality as the mobile app and is designed for school administration to monitor overall bus activity.

5.4 DATA FLOW SUMMARY

- Student scans RFID tag → Data sent to ESP32.
- ESP32 captures image via ESP32-CAM → Sent to Telegram.
- GPS tracks bus location → Data sent to Firebase.
- GSM sends SMS alerts in case of emergencies.
- All data stored in Firebase → Displayed on mobile/web apps.

This modular and layered system architecture ensures a reliable, scalable, and user-friendly solution for enhancing child safety during school transportation.

6.METHODOLOGY

The methodology for the IoT-based child security system is designed to ensure accurate real-time monitoring and verification of students during school bus transportation. The system integrates hardware components, cloud services, and user applications to provide a comprehensive safety solution.

6.1 HARDWARE SETUP:

The system uses an ESP32 microcontroller as the central unit, interfacing with various modules including RFID readers, GPS, ESP32-CAM, GSM, and switches. Each student is provided with an RFID card which they scan when boarding or exiting the bus. The GPS module continuously tracks the bus's real-time location. The ESP32-CAM captures images for secondary verification and transmits them via Telegram.

6.2 DATA ACQUISITION AND PROCESSING:

When a student scans their RFID card, the ESP32 reads the unique ID and records the timestamp. Simultaneously, the GPS module provides the current coordinates of the bus. The ESP32-CAM captures a photo to visually confirm the student's identity. These data points are processed locally on the ESP32 and then transmitted to the cloud database.

6.3 CLOUD INTEGRATION:

Firebase is used as the cloud platform to store all relevant data, including student entry and exit times, bus location updates, and emergency alerts. The system updates Firebase in real-time, ensuring that parents and school administrators can access current information without delay

6.4 NOTIFICATION SYSTEM:

In case of emergencies or irregularities—such as a student failing to scan out at the correct stop or the activation of the SOS switch—the GSM module sends instant SMS alerts to parents and school authorities. Additionally, Telegram messages containing captured images provide an extra layer of security verification.

6.5 USER INTERFACE:

A mobile and web application, developed using MIT App Inventor, enables parents and school staff to monitor the bus location, view student boarding/deboarding records, and receive notifications. The interface displays timestamps and locations associated with each student's travel, enhancing transparency and communication.

6.6 SYSTEM SYNCHRONIZATION:

All hardware modules communicate through the ESP32 microcontroller, with software developed in the Arduino IDE using C-based libraries to ensure efficient operation. The synchronization between real-time data capture, cloud storage, and user notification is managed seamlessly for reliable performance.
This methodology ensures a robust and user-friendly system that improves child safety and streamlines school bus transportation management.

7. IMPLEMENTATION

The implementation of the IoT-based child security system involves the integration of hardware components, software programming, cloud storage, and a user interface to achieve real-time monitoring and secure student verification during school bus travel. The process was carried out in several phases:

7.1 Hardware Integration:

- ESP32 Microcontroller was selected as the central processing unit due to its built-in Wi-Fi and Bluetooth capabilities, enabling wireless data transmission.
- An RFID Reader was connected to the ESP32 to scan each student's RFID card during boarding and deboarding.
- A GPS Module was used to provide the real-time geographical coordinates of the bus.
- An ESP32-CAM was configured to capture and transmit images of students through Telegram for additional verification.
- A GSM Module was implemented to send SMS alerts in emergency situations.
- Two switches were added: one for starting the system and another as an SOS panic button for emergencies.

7.2 Software Development:

- The firmware for ESP32 was developed using **Arduino IDE**, where C-based libraries were utilized for handling the GPS, RFID, GSM, and Firebase modules.
- The ESP32 continuously reads RFID inputs, checks location via the GPS module, captures images, and uploads this information to **Firebase**, a real-time cloud database.
- **Telegram Bot API** was integrated using HTTP requests to send captured images for visual confirmation.

7.3 Cloud Configuration:

Firebase Realtime Database was configured to store:

- Student entry and exit timestamps
- Bus location logs
- Emergency SOS activations
- RFID authentication records

The database allows continuous synchronization between the microcontroller and the user interface (mobile and web apps).

7.4 Application Development:

- A mobile application was created using MIT App Inventor.

- The app connects to Firebase and displays:
- Current bus location
- Student in/out logs with time and location
- Emergency alerts and status
- Parents and school staff can log in to monitor their respective data securely.

7.5 Testing and Validation:

- The system was tested in a controlled environment to simulate boarding, tracking, and emergency scenarios.
- Each module was validated for reliability, speed, and accuracy.
- Real-time data updates and alert notifications were monitored to ensure system responsiveness.

This implementation provides a secure, reliable, and efficient system for improving student safety and bus transport management. By integrating IoT technologies, the solution offers real-time monitoring, quick alerts, and a transparent communication platform for parents and school authorities.

8 SYSTEM ARCHITECTURE :

The system architecture of the IoT-based child security system is designed to enable real-time monitoring, secure student identification, and effective communication between the school bus, cloud server, and end users. It is structured into three major layers: Sensing Layer, Network & Processing Layer, and Application Layer

8.1 Sensing Layer (Hardware Components)

- This layer includes all the on-bus hardware devices responsible for data collection and initial processing:
- RFID Reader: Detects and reads RFID cards assigned to each student to register their boarding and deboarding events.
- GPS Module: Continuously fetches the current geographic coordinates of the bus.
- ESP32 Microcontroller: Acts as the central unit, interfacing with all modules and managing data collection and transmission.
- ESP32-CAM Module: Captures images of students at entry and exit points for additional identity verification.
- GSM Module: Sends SMS alerts to parents and school authorities during emergency or abnormal events.
- Switches: Used to start the system or trigger an SOS alert in emergency situations.

8.2 Network & Processing Layer:

- Wi-Fi/Bluetooth via ESP32: Enables wireless communication between the hardware and the cloud (Firebase).
- Data Processing Logic: The ESP32 microcontroller processes incoming data from the RFID, GPS, and CAM modules and determines valid events.
- Telegram API: Sends real-time images captured by ESP32-CAM to a Telegram channel for parent or admin verification.
- Firebase Realtime Database: Stores data such as student check-in/out times, current bus location, emergency triggers, and verification status.

8.3 Application Layer (User Interface):

- Mobile App (MIT App Inventor): Allows parents to view real-time bus tracking, student logs, and receive alerts or notifications.
- Web Dashboard: Designed for school administrators to monitor all buses, student statuses, and emergency cases.
- Authentication System: Ensures that only authorized users can access the information relevant to their children or buses.

8.4 System Communication Flow:

- Student scans RFID card → Data sent to ESP32
- GPS provides location → ESP32 processes and sends to Firebase
- ESP32-CAM captures image → Sent to Telegram
- GSM module sends emergency alert (if needed)
- Mobile/Web App fetches data from Firebase for real-time display

9. RESULTS AND OUTPUT :

The implemented system demonstrated successful integration of all hardware and software components, enabling reliable real-time monitoring and verification. The RFID module accurately recorded each student's entry and exit, with timestamps immediately updated in the Firebase cloud database. The GPS module provided continuous live tracking of the school bus, which was reflected in both the mobile application and web dashboard. The ESP32-CAM effectively captured images during student entry and transmitted them through a configured Telegram bot, providing visual confirmation for parents and school authorities. Emergency situations triggered via the SOS switch resulted in instant SMS alerts through the GSM module, along with real-time notifications on the app.

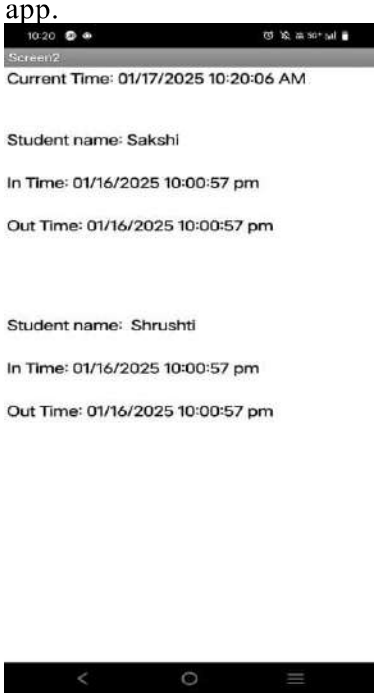


Fig: Firebase database entries (timestamps, RFID logs)

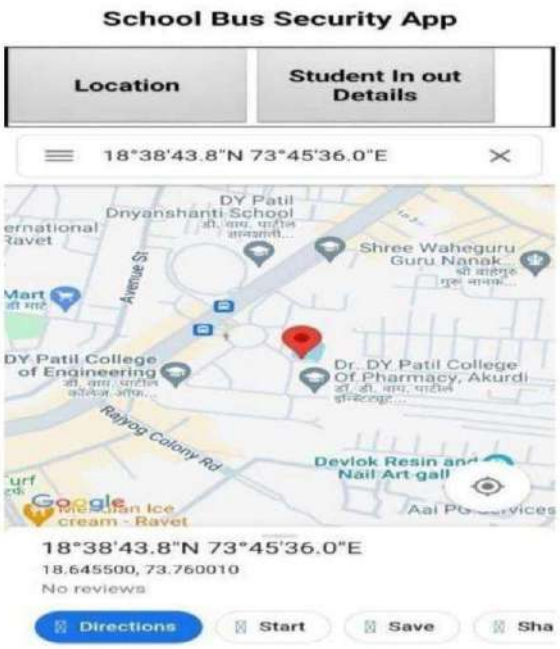


Fig. 19: Location

Fig: Web panel with live map

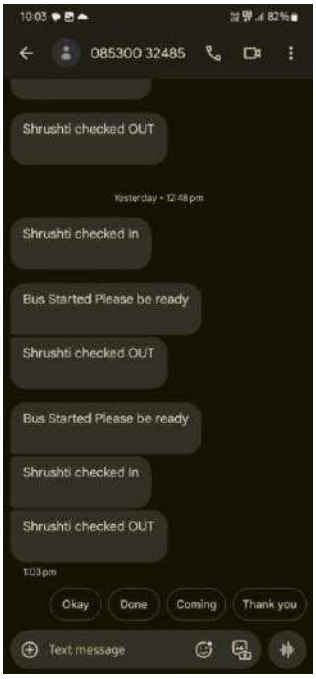


Fig: SMS Notification through GSM Module

10 . LIMITATIONS

While the IoT-based child security system for school buses offers enhanced safety and real-time monitoring, it does come with certain limitations. The system is highly dependent on a stable internet connection, and any disruption in network coverage can lead to delayed data uploads or missed notifications. Additionally, the reliability of the GSM module for sending SMS alerts may vary depending on the signal strength, especially in remote or congested areas. The accuracy of the image verification process also depends on proper lighting conditions and camera positioning, which may not always be ideal inside a moving vehicle. Another concern is the possibility of students forgetting or misusing their RFID cards, which can lead to incorrect attendance records. Furthermore, the ESP32 microcontroller has limited memory and processing power, which can restrict data handling during peak usage. Regular maintenance and power supply stability are also necessary to ensure uninterrupted system performance. Lastly, storing student data, images, and location information on the cloud introduces potential privacy risks, making it essential to implement robust data protection and access control measures.

11. FUTURE SCOPE

The proposed IoT-based child security system has significant potential for future development and expansion. In the coming years, the system can be enhanced with features such as facial recognition using advanced AI models to provide more accurate identity verification without relying solely on RFID cards. Integration with GPS geofencing can automate alerts when a bus enters or leaves predefined zones, improving route monitoring. The mobile application can be upgraded with live video streaming capabilities for parents to view bus interiors in real time, further enhancing transparency and safety. Additionally, implementing data encryption and user authentication protocols can strengthen data privacy and system security. The system could also support voice alerts and multilingual notifications to cater to diverse users. With cloud-based analytics, school administrators could gain insights into route efficiency, attendance trends, and emergency response patterns. As IoT technologies evolve and become more cost-effective, this system can be deployed at a larger scale across school networks, ensuring safer and smarter transportation for students.

12.ACKNOWLEDGEMENT

We extend our sincere gratitude to Dr. D. Y. Patil Institute of Engineering, Management and Research for providing the essential resources and support for this research. We sincerely thank our mentor for their invaluable guidance and our peers for their support and insightful feedback.

13.CONCLUSION

The IoT-based child security system designed for school buses offers a reliable and efficient solution to enhance the safety and monitoring of students during transportation. By integrating components such as RFID, GPS, ESP32, camera modules, and cloud storage, the system enables real-time tracking, identity verification, and instant alerts to parents and school authorities. The mobile and web applications developed provide a user-friendly interface to access crucial information, improving transparency and communication. Although the system has some limitations, such as dependency on internet connectivity

and hardware constraints, it successfully addresses many critical concerns related to student transportation. With further improvements and technological advancements, this system can be scaled and adapted to meet the growing safety needs of educational institutions. Overall, the project demonstrates how IoT can be effectively applied to create smarter and safer school environments.

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"WI-FI BASED DC MOTOR SPEED CONTROLLER USING ESP32"

Mr. Ganesh Ananda Patil
KJ College of Engineering and Management Research, Pune

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The Internet of Things (IoT) is taking great hold in today's technology since it facilitates comfortable and remote monitoring of machines using sensors. On the other hand, DC motors are used in industry as well as home applications. Monitoring and controlling it is a very crucial task. This project is about monitoring several parameters such as the current, voltage, temperature, and speed of an induction motor, and controlling its speed by IOT. The faults are sensed using sensors and are stored in the cloud thereby enabling one to monitor the machine with reduced manual intervention. If the engine hasa faulty state (current), the user will be notified of this issue via the mobile application

This paper details the design and implementation of an Android mobile-based system for controlling the speed of direct current (DC) motors, utilizing modern microcontrollers and wireless fidelity (Wi-Fi) technology. The system is designed and implemented using an Android mobile device, modern microcontrollers, and cloud-based IoT technology. The system incorporates a DC motor, a relay module, an electronic speed controller (ESC), and an ESP-32 microcontroller, which enables remote control of the motor's speed and direction by utilizing the android device and the integration of the ESP-32 microcontroller with the Arduino cloud platform. The results present diverse DC motor control applications in automation and IoT-enabled devices. Advanced motor control techniques have been successfully proven by results from experiments that allow the integration of mobile devices within a 70-meter range for different speed controls.

ISBN: 978-93-343-2006-0

1. Introduction

Advancements in IoT and wireless communication, the ability to control and monitor devices remotely has become increasingly valuable. This project, Wi-Fi-Based DC Motor Speed Controller Using ESP32, harnesses the power of the ESP32 microcontroller's Wi-Fi capabilities to allow users to control the speed of a DC motor through a web interface or mobile application. By utilizing Pulse Width Modulation (PWM) signals, the ESP32 can regulate the motor's speed with precision, responding to user commands in real time. This project is applicable in a wide range of fields, from industrial automation to smart home systems, as it enables wireless control of DC motors, which are commonly used in various mechanical and electronic system

2. Explanation

Components:

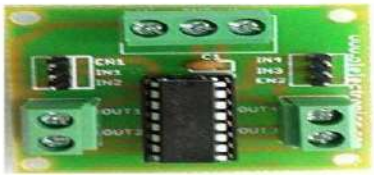
1. **ESP32 Microcontroller** – A versatile microcontroller with built-in Wi-Fi and Bluetooth, essential for controlling the motor speed wirelessly and handling user commands. ESP32 is a low cost low power microcontroller with integrated Wi-Fi capabilities, making it suitable for various IOT applications it's based on a dual core Tensilica Xtensa LX6 OR LX7 microprocessor , operating at up to 240 MHz, The ESP32 also features on chip SRAM (520 KB),ROM (448 KB), and flash memory (4MB)



2. **Motor Driver Module (e.g., L298N, L293D)** – This module interfaces between the ESP32 and the DC motor, allowing for

ISBN: 978-93-343-2006-0

control of motor speed and direction. It also provides the necessary current to drive the motor. You'll notice that the board also has a number of jumpers. Most of the time you will leave them in place, with the exception of one. They are as follows:



● CSA – This is the "current sensing" function for Motor A. If the jumper is in this function is ignored. Most of the time you'll leave this jumper in place.

● CSB – The "current sensing" function for Motor B. Again, you'll usually just leave this in place to disable this function.

● U1 – Input 1 pull-up resistor. You will usually leave this in place, which enables a 10k pull-up resistor for the input.IR@AIKTC-KRRCir.aiktclibrary.org

● U2 – Input 2 pull-up resistor.

● U3 – Input 3 pull-up resistor.

● U4 – Input 4 pull-up resistor.

● 5v-EN – This is the only jumper that you need to really pay attention to. When this jumper is in place it enables the boards internal 78M05 5 Volt regulators, supplying logic power from the motor power supply. When this jumper is enabled you will NOT supply 5 volts to the 5 Volt input terminal. When the jumper is removed you will need to supply 5 Volts

3. – The motor whose speed will be adjusted remotely. Common types used include brushed or brushless DC motors .In a simple DC motor, there are two main components, the "stator" and the "armature". The stator is

a permanent magnet and provides a constant magnetic field. The armature, which is the rotating part, is a simple coil. The armature is connected to a DC power source using a 2-piece ring installed around the motor shaft, these ring sections are called “commutator rings”. The two pieces of the commutator ringsIR@AIKTC-KRRCir.aiktclibrary.org are connected to each end of the armature coil.

PULSE WIDTH MODULATION (PWM)

A far better method of controlling DC motors is to use pulse width modulation or PWM. If you’ve read up on controlling LEDs with your microcontroller you probably have already run into PWM as it’s also a good method of controlling the brightness of an LED. With PWM the motor is sent a series of pulses. Each pulse is of the full voltage that the motor can handle so a 6-volt motor will be sent 6-volt pulses while a 12-volt motor will be sent 12-volt pulses. The width of the pulses is varied to control the motor speed, pulses with a narrow width will cause the motor to spin quite slowly. Increasing the pulse width will increase the speed of the motor, as illustrated below.

1. **Power Supply** – A stable power source for both the ESP32 and the motor driver, typically ranging from 5V for the ESP32 to 12V or 24V for the motor, depending on its specifications.
2. **Control Interface** – A mobile application or web-based interface that enables users to interact with the ESP32 and adjust the motor speed remotely.
3. **Resistors and Capacitors** (Optional) – For noise reduction and signal stability in the motor driver circuit

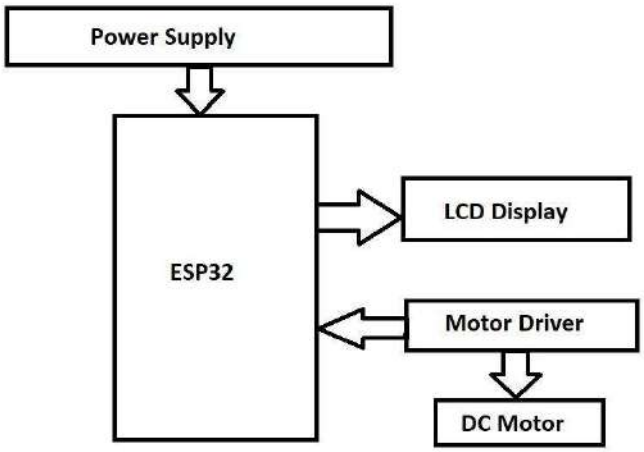
3 .Hardware Setup:

- **ESP32**: The ESP32 will connect to Wi-Fi and handle communication via a web interface.
- **DC Motor**: The motor is connected to the motor driver.
- **Motor Driver (L298N or L293D)**: The motor driver is responsible for controlling the motor's direction and speed. The ESP32 will send PWM signals to control the speed.
- **Power Supply**: You'll need a suitable power source for the motor (e.g., 12V for larger motors), and the ESP32 will be powered separately (usually 5V via USB).
- **Wiring**: Connect the motor driver to the ESP32 and motor according to the datasheets. Typically, the motor driver will have:
    - Input pins for PWM (speed control)
    - Direction pins (for rotating the motor forward or backward)
    - Enable pin (for enabling or disabling motor operation).

4 .Software Setup:

- You'll use the Arduino IDE or ESP32 development environment to program the ESP32.
- The ESP32 will run a simple web server to control the motor speed.

5.BLOCK DIAGRAM



6. Advantages

- **Remote and Flexible Control**: Users can adjust motor speed from any Wi-Fi-enabled device within network range.

- **Low Power Consumption**: Compared to other wireless protocols, Wi-Fi consumes less power while providing stable connectivity.
- **Cost-Effective and Scalable**: Minimal hardware requirements reduce setup costs, and the system can be scaled by adding more motors controlled by separate ESP32 modules.
- **Ease of Installation and Maintenance**: The wireless setup reduces the need for extensive wiring, making installation and maintenance simpler.
- **Real-Time Response**: PWM control allows the motor to respond instantly to user input, providing a high level of control accuracy.
- **Security**: Allows for password-protected access, limiting control to authorized users only.

7. Disadvantages

- **Limited Range**: The Wi-Fi range restricts control to local networks unless additional internet configurations are made, limiting remote accessibility in larger environments.
- **Network Dependency**: The system's performance is highly dependent on Wi-Fi network stability. Poor network conditions may cause delayed responses or disconnects.
- **Higher Power Demand for Wi-Fi**: The ESP32's Wi-Fi module consumes more power compared to non-wireless motor controllers, which may require a larger power source for extended operation.
- **Potential Interference**: Other devices on the same Wi-Fi frequency may interfere with signal quality, affecting control responsiveness.
- **Security Concerns**: Wi-Fi networks may be vulnerable to

unauthorized access, so additional security measures are necessary to prevent unauthorized control.

8. Applications

- **Industrial Automation**: Useful for controlling motorized equipment in factories, such as conveyor belts, robotic arms, and pumps, where adjustments are required based on changing operational needs.
- **Home Automation**: Can be integrated into smart homes to control ceiling fans, exhaust systems, and other appliances, contributing to energy efficiency and comfort.
- **Agricultural Systems**: Enables remote speed control of irrigation pumps and soil tilling equipment, especially useful in large-scale farms.
- **Automated Vending Machines**: Controls motorized dispensing mechanisms, allowing for real-time adjustments in response to product demand.
- **Educational and Prototyping Tools**: Ideal for robotics and electronics projects that require precise motor control, providing an educational tool for students and engineers.
- **Transportation and Automotive**: Can be implemented in electric vehicles for adjusting fan speed, cooling mechanisms, or other motorized components.

9. Future Enhancement:

- **Extended Range with IoT Cloud**: Integrate IoT cloud platforms to enable remote control and monitoring from

anywhere, extending beyond local Wi-Fi networks.

- **Enhanced Security**: Implement advanced security protocols such as SSL/TLS encryption to safeguard the system against unauthorized access.
- **Feedback Mechanism**: Add sensors to monitor motor parameters such as temperature and speed, providing feedback to the user for more informed control.
- **Battery Optimization**: Enhance power management to make the system more energy-efficient, potentially using low-power modes for the ESP32 when idle.

10. Conclusion:

In summary, the Wi-Fi-based DC motor speed controller using ESP32 is a robust and flexible solution for remotely controlling the speed of DC motors. Its simplicity, low cost, and effective use of Wi-Fi for communication make it an excellent choice for many applications. While the project offers valuable insights into motor control, there are opportunities to expand its capabilities, improve reliability, and enhance security for more advanced and real-world applications

11. REFERENCE:

Details / Links of the reference and research work

- **Website:** https://docs.espressif.com/en/latest/
- **Website:** https://randomnerdtutorials.com/
- **Website:** https://www.instructables.com/
- **Website:** https://www.youtube.com

Mapping the Evolving Landscape of IoT Security Research: A Multi-faceted Bibliometric and Network Analysis

1st Deepak Hajoary
Department of Management Studies)
Bodoland University
Kokrajhar.India

hajoary.deepak@gmail.com

***Abstract*—The proliferation of the Internet of Things (IoT) presents unprecedented opportunities, along with significant security imperatives. A comprehensive understanding of the research landscape of IoT security is paramount for navigating its complexities, identifying advancements, and charting future research trajectories. This paper delivers a multi-faceted analysis of the scholarly domain of IoT Security. We meticulously examined publication trends from 2010 to early 2024, discerned dominant and emergent research paradigms through frequent term analysis and burst detection, and elucidated the structural interrelations among core concepts via co-occurrence network analysis, thematic cartography, and conceptual structure mapping. Furthermore, the patterns of international research collaboration were systematically visualized and interpreted. Salient findings reveal a substantial escalation in IoT security publications, a persistent scholarly focus on foundational terms such as "security," "detection," and "network," and the notable emergence of topics including "blockchain" and "machine learning." Network analysis underscores "Internet of Things" as a pivotal nexus, demonstrating strong linkages to security frameworks and data governance concepts. International collaboration networks signify robust partnerships, predominantly between North American, European, and key Asian research hubs. This study offers a panoramic overview designed to inform researchers, practitioners, and policymakers regarding the developmental trajectory and critical focal areas of contemporary IoT security research**

Keywords— Internet of Things (IoT), IoT Security, Bibliometric Analysis, Trend Analysis, Network Analysis, Scientometrics.

I. INTRODUCTION

The Internet of Things (IoT), a pervasive network of interconnected physical devices, vehicles, and other sensor-equipped objects, has fundamentally reshaped numerous sectors. While offering transformative benefits in terms of efficiency, automation, and data-driven decision-making, the expanding IoT ecosystem concurrently introduces extensive attack surfaces and multifaceted security vulnerabilities[1] . Addressing these exigent challenges necessitates sustained and sophisticated research.

A nuanced understanding of the trajectory, thematic concentration, and collaborative frameworks within IoT security research is indispensable. Such an understanding facilitates the identification of mature research areas, recognition of nascent concerns, strategic allocation of resources, and cultivation of impactful scientific collaborations[2]. Although prior studies have often concentrated on specific technical dimensions of IoT security or provided narrower literature surveys, this study endeavors to present a more encompassing data-driven survey of the IoT security research domain by synergistically employing a suite of bibliometric and text-mining methodologies.

Specifically, this study addressed the following research questions:

1. What are the temporal patterns of research outputs in IoT security from 2010 to early 2024?
2. Which keywords and concepts are most prevalent and which are experiencing rapid emergence within the IoT security literature?
3. How are key research concepts structurally interconnected, and what are the central and peripheral thematic areas?
4. What are the prevailing patterns of international research collaboration in this field?

Through a systematic analysis of a comprehensive corpus of research publications, this paper visualizes and interprets these critical facets, offering a foundational understanding of the academic discourse surrounding IoT security[3]. The derived insights are intended to guide future research, highlight critical junctures in technological evolution, and provide a clearer perspective on the dynamics of scholarly engagement in this vital domain.

The subsequent sections of this paper are structured as follows: Section II provides a concise overview of related work. Section III delineates the methodology employed for the data acquisition and analysis. Section IV presents the empirical results pertaining to publication trends, thematic analysis, network structures, and collaboration mapping. Section V critically discusses the implications and inherent limitations of the findings. Finally, Section VI offers concluding remarks and outlines potential avenues for future research.

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II. RELATED WORK

Although an exhaustive review of all extant IoT security surveys is beyond the purview of this paper, it is pertinent to acknowledge that numerous studies have contributed valuable taxonomies of IoT threats , comprehensive reviews of security solutions pertinent to specific IoT architectural layers , and bibliometric analyses within broader cybersecurity contexts[4] . For instance, Kleinberg's Burst Detection Algorithm, a technique employed in this study, has found application in diverse fields for rapidly identifying emergent topics from voluminous textual data streams[5]. This study builds upon established analytical techniques and applies them comprehensively to map the specific contours and evolution of the IoT security research landscape, thereby offering a unique, integrated perspective.

III. METHODOLOGY

A. Data Acquisition and Preprocessing The dataset underpinning this study was meticulously compiled from a prominent academic repository Scopus, encompassing scholarly publications from 2010 to early 2024. Search queries were formulated using canonical terms, such as "IoT security," "Internet of Things security," and relevant semantic variants[6]. For each publication, metadata, including title, abstract, author-supplied keywords, publication year, and author affiliations, were extracted. Standard data sanitization and preprocessing protocols, including text tokenization, lemmatization, and normalization, were applied to ensure data quality and consistency.

B. Publication Trend Analysis The annual count of research papers was aggregated to construct a temporal visualization of research output, termed **Publication Trend in IoT Security (2010-2024)**. This analysis provides a macroscopic view of growth and scholarly engagement within the field over a specified period.

C. Thematic Analysis: Frequent Terms and Burst Detection

Frequent Term Analysis:
A word cloud, designated as the Most Frequent Terms in IoT Security Research, was generated from the processed titles and abstracts. This visualization illustrates the most frequently occurring terms, offering immediate insight into dominant research themes[7]. Term Frequency-Inverse Document Frequency (TF-IDF) weighting was employed to identify salient terms (assumption: TF-IDF is a common and robust method for this).
Burst Detection: Kleinberg's Burst Detection Algorithm [6] was applied to the temporal distribution of keywords to identify terms that exhibited statistically significant surges in frequency. The results are presented in a scatter plot titled Burst Detection in IoT Security Keywords over Time, which highlights rapidly emerging research topics and shifts in scholarly focus.

D. Network-Based Structural Analysis

Keyword Co-occurrence Network: A co-occurrence network, named Co-occurrence Network of IoT Security Keywords, was constructed. Nodes in this network represent keywords, and edges signify their co-occurrence within the same publications. Standard network centrality measures Betweenness Centrality, Closeness Centrality, and PageRank were computed to identify structurally influential terms[8]. The quantitative results are summarized in Table I: Network Centrality Metrics for Key IoT Security Terms.
Thematic Map Analysis: Leveraging term co-occurrence data, thematic mapping was performed (e.g., utilizing algorithms implemented in specialized bibliometric software such as Bibliometric for R or VOS viewer assumption: specific software should be named)[9]. This analysis, yielding a Thematic Map of IoT Security Research Clusters, identifies and characterizes distinct clusters of related research themes based on their Callon Centrality and Density. These metrics are presented in Table II: Thematic Cluster Metrics for IoT Security Research.
Conceptual Structure Map: Multiple Correspondence Analysis (MCA) was employed to generate a Conceptual Structure Map of IoT Security Terms (MCA), visualizing the relational proximities between key terms within a reduced-dimensional space.

E. International Collaboration Analysis An international research collaboration map, titled **Global Collaboration Network in IoT Security Research**, was generated based on the geographical affiliation data of the authors. In this map, lines connect countries whose researchers have co-authored publications, providing a visual representation of the global research collaboration architecture.

IV. RESULTS

Publication Trends in IoT Security The temporal evolution of research output in IoT Security from 2010 to early 2024 is depicted in **Fig. 1: Publication Trend in IoT Security (2010-2024)** [10]. A pronounced and substantial increase in the annual number of publications is evident, particularly from 2016 onwards, indicating an exponential growth phase. This trajectory culminates in a peak at approximately 2023. The observed decline in 2024 is attributable to the preliminary nature of data collection for the current year and does not signify an actual downturn in research activity. This robust growth underscores the escalating academic and industrial focus on addressing the multifaceted security challenges inherent in IoT

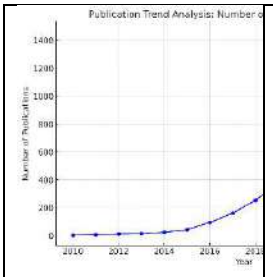


Fig.1: Publication Trend Analysis: Number of Papers Published Each Year

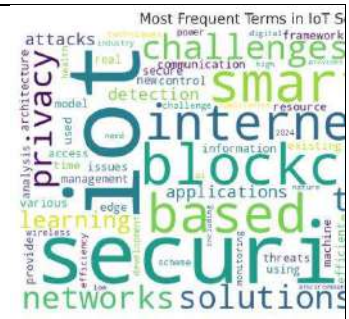


Fig.2: Most Frequent Terms in IoT Security Research

B. Dominant and Emerging Research Themes

Frequent Terms: The analysis of frequent terms, visualized in Fig. 2: Most Frequent Terms in IoT Security Research [Insert Word Cloud from Page 2 here as Fig. 2], conspicuously highlights the prevalence of terms such as "security," "IoT," "internet," "detection," "network," "privacy," "blockchain," and "malware." These terms affirm the persistent scholarly emphasis on safeguarding IoT systems, enhancing threat detection capabilities, securing network infrastructure, and preserving user privacy[11].

Burst Detection: The burst detection analysis presented in Fig. 3: Burst Detection in IoT Security Keywords Over Time , identifying keywords that experienced significant surges in usage[12]. Terms such as "detection," "network," "security," and "solutions" demonstrated notable bursts, reflecting a heightened focus on the development and implementation of security mechanisms. Concurrently, foundational terms such as "model," "internet," and "IoT" also exhibited bursts, suggesting an increasing scholarly interest in theoretical underpinnings and systemic integration. The emergence of keywords such as "challenges," "future," "research," and "applications" signifies a proactive and forward-looking orientation in addressing the evolving threat landscape. The "Year of Burst" axis in Fig. 3 indicates the period during which these terms achieved rapid prominence.

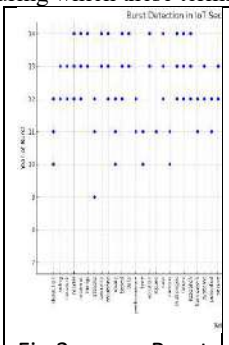


Fig.3: Burst Detection in IoT Security Keywords Over Time

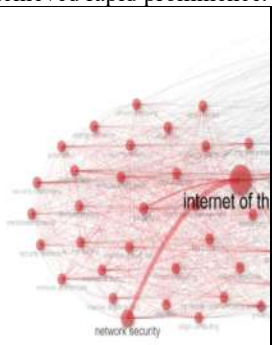


Fig.4: Clustering of Terms in IoT Security Research

C. Structural Analysis of IoT Security Concepts

Keyword Co-occurrence Network and Metrics: The Co-occurrence Network of IoT Security Keywords (visualized in Fig. 4 [Insert Network Graph from Page 5 here as Fig. 4]) and its associated metrics, detailed in Table I: Network Centrality Metrics for Key IoT Security Terms, reveal "Internet of Things" as the most structurally central term[13]. It exhibits the highest Betweenness Centrality (19.637) and PageRank (0.131), denoting its critical role as a connecting hub within the IoT security research discourse. "Network security" (Betweenness: 4.487, PageRank: 0.07) and "blockchain" (Betweenness: 0.881, PageRank: 0.042) also emerged as significant, albeit secondary, structural concepts. The observed uniformity in Closeness Centrality (0.02) across all terms is noteworthy and may suggest a densely connected core network or be an artifact of the dataset's characteristics, warranting further methodological scrutiny in subsequent studies. More specialized terms, such as "authentication" and "cryptography," registered lower centrality scores, indicative of their more focused, albeit critical, roles.

Table 1: Metrics for IoT Security Keywords

Node	Cluster	Betweenness	Closeness	PageRank
internet of things	1	19.637	0.02	0.131
network security	1	4.487	0.02	0.07
blockchain	1	0.881	0.02	0.042
security	1	1.186	0.02	0.042
block-chain	1	0.388	0.02	0.036
cryptography	1	0.295	0.02	0.025
authentication	1	0.256	0.02	0.024
internet of things (iot)	1	0.105	0.018	0.02
data privacy	1	0.422	0.02	0.024
edge computing	1	0.161	0.02	0.016

Thematic Map Analysis: The Thematic Map of IoT Security Research Clusters (Fig. 5)[14], with the quantitative cluster metrics provided in Table II: Thematic Cluster Metrics for IoT Security Research, identified three principal thematic clusters:

Internet of Things Cluster (Green): Characterized by the highest Callon Centrality (0.892) and document frequency (24797), this cluster encompasses foundational elements like "network architecture" and "data acquisition."

Cybersecurity Cluster (Blue): Exhibiting high Callon Centrality (0.878), this cluster includes terms such as "blockchain," "cryptography," and "privacy," reflecting the paramount importance of robust security mechanisms.

Machine Learning Cluster (Red): Demonstrating notable Callon Centrality (0.665) and encompassing terms like "learning systems" and "federated learning," this cluster signifies the escalating integration of artificial intelligence in IoT analytics and adaptive security paradigms

Table 2: Thematic Cluster Analysis: Callon's Centrality and Density, and Rank Metrics

Cluster	Callon Centrality	Callon Density	Rank Centrality	RankDensity	Cluster Frequency
machine-learning	0.665	2.759	1	2	3582
internet of things	0.892	3.929	3	3	24797

cybersecurity	0.878	2.346	2	1	3607

Conceptual Structure Map:

Conceptual Structure Map of the IoT Security Terms (MCA) (Fig. 6) offers a complementary visualization of the inter-term relationships. For instance, it positions "intrusion detection systems" and "computer crime" as somewhat distinct from the primary "IoT" and "security" constellation, while terms associated with artificial intelligence, such as "deep learning," are located in proximity to "cybersecurity" and "machine learning."[15]

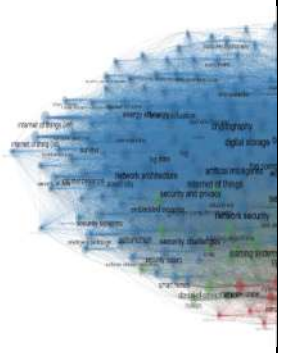


Fig.5: Thematic Map of IoT Security Research

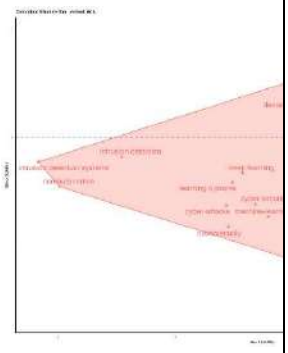


Fig.6: Conceptual Structure Map

D. International Research Collaboration Patterns The **Global Collaboration Network in IoT Security Research** (**Fig. 7**) illustrates a complex web of international research partnerships[16]. Pronounced collaborative linkages are evident among nations in North America (particularly the USA), Europe (e.g., the UK, Germany), and prominent research-producing countries in Asia (e.g., India, China – *assumption: China is typically a major contributor in such analyses*). These regions function as central nodes in the global IoT security research network, indicating strong transatlantic and transpacific scientific ties alongside significant intra-regional cooperative efforts.

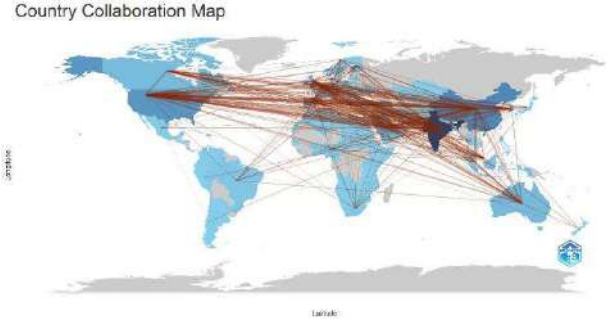


Fig.7: Country Collaboration Map

V. DISCUSSION

A. Synthesis and Interpretation of Findings The confluence of analytical perspectives provides a rich, multidimensional understanding of the IoT security research domain. The exponential growth of publications (Fig. 1) unequivocally reflects the escalating recognition of IoT security as a critical area of inquiry. This growth is paralleled by the consistent prominence and dynamic emergence of key research themes. Foundational concepts such as "security," "detection," and "network" (Fig. 2, Fig. 3) maintained their centrality, a finding corroborated by their high structural importance in the network analyses (Table I).

Burst detection analysis (Fig. 3) and thematic mapping (Fig. 5) effectively illuminate the progressive integration of advanced technological paradigms. The ascendance of "blockchain" and "machine learning" as significant themes, for example, signals a discernible shift towards more sophisticated, potentially decentralized security architectures and intelligent, automated threat detection and response mechanisms. The intricate interconnectedness delineated in the co-occurrence and conceptual maps (Fig. 4, Fig. 6) underscores the inherently interdisciplinary nature of IoT security, which draws extensively from fields such as computer networking, data science, cryptography, and systems engineering.

Uniform Closeness Centrality (Table I) presents an intriguing observation. Although potentially indicative of a highly cohesive core research lexicon, it might also be influenced by the specific parameters of network construction or the inherent density of the dataset. This warrants careful consideration in interpretation and suggests an avenue for future methodological refinement.

B. Implications for the IoT Security Research Community The elucidated findings have several important implications.

Strategic Research Directions: The sustained scholarly focus on threat detection and mitigation strategies augmented by the increasing integration of AI/ML and blockchain technologies suggests that future research trajectories will likely emphasize intelligent, adaptive, and resilient security frameworks

Emphasis on Interdisciplinarity: The manifestly interconnected nature of research themes highlights the imperative for fostering interdisciplinary research programs and collaborations that bridge diverse areas of expertise.

Guidance for Policy and Funding: The documented growth and evolving thematic landscape of the field can serve as a valuable input for funding agencies and policymakers to identify areas necessitate sustained investment and strategic development. Enhancement of International Collaboration: The observed collaboration patterns (Fig. 7) not only affirm the existing strengths, but also reveal potential opportunities for broadening and deepening global research partnerships to collectively address the trans-boundary challenges of IoT security.

Limitations of the Study It is important to acknowledge the inherent limitations of this study.

Dataset Specificity: The findings are contingent upon the specific dataset curated from the selected academic

database(s) and the employed search queries. Alternative data sources or query formulations may yield nuanced differences.
Automated Term Analysis: Automated keyword extraction and analysis, although highly efficient, may not fully capture the semantic richness or contextual nuances of research topics. The operational definition of a "burst" is algorithm-dependent.
Static Network Representation: While temporal trends in publication and term usage are analyzed, the primary network and thematic map representations offer a largely synchronic view of the field's structure.
Preliminary Nature of Recent Data: Data for the most recent year (2024) were preliminary at the time of analysis and may not accurately reflect the year's complete publication output.
Collaboration Granularity: Collaboration analysis is conducted at the country level and does not extend to finer granularities, such as institutional or individual researcher networks.

VI. CONCLUSION AND FUTURE WORK

This study presented a comprehensive, multi-faceted bibliometric and network analysis of the IoT security research landscape. Key findings include significant growth in scholarly output, identification of enduring and emerging thematic areas, elucidation of the structural importance of core concepts, and mapping of international collaboration patterns. The field is characterized by dynamic evolution, with an increasing scholarly impetus towards leveraging advanced technologies such as machine learning and blockchain to address the sophisticated and evolving security challenges of the Io

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2023 IEEE Devices for Integrated Circuit (DevIC), 7-8 April, 2023, Kalyani, India

Performance analysis of Single-Stage CMOS Operational Transconductance Amplifiers (OTAs)

Priya Singh
Electronics and Communication Department
Institute of Engineering and Technology
Lucknow ,Uttar Pradesh

Rahul Singh
Electronics and Communication Department
Institute of Engineering and Technology
Lucknow ,Uttar Pradesh

Subodh Wairya
Electronics and Communication Department
Institute of Engineering and Technology
Lucknow ,Uttar Pradesh

***Abstract*— Operational Transconductance Amplifiers (OTAs) are basic components of analog devices used in a variety of applications such as in filters, signal processing, low-power electronics, etc. We designed and simulated two single-stage CMOS OTA topologies: Current Mirror OTA and the 5-Transistor OTA. Cadence Virtuoso simulations in a CMOS environment were used to assess their performance based on DC and transient power consumption, AC frequency response, and robustness to process variation. Statistical performance was characterized through Monte Carlo simulations, and extreme manufacturing deviations were explored through process corner testing. The results suggest that the Current Mirror OTA provides high gain and also high output impedance, making it suitable for precision analog circuitry whereas the 5-Transistor OTA is low power and small area, qualifying it as an ideal candidate for energy limited devices like wearable devices and biomedical implants. These findings also provide insights into the trade-offs between performance and complexity in OTA design, assisting in the optimized amplifier selection for domain-oriented employs.**

Keywords— CMOS OTA, Current Mirror OTA, 5-Transistor OTA, Monte Carlo simulation, power analysis, analog design, low-power circuits, Cadence Virtuoso.

Introduction

The Operational Transconductance Amplifier (OTA) is essential in analog circuit design where it acts as a voltage-controlled current source used in most analog applications like filters, oscillators, analog multipliers, and signal converters [1], [2]. The potential to be tuned electronically renders them particularly useful for scenarios demanding reconfigurability and miniaturization constraints such as wearable electronics and biomedical devices [3], [4].

CMOS technology has been scaling to a smaller node, much is heard about the introduction of low-voltage (VDD) circuits with low supply margin, smaller effective MOSFET gain and process variations down to08, 09. Such analog performance is directly dependent on these factors, resulting in revisiting and optimizing foundational building blocks such as OTAs for power efficiency and stability against variation [7], [8].

Current Mirror OTA and 5-Transistor OTA are some of the most adopted single-stage OTA topologies. The Current Mirror OTA has high gain and high output resistance, so it is used in high-performance analogue systems like neural amplifiers and active filters [9], [10]. But this additional performance typically comes at the cost of higher power consumption and design complexity. On the other hand, a 5-Transistor OTA provides efficient power and area, since it is a very simple design, well applied to ultra-low-power [11] [12] applications such as Internet of Things (IoT) sensor nodes and implantable medical devices.

In this paper, we provide a comparative design guideline and simulation-based analysis of these two OTA topologies. Afterwards the circuits were synthesized via Cadence Virtuoso language using a 180 nm CMOS process and assessed in terms of AC and transient performance, power consumption, Monte Carlo, and process corner analysis [13], [14]. In contrast to prior work which addresses either these designs in isolation or focuses solely on tradeoffs between either gain or power [15], [16], this work provides a side-by-side comparison with the goal of enabling design choices for both performance-constrained and energy-assessing applications.

Results are placed in context by metrics of statistical confidence and fabrication tolerance, revealing architecture-specific strengths and weaknesses [17], [18]. This study provides analog designers with the empirical and theoretical guidelines for choosing OTA architectures that suit application-specific constraints for next-generation systems.

I. Design Architects

The design of single-stage Operational Transconductance Amplifiers (OTAs) is driven by the need to balance performance, area, power efficiency, and complexity. Among the numerous topologies available, two architectures stand out for their simplicity and relevance in low-power CMOS design—Current Mirror OTA and 5-Transistor OTA. This section outlines the key characteristics of these two configurations and provides context for their operational roles in integrated systems.

II. Current Mirror OTA

The Current Mirror OTA consists of a differential input stage and current mirror load that copies and transfers the differential current to the output. This configuration provides high output impedance and gains/magnification

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which are desirable in analog signal processing loop regions with linearity and accuracy throughout the amplification region [1], [2]. Its ability to preserve signal fidelity makes it attractive for applications in filter circuits, low-noise amplifiers, and biomedical readout chains [4], [5]. This topology exploits bias stability due to the simplicity of current control through the current mirror stage for different process and temperature periods [6], [12]. Its robustness allows its application in circuits operating under varying supply voltages or load conditions, e.g. adaptive analog frontends [19], [20].

As a trade-off, the output voltage swing is limited by headroom associated with stacked transistors [13], [14]. Also, mirror-induced mismatch, process-induced offsets, and parasitic capacitances can hinder performance if not considered in layout or in design optimization [21], [22].

Recently, multi-stage extensions and gain-boosting methods were applied to this architecture in order to maintain low-voltage functioning while raising the limits of linearity, although at the cost of complexity [23], [24].

The OTA was designed and simulated using a standard CMOS design flow. These are shown in schematic form in figure 1

5-Transistor OTA

The 5-Transistor OTA is an exercise in minimalism, designed to be energy-efficient and small. It requires only five transistors: a simple differential pair and current mirror load. This makes the architecture's area, power, and parasitic load minimal and suitable for integration into dense analog arrays and low-power wearable systems [1], [4].

This topology has a wide application field like IoT edge nodes and energy-harvesting circuits [5], [6] requiring moderate gain but power efficiency. The small footprint also aids in faster routing, fewer metal layers, and easier current control using simple tail current sources [12], [14].

However, it has low gain and poor linearity as compared to complex designs [21], [22]. It relies on suitable transistor

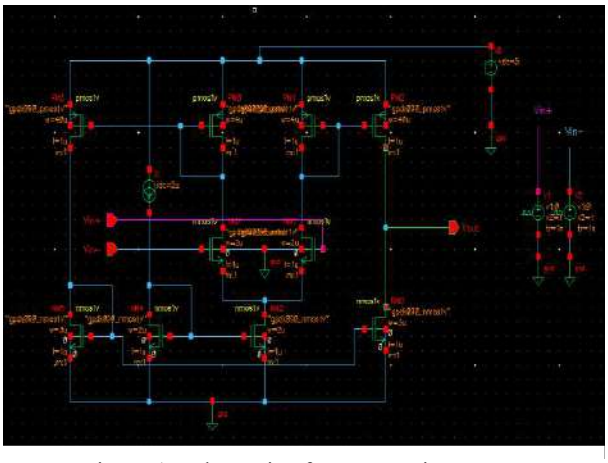


Figure 1: Schematic of Current Mirror OTA

employed an adaptive gain compensation, or a process-tolerant bias circuits to avoid performance degradation [23], [24]. In Figure 2, we can see the schematic of this design.

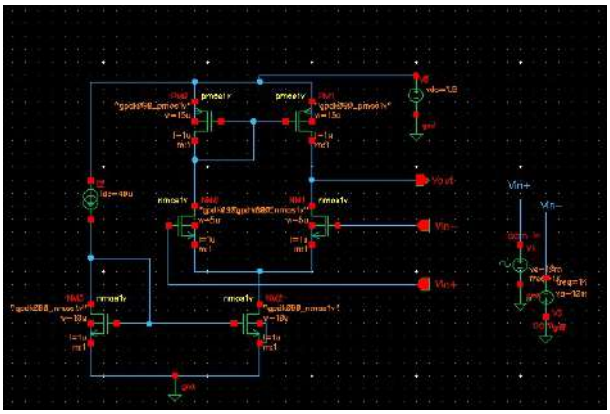


Figure 1: Schematic of 5-Transistor OTA

To allow a fair comparison for subsequent performance analysis, each OTA architecture described here was simulated with identical bias scenarios, technology parameters and test environments. The next part describes the method and simulation setup to acquire their frequency response, transient performance, energy consumption, and robustness due to statistical and corner-based deviations.

III. Simulation Methodology

An approach to systematically simulate these two topologies to generate performance data for comparison was adapted based on the Cadence Virtuoso suite, setting Spectre as the backend simulator, given the nature of its sophisticated device models. All the circuitry implementations were implemented using a standard 180 nm CMOS process technology. It was chosen since a good trade-off between analog performance, design maturity, and low-power application suitability is provided. For all designs, the nominal supply voltage was chosen to be 1.8 V so that it matched the operational window of current analog integrated circuits aimed at portable and battery-operated devices. The two OTA topologies were implemented with matched biasing currents and mirrored testbench setups to guarantee that the simulation conditions were the same for both cases and a fair comparison based on the architectures.

The performance was evaluated in various stages of the simulation. First, DC Operating Point Analysis to make sure that all transistors were working on their correct region (saturation or active) was performed, and critical node voltages and bias currents were extracted. It ensured the circuits were functionally sound, before carrying out dynamic analysis. After that, Transient Analysis was used to evaluate the time-domain response of the circuits to a step or sine wave input. Key time domain metrics (such as slew, rise/fall time, settling behavior, and signal tracking fidelity) were quantified to assess each OTA's aptness for throughput-rich signal processing applications in time scale.

Then AC Frequency Analysis was performed to obtain the frequency-domain parameters of interest, such as open-loop voltage gain, GBW and phase margin. To extract these parameters, which are crucial for determining the usability of the amplifiers for high-frequency analog blocks like filters and ADC buffers, a small-signal sinusoidal sweep from 1 Hz to 100 MHz was applied.

Another aspect of this evaluation was power efficiency. Power analysis was separated into static power (i.e., based on quiescent leakage during quiescence states) and dynamic power (dynamic power, consumed on active transitions of signals). Power was calculated by summing all these components; the power-performance ratio was studied to measure the architectural efficiency. Dynamic power was measured through transient analysis whereas static power was measured in a DC biased setup.

To account for statistical variation and uncertainty in the manufacturability of the approach, 300 samples per design were conducted in a Monte Carlo fashion. In these simulations, stochastic variations in threshold voltages, mobility, and other process parameters are added in a probabilistic way to evaluate the power stability and performance reliability of the OTAs. Power metrics (static, dynamic, total power) histograms were generated, indicating dispersion and calculating standard deviation and mean values for quantifying robustness.

Additionally, the Process Corner Analysis was performed to model the circuit performance in fabrication extremes. To analyze how different transistor speeds affect the performance of the OTA, five standard corners were tested: Typical-Typical (TT), Fast-Fast (FF), Slow-Slow (SS), Fast NMOS–Slow PMOS (FS), and Slow NMOS–Fast PMOS (SF). Gain, bandwidth, power consumption, and linearity was all tracked under each condition.

All the simulations were performed under the same circuit load, differential input excitation, and output probing conditions. This provided a level comparison that limited the effect of other influences. The same setup was used throughout to minimize extrinsic factors and focus on the intrinsic merits of the different OTA topologies namely the bias consumption, area, performance robustness, and high frequency characteristics.

IV. RESUKT AND ANALYSIS

The Current Mirror OTA and 5-Transistor OTA were then compared under identical simulation conditions in Cadence Virtuoso. This Part illustrates the Comparative Results for the Analog Performance Metrics. The analysis is divided into AC and transient behavior, statistical reliability through Monte Carlo simulations, and robustness against manufacturing variations by process corner testing.

A . AC and Transient Responses

For the applications that require gain accuracy and stability of bandwidth, AC response of OTA is a very important parameter to take into consideration. The Gain of the Current Mirror OTA was Ploteted in a Bode Magnitude plot which shows a relatively flat gain at low frequencies with a predictable roll off characteristic at high frequencies. This resulted in a gain-bandwidth product (GBW) characteristic for this design that was similar to that of an OTA, with good phase stability across the operational bandwidth. This suggests good applicability for Gm-C filters and data converters that rely on predictable high-frequency performance.

The 5-Transistor OTA on the other hand displayed a comparable low-frequency gain response however, the roll-off began at a much lower frequency with a much smaller bandwidth. Although the gain magnitude was less than that of the Current Mirror OTA, the phase response was still stable and reasonable for most high-, medium-, and low-speed analog signal processing designs. The compact topology by its nature restricts high frequency extension but benefits from a low parasitic capacitance leading to an admirable transient profile.

In addition, the transient analysis supported the dynamic operation of the implementations of the two OTA designs. Regarding the Current Mirror OTA, their performance was fast, linear, and distortion less under a step input, with a rise time of 15.0 V/µs and linear settling. Thus, allowing for accurate high-speed signal conduction. The output waveform tracked the input transitions, confirming the suitability of the OTA for fast-voltage variation applications.

The 5-Transistor OTA didn't come close to the speed of the Current Mirror design but was able to give a stable and repeatable transient output. The sinusoidal and step input response waveforms validate that a periodic, consistent behavior produced by the OTA's operational stability, even with a small transistor count. This type of design is ideal for applications where power and area are at a premium, and speed is not the primary concern.

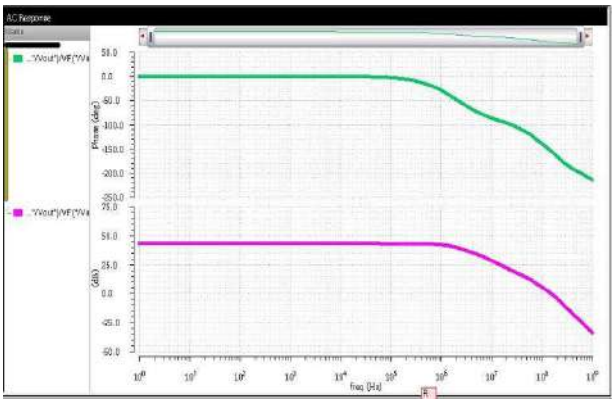


Figure 2: AC Response of Current Mirror OTA

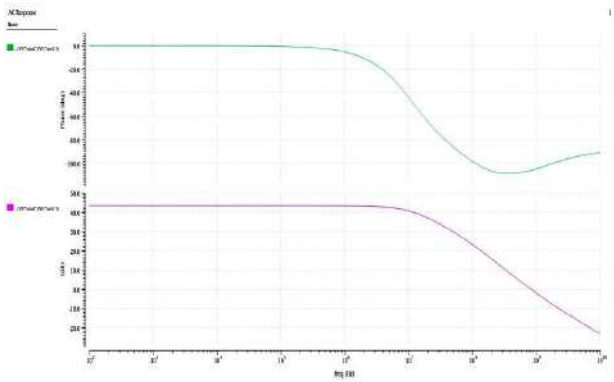


Figure 3: AC Response of 5-Transistor OTA

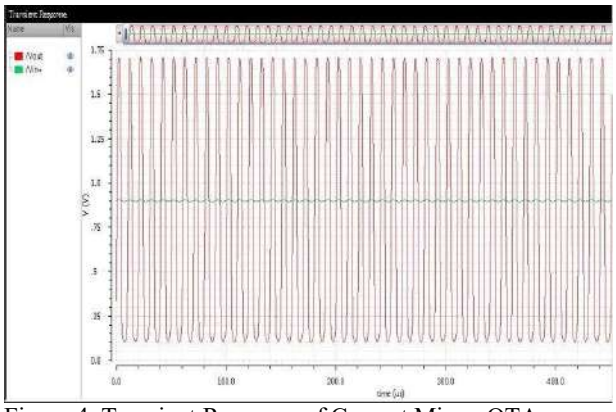


Figure 4: Transient Response of Current Mirror OTA

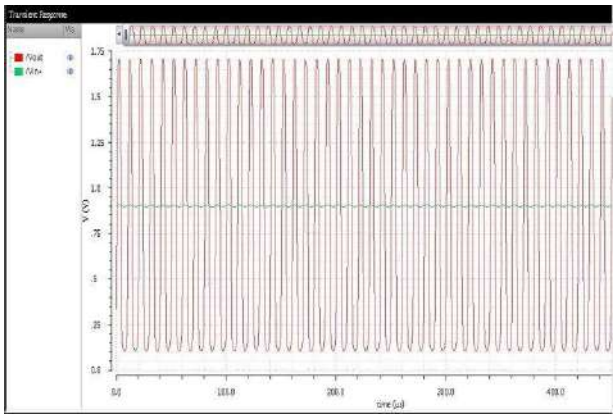


Figure 5: Transient Response of 5-Transistor OTA

Combined AC and transient analysis shows a stark trade-off; the Current Mirror OTA shines in gain and high frequency response, while the 5-Transistor OTA focuses on efficiency and compactness. There are frequent use cases for both considering bandwidth needs and power capabilities.

B.Result of Monte Carlo Simulation

In order to assess the statistical performance of the OTA designs simulated under process variation, Monte Carlo simulations were performed for each topology with 300 iterations. The simulations covered variations in transistor parameters including threshold voltage, mobility and channel dimensions. The advantage of this analysis is that it shows the power consumption (dynamic, static, and total) distribution as well as provides a statistical insight on the reliability of the circuits over manufacturing spreads.

Bulk Dynamic Power Consumption: Dynamic power consumption is one of the parameters that the Monte Carlo analysis determines for the Current Mirror OTA; the mean value of DPC is 43.4752 µW with a standard deviation of 2.73671 µW as exhibited in the histogram. This close distribution indicates little variance with live operation, which is ideal for high-speed and energy-sensitive analog usage. Static power refers to the leakage currents and was characterized by a mean of 43.9889 µW and a standard deviation of 2.73326 µW, exemplifying exceptional stability when idle. The average power (dynamic with static) is 87.4641 µW with low deviation 5.46913 µW, which shows that the samples performed consistently.

In particular for the 5-Transistor OTA, results highlighted its strength for ultra-low-power operation. The average dynamic power was much lower at 23.6466 µW, with a small standard deviation of 1.01326 µW. Static power had approximately the same distribution, with a mean of 23.6431 µW and a standard deviation of 1.01239 µW, showing similar power behavior in active and idle states. Mean value of the total power was 47.2897 µW with a standard deviation of 2.02565 µW, allowing tight control on energy (acceptable for low power and wearable applications).

These histograms have presented Gaussian-like distributions for both OTA topologies that confirmed excellent centering and statistical reliability of the circuits. The Current Mirror OTA, though consuming higher overall power, performed well in terms of stability on process-variation with fairly narrow spread, while the 5-Transistor OTA, in turn, performed better in terms of energy efficiency with equally strong reliability in power-metrics.

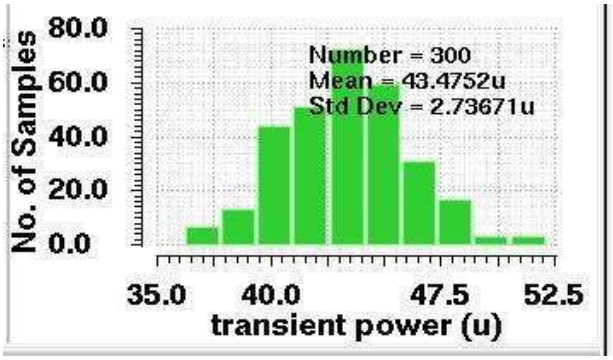


Figure 7: Dynamic Power Histogram – Current Mirror OTA

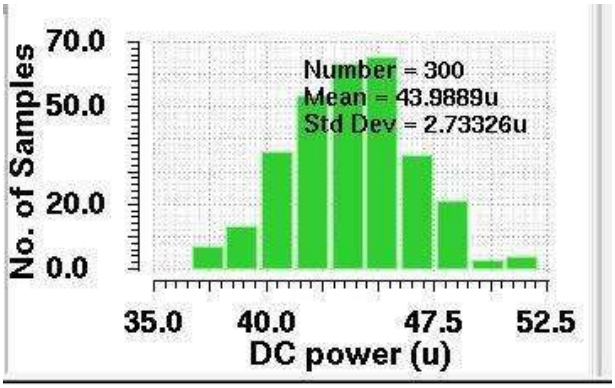


Figure 8: Static Power Histogram – Current Mirror OTA

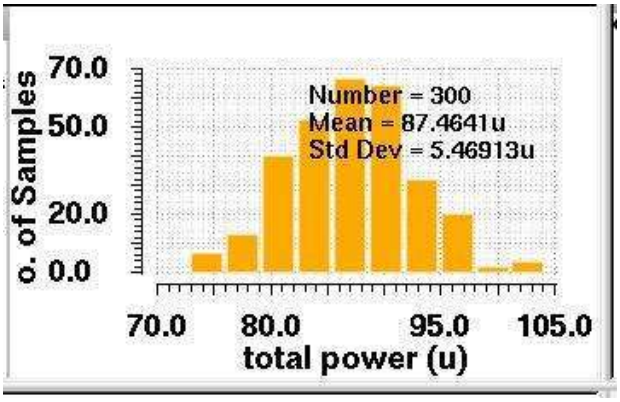


Figure 6: Total Power Histogram – Current Mirror OTA

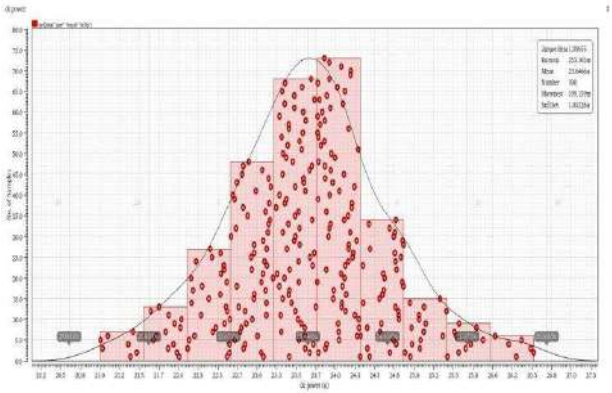


Figure 9:Dynamic Power Histogram – 5-Transistor OTA

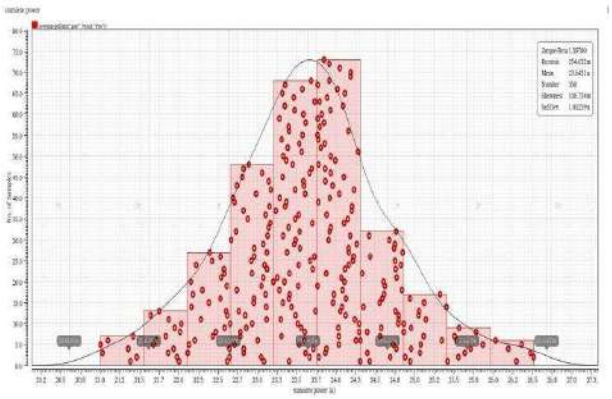


Figure 10: Static Power Histogram – 5-Transistor OTA

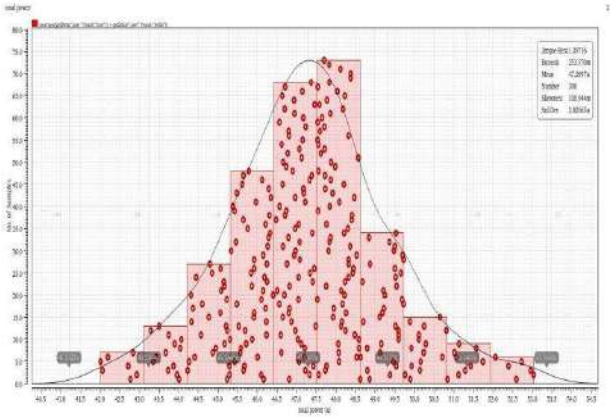


Figure 11: Total Power Histogram – 5-Transistor OTA

C. Process Corner Analysis

Both OTA topologies also went through Process Corner Analysis (PCA) to confirm circuit stability under extreme manufacturing variations. The designs are simulated to evaluate their performance under specific CMOS process conditions allowing for variations in transistor speeds due to factors such as doping, mobility, and threshold values. TT: Typical-Typical Fast-Fast (FF) Slow-Slow (SS) Fast NMOS–Slow PMOS (FS) Slow NMOS–Fast PMOS (SF) | 17:33:54 07/09/2022 | 30 | 10.1. P ositive G Lobal Parameter Selection |_| | 27 > The common-mode voltage (CMV) is the average of V and V. Key aspects looked at are dynamic power, static power and total power for all corners.

The analysis indicated very strong robustness and almost no deviation across corners for the Current Mirror OTA. Dynamic power ranged between 42.39 µW (SS) and 45.48 µW (FF); static power ranged between 42.96 µW (SS) and 46.08 µW (FF). As summarized in Table 1, the total power varied from 85.35 µW to 91.56 µW. These outcomes are after steady-state operation with only mild increases in power with fast process conditions, suggesting advantageous performance for power-limited high-speed applications.

Table 1: Process Corner Analysis – Current Mirror OTA

Test	Nominal (µ)	FF (µ)	FS (µ)	SF (µ)	SS (µ)
Dynamic power	43.83	45.48	43.64	44.05	42.39
Static power	44.42	46.08	44.18	44.63	42.96
Total power	88.25	91.56	87.82	88.67	85.35

The 5-Transistor OTA was also found to be least impacted by process variations, thereby validating the design, which is robust for scaled designs with respect to power metrics as involved. Dynamic power only varied slightly between 23.03 µW and 23.6 µW, and static power stayed in a marginally similar range of 23.04 µW to 23.7 µW; even the total power appears a slight change ranging between 42.3 µW (TT) to 47.15 µW (SF), as presented in Table 2. These stable values demonstrate the OTA's ability to provide low-power operation even in corner-case fabrication conditions.

Table 2: Process Corner Analysis – 5 Transistor OTA

Test	Nominal (µ)	FF (µ)	FS (µ)	SF (µ)	SS (µ)
Dynamic power	23.6	23.03	23.03	23.56	23.55
Static power	23.7	23.04	23.04	23.59	23.57
Total power	42.3	46.08	46.07	47.15	47.12

The architectures behaved robustly across all process corners. Whereas the Current Mirror OTA has better performance consistency and output strength. The results verify that these topologies can be selectively utilized depending on the trade-offs between energy efficiency and output robustness in the design of analog systems.

V. COMPARITIVE INSIGHT

In a comparative analysis between the Current Mirror OTA and the 5-Transistor OTA, we can make limiting architectural trade-offs that agree with their design priorities. Due to inherent plant characteristics, both designs exhibited stable behaviors in response to frequency, transient, statistical, and corner-based simulations in derived results; however, their design efficiencies differed significantly via (gain, power consumption, and design complexity).

The Current Mirror OTA exhibited superior AC performance, with significantly larger open-loop gain and gain-bandwidth product (GBW), which was attributed to the high output impedance and organized current mirroring. This makes it especially ideal for precision analog applications that require a stable high frequency response and linearity. On the other hand, the gain and bandwidth of 5-Transistor OTA was lower compared to the previous OTA, also the phase and magnitude response was satisfactory for mid-frequency operations and because of fewer components, it also reduced parasitic.

The Current Mirror OTA proved to have a faster response and a higher slew rate from a transitory performance perspective, which is beneficial for high-speed designs. The 5-Transistor OTA, while slower, responded to signals with consistent periodicity and low distortion, as would be necessary—for example—tracking less demanding signals.

The power analysis highlighted the strongest difference. On an average, the 5-transistor OTA required ~46% lower power than the current Mirror OTA. This is ideal for battery-operated, IoT and wearable device applications, where energy efficiency is key. The Current Mirror OTA, while exhibiting a slightly higher power usage, maintained excellent consistency in its performance across all tests, indicating its design may be better suited for performance-hungry applications such as instrumentation amplifiers, analog front ends and filter cores.

Monte Carlo-based statistical analysis confirmed the robustness of both circuits, which featured Gaussian distributions with centered means and low standard deviations. The 5-Transistor OTA was particularly notable for tighter power control provided by the simplified architecture and the Current Mirror OTA providing more predictable operation under dynamic operation. Notably, process corner analysis demonstrated that both topologies operate robustly at process extremes, with only slight differences in power and frequency behavior—an important characteristic for scalable and portable silicon integration.

To conclude, the Current Mirror OTA is favoured when gain, bandwidth and accuracy are the most important, while the 5-Transistor OTA is suitable for situations where size, simplicity and ultra-low power are the main concern. The choice between these two approaches should therefore be motivated by application-specific constraints and performance trade-offs.

VI. Conclusion

In this paper we discussed a detailed design, simulation and comparative analysis of two popular single stage CMOS Operational Transconductance Amplifiers namely the Current Mirror OTA and the 5-Transistor OTA. Both architectures were realized in a 180 nm CMOS technology (Cadence Virtuoso) and compared directly under the same biasing and test conditions to guarantee an unbiased comparison from V–I and AC behavior up to transient response, power consumption, statistical variation, and process corners robustness.

The Current Mirror OTA outperformed both in terms of open-loop gain, frequency stability, and transient speed, thus presenting itself as the most suitable option for high-precision analog applications in which signal fidelity and constancy in behavior under varying load and frequency readouts are required. However, this improved performance comes at a price with greater power consumption and complexity of design.

On the other hand, the 5-Transistor OTA demonstrated an ideal power-favorable scaling and footprint, rendering it an excellent candidate for energy-efficient devices, such as: wearables, biomedical implants and/or sensors, IoT systems. Its gain and frequency response are moderate in comparison to the Current Mirror OTA, but it is quite consistent and exhibits great resistance to process and statistical variations.

The analysis thus confirms that both OTA designs are feasible based on the target application contexts. Depending on system constraints, designers can choose whether to optimize for power or performance fidelity. This work acts both as a tutorial describing the internal trade-offs between OTA architectures as well as a steppingstone for future optimization metrics balancing gain, bandwidth, area, and power in analog integrated circuits.

VII. Future Work

However, with exploration of additional requirements and flexibility in design, this study imparts important insight into two commonly applied OTA architectures, but there are still many avenues available for design exploration to make these circuits more applicable to emerging technologies. A possible area of exploration can be the adoption of adaptive biasing techniques, which adapt current consumption to the circuit signal conditions. Those techniques can, however, be a significant improvement on power efficiency, especially in variable workload systems like a biomedical monitor or event-driven IoT sensor.

A promising route is the port of these OTA designs to advanced technology nodes (e.g. 65 nm or 45 nm CMOS) where the supply voltage and threshold voltages is very different from a 180 nm baseline. These migrations will also need re-optimization of the transistor dimensions and biasing conditions, but can also result in speed and area improvements in exchange for increased leakage and variability.

Another step would go the layout-level route and then post-layout simulations with parasitic extraction (PEX), which would provide a better sense of performance and reveal second-order effects including coupling noise, mismatch, and layout-dependent parasitic capacitances. This has been a key step ensuring that the anomly-free performance seen at the schematic-level translates to real Silicon implementations.

New hybrids gain of Current Mirror OTAs and efficiency of 5-Transistor OTAs may also be considered. These could include cascoding techniques, gain-boosting, or even differential gain-stage enhancement with minimal power loss. Further highlights would include investigating OTA-based neural amplifiers, analog front-ends for sensor interfaces, and Gm-C filter designs for specialized applications (such as ECG, EEG, and real-time signal conditioning), providing more closure regarding the engineering choices under practical constraints.

Overall, this pioneering work can be a jumping-off point for future advances in next-generation compact, reliable, energy-model-aware (sensing) analog design.

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“Telemedicine Kit for Remote Health Monitoring”

(*Rahimraja Shaikh*[1], M Altamash Jundre [2], Rohit Konda [3], Rushikesh Kunjir [4])
Department of Electronics & Telecommunication
KJ College of Engineering & Management Research
Pune, India.
(rahimrajashaikh.kjcoemr@kjei.edu.in[1] , altamashjundre847@gmail.com[2], kondarohit102@gmail.com[3] , rushikeshkunjir7404@gmail.com[4])

ABSTRACT
This paper presents a Telemedicine Kit for Remote Health Monitoring that enables real-time patient care through IoT-connected medical devices. The kit includes essential sensors such as a digital stethoscope, ECG monitor, blood pressure sensor, and pulse oximeter, transmitting data securely via Wi-Fi, Bluetooth . A cloud-based platform ensures continuous monitoring, benefiting chronic disease patients, elderly individuals, and those in remote areas. Integrated AI and predictive analytics enhance early diagnosis and intervention, improving healthcare accessibility and efficiency.

Keywords: Telemedicine, Remote Monitoring, IoT Healthcare, AI in Medicine, Smart Health Solution

1. .INTRODUCTION

The demand for accessible healthcare has grown significantly, especially in remote and underserved areas where healthcare facilities are limited. For individuals with chronic conditions, elderly patients, and those recovering from illness, regular health monitoring is essential to maintain well-being. However, frequent visits to hospitals or clinics can be challenging due to distance, mobility issues, or financial constraints. This is where a Telemedicine Kit for Remote Health Monitoring can play a transformative role. A telemedicine kit is a portable and user-friendly device equipped with sensors to monitor vital health parameters such as heart rate, blood pressure, oxygen levels, body temperature, and more. By utilizing Internet of Things (IoT) technology, the kit collects and transmits real-time health data to healthcare providers through secure networks, allowing for continuous patient monitoring without the need for physical visits. This not only enhances patient convenience but also enables medical professionals to respond promptly in case of abnormal readings or emergencies.

2. PROBLEM STATEMENT

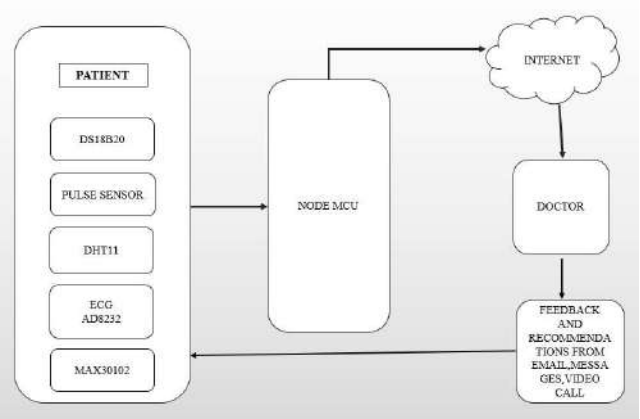
Access to timely healthcare is challenging in many areas, especially in rural and underserved communities, often leading to delayed medical care and diagnosis. Patients with chronic conditions, the elderly, and individuals recovering from illness need consistent monitoring of vital signs like heart rate, blood pressure, oxygen saturation, and temperature.

3. OBJECTIVES

This research aims to develop a Telemedicine Kit for Remote Health Monitoring to improve accessibility, efficiency, and real-time patient care. The key objectives are:

- **Enhance Accessibility:** Provide remote access to healthcare services for individuals in rural or underserved areas.
- **Improve Patient Care:** Enable continuous health monitoring to detect early signs of illnesses and prevent complications.
- **Support Healthcare Professionals:** Assist clinicians by providing reliable, real-time patient data for informed decision-making.
- **Promote Convenience:** Reduce the need for in-person hospital visits by enabling remote consultations and diagnostics

4. PROPOSED METHODOLOGY



The **Telemedicine Kit for Remote Health Monitoring System** is designed to enable real-time health tracking by integrating IoT-based sensors with a cloud-connected microcontroller. The system is composed of the following essential components:

Node MCU (ESP8266)

The NodeMCU (ESP8266) serves as the primary microcontroller, interfacing with sensors such as DS18B20(temperature sensor), Pulse Sensor, DHT11 (humidity and temperature sensor), and AD8232 (ECG module). It gathers real-time physiological data, including body temperature, pulse rate, ECG signals, and environmental factors.

Once the data is collected, NodeMCU processes and organizes it for transmission. With its integrated Wi-Fi module, the microcontroller sends the processed data to a cloud platform(ThingSpeak).

The real-time health data can be accessed remotely by healthcare providers.

Digital Temperature Sensor (DS18B20):

A precise temperature sensor that communicates using the 1-Wire protocol, allowing efficient data transfer with minimal wiring. It ensures accurate body temperature measurement.

Pulse Sensor:

A biometric sensor designed to monitor heart rate by detecting variations in blood flow at the fingertip, helping in cardiovascular health assessment.

DHT11 (Temperature & Humidity Sensor):

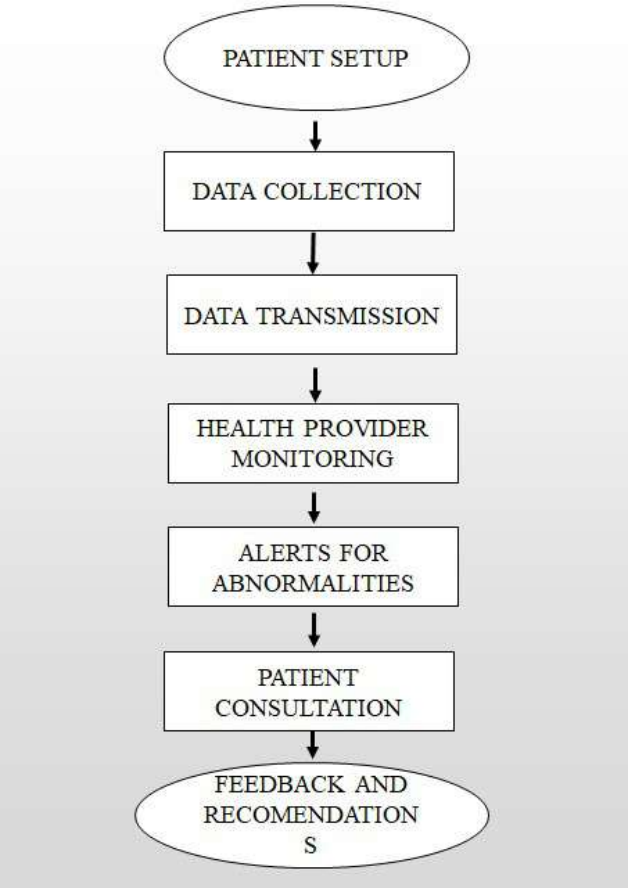
Measures ambient temperature and humidity levels, providing environmental context for the patient's health condition.

ECG Sensor (AD8232):

Records **electrocardiogram (ECG) signals**, offering insights into heart rhythm and detecting potential cardiac anomalies.

MAX30102 :

The MAX30102 is a pulse oximeter and heart rate sensor module that uses photoplethysmography (PPG) to measure blood oxygen saturation (SpO2) and heart rate. It combines two LEDs (red and infrared), a photodetector, and an optical filtering system to detect changes in blood volume.



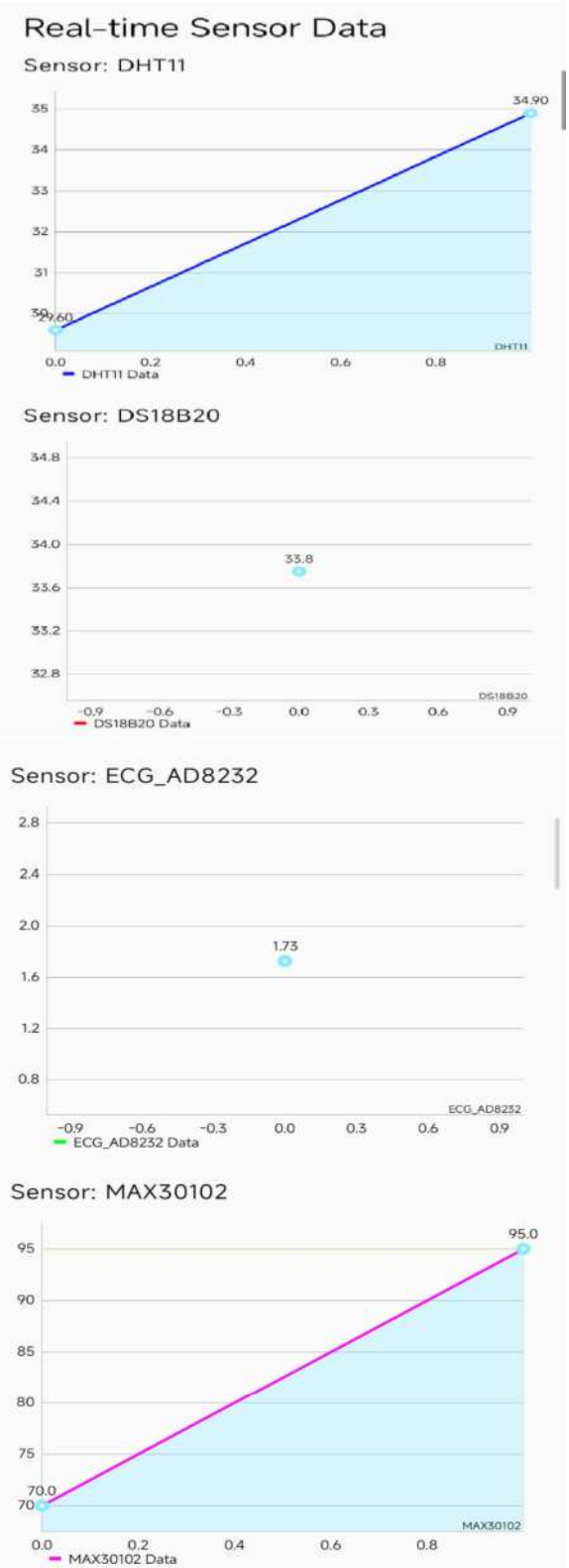
5. IMPLEMENTATION

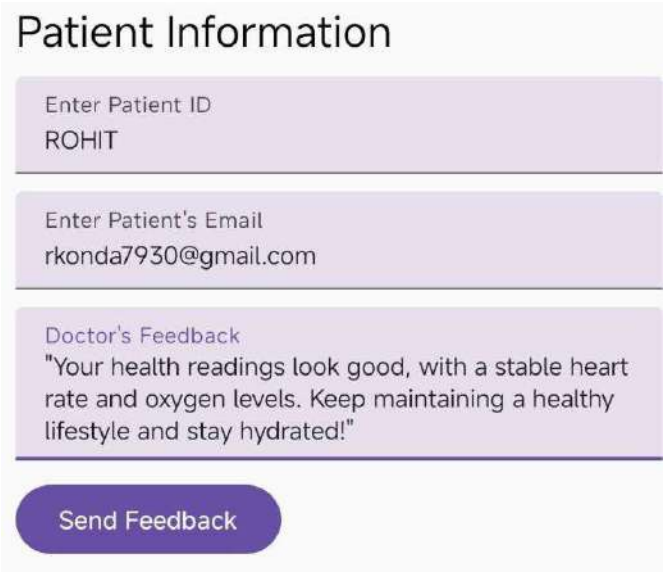
The implementation section consists of the flowcharts. The flowcharts are as shown below:

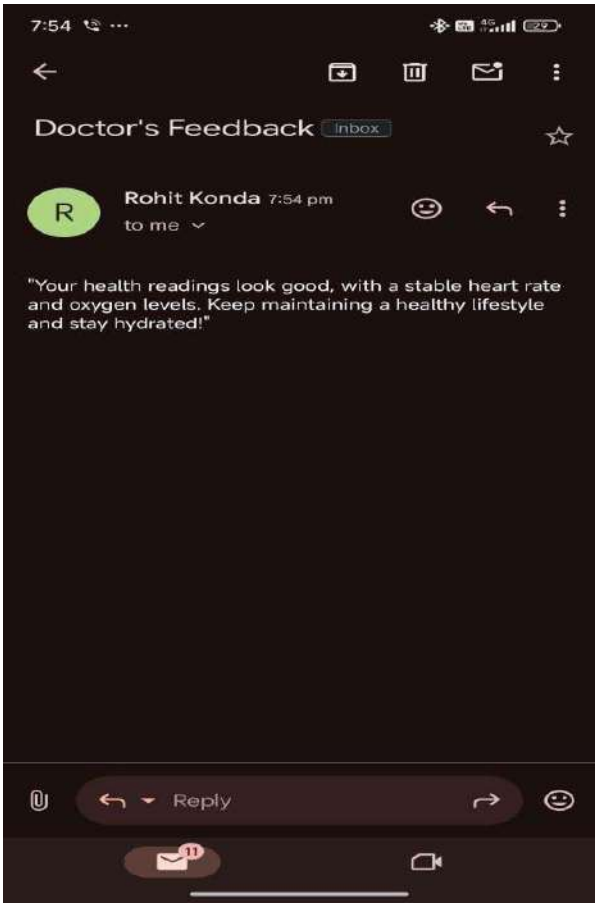
ALGORITHM

1. Power on the **NodeMCU (ESP8266)** and establish a Wi-Fi connection.
2. Configure and initialize sensors (**DS18B20, Pulse Sensor, DHT11, ECG AD8232**).
3. Continuously collect temperature, humidity, pulse rate, and ECG signals from the sensors.
4. Filter and validate sensor readings to eliminate noise and inaccuracies.
5. Transmit processed data to the **Telemed (application)** via **NodeMCU.**
6. The cloud platform stores and visualizes the health parameters.
7. The doctor accesses the real-time data through a web interface or mobile application.
8. If any vital sign crosses predefined thresholds, an alert notification is sent to the doctor and patient.
9. The system continuously updates health data at regular intervals, ensuring real-time monitoring and timely medical intervention.

6. EXPECTED RESULT







7. CONCLUSION

Telemedicine kits for health monitoring represent a significant advancement in healthcare delivery, offering numerous benefits such as remote patient monitoring, early detection of health issues, and enhanced access to care, particularly for those in rural or underserved areas. By integrating wearable sensors, mobile platforms, and real-time data transmission, these kits enable continuous health tracking for chronic conditions, post-surgery care, elderly support, and more. The ability to remotely connect with healthcare professionals ensures timely interventions and reduces the need for frequent in-person visits. Telemedicine kits also pave the way for better healthcare management through data analytics, allowing for personalized care plans and improved patient outcomes. Overall, the use of telemedicine in health monitoring enhances both convenience and efficiency, contributing to a more accessible, cost-effective, and patient-centered healthcare system.

8. FUTURE SCOPE

1. **AI-Based Analysis for Early Health Issue Detection:** Machine learning plays a crucial role in telemedicine by analyzing patient data to detect early signs of health issues. AI algorithms process real-time sensor data, identify patterns, and predict potential risks, such as irregular heart activity or respiratory problems. By providing timely alerts to both patients and healthcare providers, AI enables proactive intervention, reducing complications and hospitalizations. This technology enhances diagnostic accuracy, supports personalized treatment plans, and improves overall patient outcomes.

2. **Wearable Integration for Continuous Monitoring:** Integrating smartwatches with telemedicine kits enables real-time health tracking. These wearables monitor vital signs like heart rate, oxygen levels, and activity, sending data to healthcare providers for early detection of health issues. AI-driven analysis enhances accuracy, allowing proactive care and timely medical intervention. This seamless integration makes remote health monitoring more efficient and accessible.

3. **5G & Edge Computing for Real-Time Processing:** 5G and edge computing enhance telemedicine by enabling faster data transmission and real-time processing. With low latency and high-speed connectivity, patient data from sensors and wearables is analyzed instantly at the edge, reducing reliance on cloud servers. This improves response time, ensures seamless monitoring, and supports timely medical decisions..

4. **Automated Alerts for Emergency Response:**The telemedicine kit features automated alerts to notify emergency services in critical situations. When abnormal vital signs are detected, the system instantly sends alerts to healthcare providers or emergency contacts, ensuring timely medical intervention and improving patient safety.

5. **IoT Expansion for Advanced Health Monitoring:** Integrating additional IoT sensors allows the telemedicine kit to monitor a wider range of health parameters, such as blood pressure, ECG, and oxygen levels. This enhances remote diagnostics, enabling comprehensive and real-time patient monitoring for better healthcare outcomes.

6. **Global Accessibility In Telemedicine:** Expanding telemedicine makes remote healthcare more affordable and scalable ensuring medical access in underserved areas. Cost-effective technology and internet connectivity enable real-time monitoring, reducing hospital visits and improving global healthcare reach.

7. **Blockchain Security For Patient Data Protection:** Blockchain ensures secure and private storage of patient data in telemedicine.Its decentralized and tamper-proof system prevents unauthorized access, enhances data integrity, and maintains patients confidentiality.This strengthens trust and compliance with healthcare regulations.

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Adaptive Health Monitoring Revolution Using IoMT For Physically Challenged

Ravi Yadav[1], Harshita Kushwah[1] and Nitin Chouhan[1,*], Deepak Rathore[2]

[1] Department of Electronics & Telecommunication Engineering, Shri Govindram Seksaria Institute of Technology & Science, Indore
[2] Department of Computer Science Engineering, Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore
nchouhan@sgsits.ac.in

Abstract. Internet of Things (IoT) is one of the raising technologies that continues to rise with newer improvement in medical and health sector. Internet of Medical Things (IoMT) is subset of IoT and it is a network of interconnected medical devices (sensors) and applications that communicate wirelessly to the internet to monitor and collect health data. Health care is very important for every person but it is more important for physically challenged patients. A very proper care is required for physically challenged patient whether they are at home or in hospital. If the physically challenged is alone, if there condition is suddenly change or if they fall from the bed, then they need an immediate attention. Toward this, we present the design and implementation of IoMT based health monitoring system for physically challenged patients in this paper. This system incorporates the gravity sensor, heart rate sensor and temperature sensor for monitoring the condition of physically challenged patients. These sensors continuously monitor the patient condition. Whenever the condition of patient is abnormal either they fall from the bed and due to health issue, an alert will be sent to the resource person or medical concern person using SMS (via GSM) and information on global monitoring using IoT and cloud. The main aim of this project is to take care of physically challenged patients and inform the particular person if any abnormality occurs so that they can save the patient's life.

Keywords: IoMT, physically challenged patient, Sensors.

1 Introduction

Nowadays, use of IoT in medical field termed as IoMT [1, 2] is rapidly increases, transform healthcare by remote monitoring, real time monitoring and hospital automation. Health monitoring of patient is one of the serious issue in hospitals as well as in home. The doctor/nurse in hospital or person in home cannot continuously monitor the condition of patient. Sometimes the situation is arises when the patient is alone and if there is an emergency occurs, then they need immediate response otherwise there will be panic condition. This condition is more critical if the patient is physically challenged. So there is a requirement of such system which continuously monitors the

condition of patient and if there is any emergency, then system will inform the doctor/nurse/person.
This paper presents a proposed project for continuously monitoring the health condition of physically challenged patients. IoT is used for developing this project; so that data can be send to remote server as well as on cloud. This project is designed using Arduino ATmega328p, ESP-32 Microcontroller, HC-12 Transceiver, LCD Display, Gravity sensor, Heart rate sensor and Temperature sensor. Gravity sensor senses the fall detection, heart rate sensor senses the heart rate and temperature sensor senses the body temperature of the physically challenged patient. Firstly sensors are mounting on the patient's body that continuously senses the particular parameter and it is fed to the Arduino microcontroller. Microcontroller analyzes this data and send to the remote location using HC-12 Transceiver. Remote location is situated at the nursing staff counter where this data is received by the other HC-12 Transceiver. From receiver this data send to ESP-32 Microcontroller where it is continuously shown on the LCD display and also stores on the cloud. In case of any emergency situation occurs then the ESP -32 microcontroller send warning message to the concerned person.

The major contributions of this paper are:

1. Introducing the IoT based system for monitoring the health condition of physically challenged patients.
2. For monitoring health patients, various sensors are senses the parameters (temperature, heart rate, fall detection) of the patient.
3. Results are analyzed using the microcontroller and also display on the LCD screen at the nursing staff room.
4. In case of emergency a warning message is sent to the concerned person.

The rest of the paper is organized as follows: Section 2 discuss the related work on health monitoring using IoT. Hardware used for the project is explained in Section 3. System design is present in Section 4 followed by result in Section 5. Finally we conclude this paper in Section 6.

2 Related Work

This section presents a related work on health monitoring using IoT. In this section we discussed various works presented on health monitoring.
In [3] authors present a health monitoring system using AI and IoT for old age peoples. The proposed system continuously monitors ECG, heart rate and temperature of the patient and sending immediate alerts to concern person upon detecting abnormalities. Author of [4] proposed a remote health monitoring using IoT. In the paper author focuses on a portable physical monitoring system that can track a patient's temperature, heart rate, and other parameters on a regular basis. This monitor data is stored on IoT platform where a licensed physician can access the stored data and use it to diagnose the patient's diseases. In [5] authors present Health Care Monitoring (HCM)

ISBN: 978-93-343-2006-0

application using IoT system for temperature and heartbeat monitoring of the patient. The system continuously monitors and collects data in real time from the sensors and transmits it to computing devices. The system also informs the physicians in the event of an emergency. Author of [6] proposed a tracking and health monitoring system for soldiers using IoT system. The proposed system can be placed on the soldier's body to track their current location and health state. The Internet of Things will be used to send this data to the control room. Sensors, transmission modules, and small wearable physiological devices make up the proposed system.

In [7] author proposed a secure remote health monitoring and assessment system using IoT. The proposed model consist of four layers i.e. web services, cloud, Android, and embedded layers. The cloud helps for critical analysis, while web services are used for frontend presentation and end user monitoring. Real sensor data was supplied onto the server through an Android layer. Medical data is collected by the embedded technology. Homomorphic-based encryption is used to securely transfer data from the Android device to the cloud through the Bluetooth module (HC-05). Various health indicators are included in the final output, which is labeled as critical, normal, or dangerous. The administrator who is keeping an eye on the patient's vitals takes the appropriate action based on this output. Authors of [8] present an enhanced health monitoring system using IoT and machine learning. The study presents a smart glove that uses built-in sensors to gather and process users' vital signals of health. After that, an Arduino hardware module transfers the data to MATLAB. Using the gathered test data, machine learning algorithms—more especially, the K-Nearest Neighbor classifier—are used to determine whether the user's physical condition is normal or abnormal. The user receives a notification about their health status and a prescription is created based on the prognosis. Our smart glove solution uses IoT and machine learning to provide personalized health monitoring, increasing the overall efficacy and efficiency of remote health monitoring systems.

3 Hardware Used for the system

3.1 Microcontroller – Arduino (ATmega328)

It is a microcontroller board built around the 8-bit ATmega328P microcontroller. For supporting the microcontroller many blocks include such a voltage regulator, serial communication crystal oscillator etc. The Arduino features a six analog input pins, a USB port, , reset button an ICSP header, a power barrel jack and fourteen digital input/output pins, six of which can be utilized as outputs of PWM.

3.2 ESP-32 Microcontroller

ESP32 is comes with Bluetooth and Wi-Fi combination chip which designed whit TSMC (Taiwan Semiconductor Manufacturing Company) ultra-low power 40nm Technology. It is single chip controller operate on 2.4 GHz clock frequency and it

optimized and designed for the best power performance, robustness, reliability and RF performance.

3.3 HC-12- Transceiver

Using UART (Universal Asynchronous Receiver-Transmitter), the HC-12 is a 433 MHz wireless transceiver module intended for transparent serial communication. By supporting baud rates ranging from 1,200 to 115,200 bps and operating in the 400–473 MHz frequency band, it enables flexible data transmission over up to 1.6 km in open space when equipped with the right antenna. In contrast to complicated wireless protocols, the HC-12 module requires little setup and may be used with straightforward AT instructions to communicate with microcontrollers such as Arduino, ESP32, and Raspberry Pi.

3.4 LCD Display

It is an electronic display unit which gives uses number of different circuits and devices, including cell phones, calculators, computers and TV sets. Seven segments and multi-segment light-emitting diodes preferred for this display. This module's primary advantages include being affordable, easily configurable, having animations, and having no restrictions on the display of unique characters, special effects, animations, etc.

3.5 SENSORS

Heart rate Sensor (Pulse Sensor): A pulse rate sensor is a biomedical device used to measure heart rate beats per minute, BPM by detecting changes in blood volume through photo plethysmography (PPG). It operates by emitting light typically using an led onto the skin and measuring the reflected or absorbed light using a photodiode. Variations in light absorption correspond to the pulsatile flow of blood, allowing the sensor to estimate the heart rate in real time. Its can use for mainly in educational purpose.

Gravity Sensor (MPU 6050 Accelerometer): The whole 6-axis motion tracking device is the MPU6050 sensor module. It is a little gadget that combines a 3-axis accelerometer, a 3-axis gyroscope, and a digital motion processor. As a bonus, it has an on-chip temperature sensor. It has an I2C bus interface for interacting with the microcontrollers.

Temperature Sensor (MLX90614): For monitoring body temperature we use MLX90614 temperature sensor. It is an infrared thermometer sensor which measures the temperature without making physical contact to body. It is low power consumption, high accuracy body temperature sensor.

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4 Proposed System Design

The system design of our project can be divided into two parts namely, hardware part which includes interfacing of hardware's and software part which includes coding and circuit designing. For hardware parts we have two circuits: Initiator and Responder. Initiator is implemented on patient to monitor the health and Responder is implemented near nursing staff counter.

4.1 Initiator Circuit

In Initiator circuit we use different types of sensors, microcontroller and HC-12 transmitter. Sensors are mounting on patient body to monitor various health parameters. We use gravity sensor that takes the input from the motion of the patient hand, heart beat sensor that takes the input from the patient heart and temperature sensor that takes the input from the patient body. These sensors are connected to the Arduino Uno atmega328 micro-controller. Additionally we have HC-12 transmitter to send the senses data to Responder circuit. All the senses data continually send to the microcontroller where this data is analyzed and send to the communicate circuit through HC–12 transmitter. Fig. 1 shows the initiator circuit.

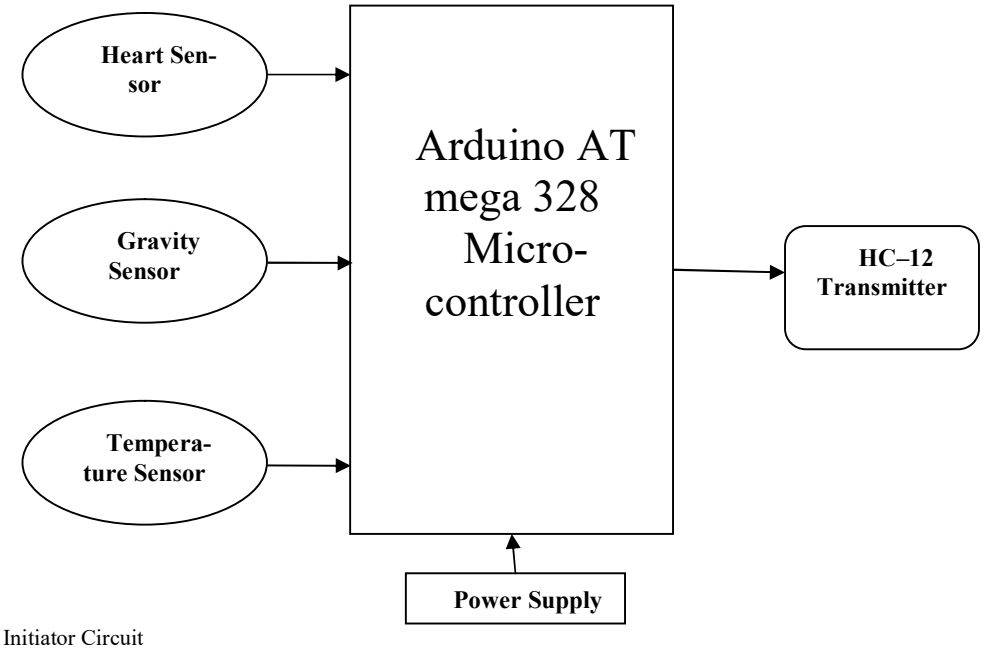


Fig. 1. Initiator Circuit

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4.2 Responder Circuit

In responder circuit (Fig. 2), firstly the data from the initiator circuit is collected using HC–12 receiver. This data is send to the ESP-32 microcontroller. From this microcontroller this data continually displayed on the LCD and store in the IoT cloud. An account is created on the public Thing speak cloud where this data is continually store. Also from ESP-32 a GSM module is connected from which warning message is send to the concerned person in case of emergency.

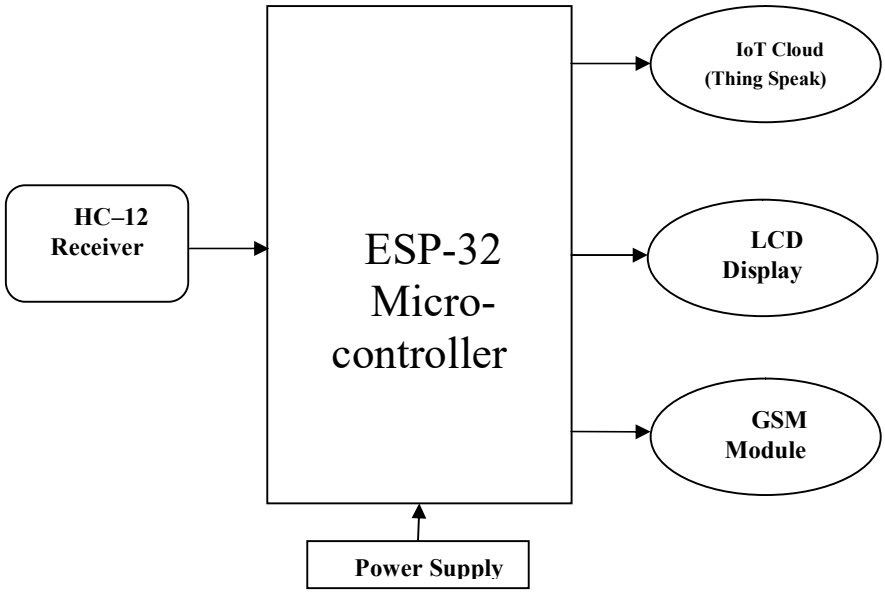


Fig. 2. Responder Circuit

5 Results

This project is implemented using both hardware part and software part. For software part we perform the coding in the Arduino IDE environment. Firstly gravity sensor is mounted on the hand glove which is wear by the patient hand as shown in the Fig. 3. Fig. 4 shows the responder circuit with LCD display and Fig. 5 show the complete project consists of both initiator and responder circuits.

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Fig. 3. Gravity sensor mounted on hand glove

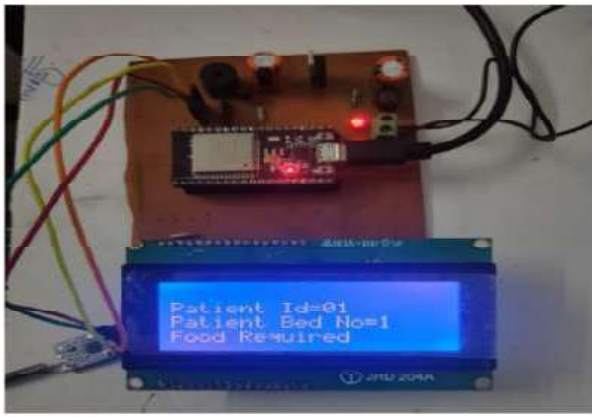


Fig. 4. Responder circuit with LCD display

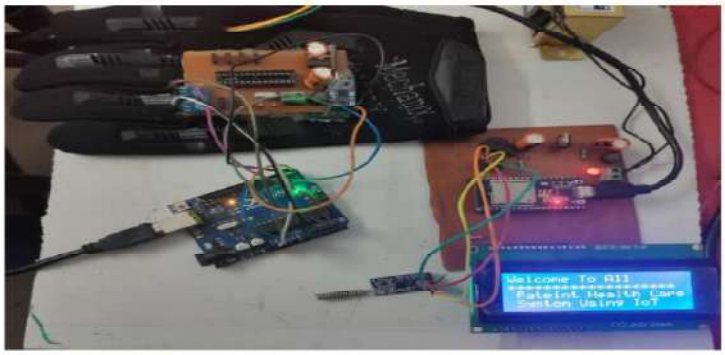


Fig. 5. Complete Proposed IoMT System

This data is continuously store on the Thing speak cloud and the result for the same is discussed in following figures. Result for gravity sensor is shown in Figs 6-7. In the

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Fig. 6, data from the controller is continuously saved and the fall indicator is also provided. If the patient is fall from the bed then gravity sensor senses the fall and the result for the same (Thing speak) is shown in Fig.7.

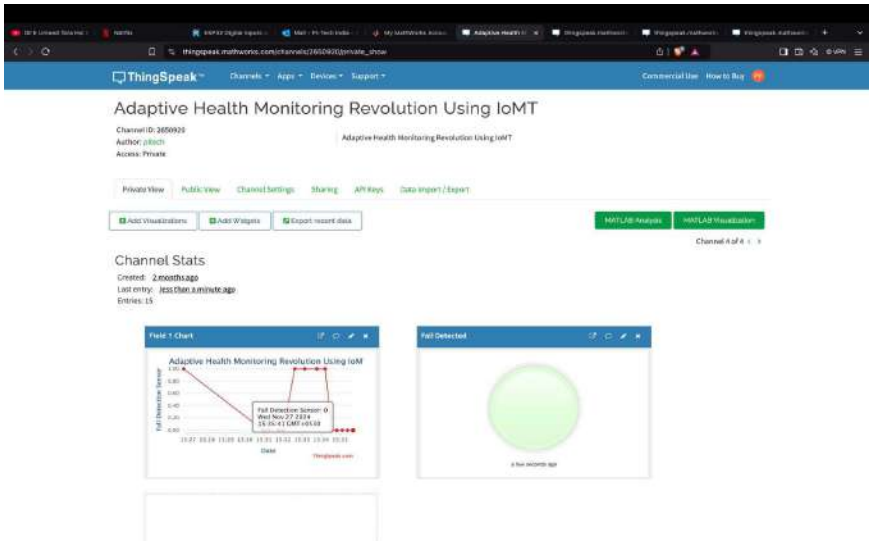


Fig. 6. Gravity Sensor Output Data on ThingSpeak Cloud

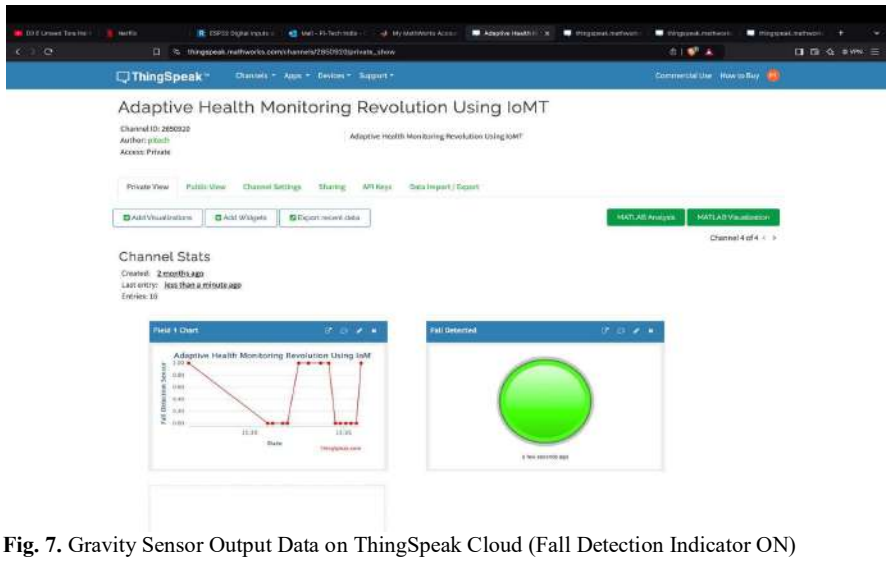


Fig. 7. Gravity Sensor Output Data on ThingSpeak Cloud (Fall Detection Indicator ON)

Result for the heart rate sensor is shown in the Fig 8. In this data we make two indicators, high rate indicator which indicate high heart rate and low rate indicator which indicate low heart rate.

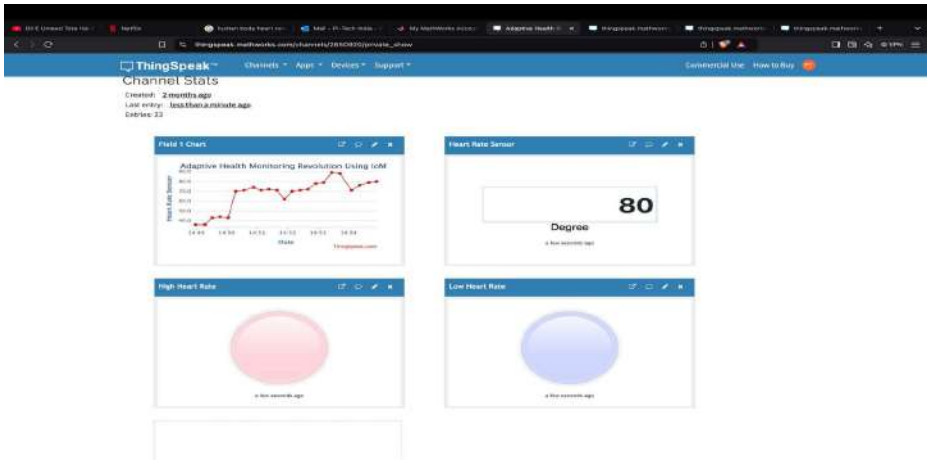


Fig. 8. Heart rate Sensor Output Data on ThingSpeak Cloud

Result for the temperature sensor with two indicators (High body temperature and low body temperature) is shown in the Fig 9.

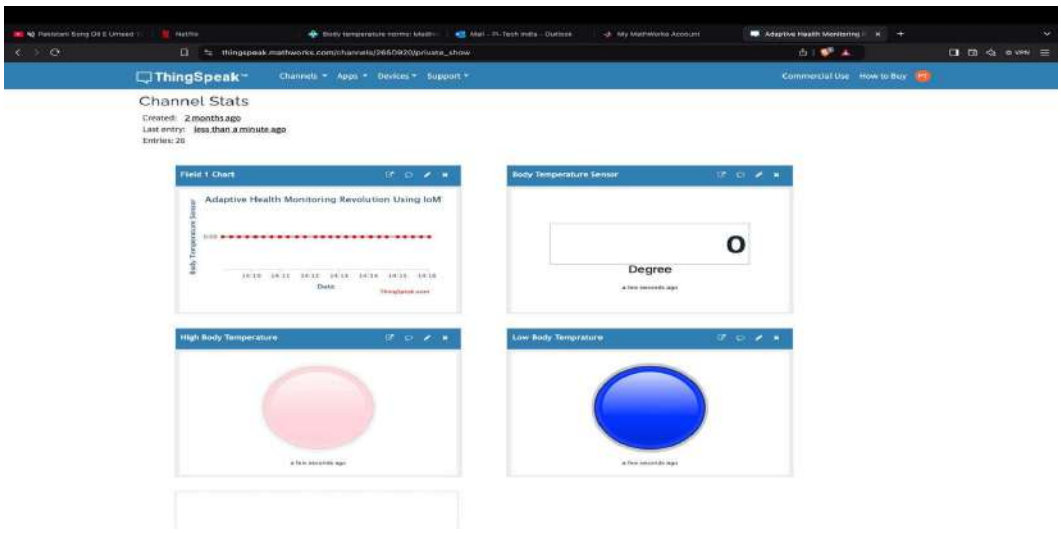


Fig. 9. Temperature Sensor Output Data on ThingSpeak (low body temperature indicator ON)

6 Conclusion

Health monitoring is very important in case of physically challenged patients (not able to walk, not able to see etc). A person is required for all the time to monitor the patient. But what happens if the patient is alone in case of any emergency occurs. Therefore, this research project presents an IoMT based health monitoring system for physically challenged patients. Proposed project senses various health parameters i.e. heart rate, temperature and fall detection continuously and also send it to IoT cloud and also displays it to on LCD. If any emergency occurs i.e. either the patient is fall or due to medical emergency an alert warning message is send to the concerned person. Therefore, proposed system would efficiently save the patient from any loss and it can be used for real time health monitoring for elderly person also. In the future, we also mount sensors to monitor other health parameters. Additionally we incorporate AI based predictive analytics with the system and also integrate with telemedicine platform.

Acknowledgments. None.

Disclosure of Interests. The authors declare that they have no conflict of interest.

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IoT-Based Real Time Smart Waste Management System with AI Waste Segregation

Dr. Pramod Chavan[1], Shravani Shingote[2], Ritika Patil[3], Atharv Landge[4]
[1,2,3,4]*Department of Electronics and Telecommunication Engineering*
KJ College of Engineering and Management Research, Pune(MH), India

dr.pu.chavan@gmail.com, shingoteshravani147@gmail.com, patilritika483@gmail.com, atharvlandge2@gmail.com

Abstract—

The paper introduces an Internet of Things (IoT)-based waste segregation system that uses moisture-based waste validation in conjunction with intelligent automation and artificial intelligence to improve the separation process. Real-time alerts are made possible by the use of ESP32 and ESP32-CAM microcontrollers, GPS, and GSM with web server. A servo motor and ESP32-CAM microcontroller is trained for AI based waste classification. The authors created an automated system with a scalable design for deployment and updates in order to enhance waste management. The suggested system provides an economical and energy-efficient substitute for the pricey and power-hungry smart trash cans that are currently in the market. Real-time testing shows that the system performs well, improving the separation of dry and wet waste and increasing user convenience through real-time features.

Keywords—IoT, AI, CNN, ESP32, ESP32CAM, Smart Waste Bin, Image Classification, Real Time

I. INTRODUCTION

By increasing productivity, automation, and real-time monitoring, the application of Internet of Things (IoT) technology to waste management has brought about creative answers to the escalating environmental issues. Manual labour, erratic pickup schedules, and ineffective sorting are common features of traditional waste collection and segregation methods, which raise operating expenses and pose environmental risks. This project describes the creation and deployment of an Internet of Things (IoT)-enabled smart waste management system that uses ESP32 microcontrollers to implement AI-based waste segregation. It uses a servomotor to automatically classify and separate waste using an ESP32-CAM running a lightweight AI model, an ultrasonic sensor, and a moisture sensor. Real-time alerts and location tracking are made possible by GSM and GPS modules, and remote bin monitoring is made possible by an ESP32 web server that can be accessed by a browser. The hardware framework, system architecture, and real-world implementation are examined in this paper.

A. Background

Among the major inefficiencies of traditional waste management systems are their reliance on manual intervention, lack of monitoring, and lack of automated segregation. These restrictions support efficient recycling procedures, higher operating expenses, and inappropriate disposal. combining artificial intelligence (AI) image-based waste classification with the internet of things (IoT) for communication and sensing. This collaboration streamlines waste collection logistics, minimizes human intervention, and enables automated sorting. For scalable, low-power, and reasonably priced urban sanitation infrastructure, such intelligent waste management frameworks are essential.

B. Proposed Approach

This paper introduces a smart waste management system that automates waste segregation and monitoring through the use of embedded AI and IoT technologies. To determine waste type, manage disposal, and detect bin capacity, a microcontroller-based architecture synchronizes sensor inputs and peripheral modules. Following mechanical segregation, waste is categorized using onboard image processing and validated by moisture analysis. GSM and GPS modules are used to enable geolocation and threshold-based alerts. Remote system access is made easier by a lightweight web server interface, which guarantees prompt response and efficient waste collection.

II. LITERATURE SURVEY

Significant inefficiencies in manual collection techniques, imprecise segregation, and a lack of real-time monitoring are evident in the state of waste management systems today. In order to create intelligent solutions that automate waste classification, bin monitoring, and timely disposal, researchers are increasingly turning to IoT and AI. Using ultrasonic sensors and GSM modules for real-time updates, Vinoth Kumar et al. (2017) "Smart Garbage Monitoring System using Sensors with GSM." proposed a smart garbage monitoring system, emphasizing how conventional collection methods lead to overflowing bins and ineffective route planning. The foundation for IoT-enabled municipal waste systems was established by their efforts. Similar to this, Lakshmana Prabu et al. (2019) "Smart Waste Management System using IoT and Machine Learning." validated the potential of AI-enhanced segregation models by demonstrating a hybrid system that separates organic from inorganic waste using IoT sensors and machine learning classifiers like SVMs. This was furthered by Sharma et al. (2020) "Deep Learning-Based Waste Classification and Smart Bins." through the use of servo-actuated compartments to automate physical segregation, CNN models for image-based waste classification via Raspberry Pi, and the integration of deep learning with IoT hardware. Their strategy is closely related to our use of servo motors and ESP32-CAM for intelligent bin management. Using cloud dashboards and fill-level predictions, Barros et al. (2019) integrated predictive analytics into smart waste systems, pointing the way toward

scalable urban deployment. Furthermore, a key component of our on-device AI approach is the demonstration by Alghamdi et al. (2020) that CNN models can be trained on large datasets and then deployed on microcontrollers for real-time classification of different waste types. This was furthered by Sharma et al. (2020) through the use of servo-actuated compartments to automate physical segregation, CNN models for image-based waste classification via Raspberry Pi, and the integration of deep learning with IoT hardware. Their strategy is closely related to our use of servo motors and ESP32-CAM for intelligent bin management. Using cloud dashboards and fill-level predictions, Barros et al. (2019) integrated predictive analytics into smart waste systems, pointing the way toward scalable urban deployment. Furthermore, a key component of our on-device AI approach is the demonstration by Alghamdi et al. (2020) that CNN models can be trained on large datasets and then deployed on microcontrollers for real-time classification of different waste types.

III. METHODOLOGY

This section describes the design, development, and implementation of the IoT-enabled Waste Management system with AI based automatic waste segregation, divided into two key phases: Hardware Architecture and Software Architecture.

A. Hardware Architecture

The ESP32 microcontroller, the central processing unit of the suggested smart waste management system, is responsible for controlling signals, communication, and real-time data acquisition. An HC-SR04 ultrasonic sensor for continuous garbage level monitoring inside the bin, a GPS module (NEO-6M) for geolocation tracking, and a GSM module (SIM900) for alert messaging are just a few of the peripheral modules that the ESP32 interfaces with. A dedicated ESP32-CAM module is deployed for AI-driven waste classification using an onboard lightweight CNN model, enabling image-based segregation between wet and dry waste. To increase classification accuracy, a capacitive soil moisture sensor is added to the moisture sensing process. A servo motor is then activated to direct the waste into the proper compartments. The ESP32, which synchronizes all modules, sends sensor readings and status information to a web-based server platform, enabling system logs, threshold-based notifications, and remote monitoring.

With all sensors and actuators connected via GPIO pins and programmatic management, the system runs on regulated DC power. For smart city waste handling applications, this scalable and modular architecture guarantees reliable performance, low power consumption, and real-time control.

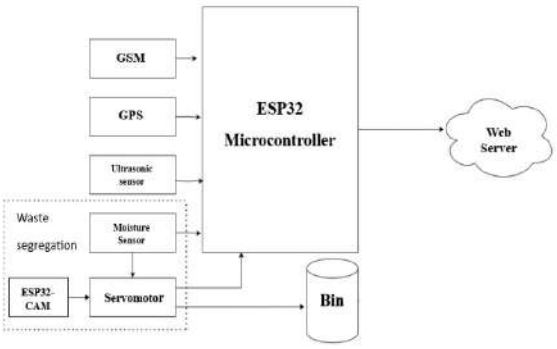


Fig.1. Hardware Architecture

B. Software Architecture

The IoT-enabled Smart Waste Management System's software architecture is designed to automate waste classification and bin status reporting by combining cloud-based monitoring, AI inference, and embedded control. In order to ensure responsive and intelligent system behaviour, the system works across multiple software layers, from web-based data visualization to edge AI on ESP32-CAM.

Embedded Firmware (ESP32 & ESP32-CAM) -

The firmware for the ESP32 microcontroller, which was created with the Arduino IDE, manages servo motor actuation, GSM/GPS communication, cloud connectivity through Wi-Fi, and sensor acquisition (ultrasonic and moisture sensors). Using image input, the ESP32-CAM runs an on-device CNN model for waste classification in real time. TensorFlow Lite is used to deploy and quantize the AI model, allowing for effective edge processing.

AI Model Development (TensorFlow on Google Colab) -

TensorFlow and Keras are used on Google Colab to develop and train the AI waste classification model. Training is done using a labeled dataset of pictures of dry and wet waste. The trained model is transformed into a thin TensorFlow Lite version that works with the memory and processing limitations of the ESP32-CAM. This eliminates the need for external servers and allows the ESP32-CAM to make waste-type predictions instantly.

Data Transmission and Monitoring -

While NEO-6M GPS modules supply location coordinates, the ESP32 uses GSM (SIM900) to send SMS alerts when the bin level surpasses 90%. Real-time updates to mobile notifications and web-based dashboards increase management effectiveness. Through edge AI and cloud integration, this multi-platform software stack improves system automation, reduces the need for manual intervention, and offers intelligent waste segregation and status reporting.

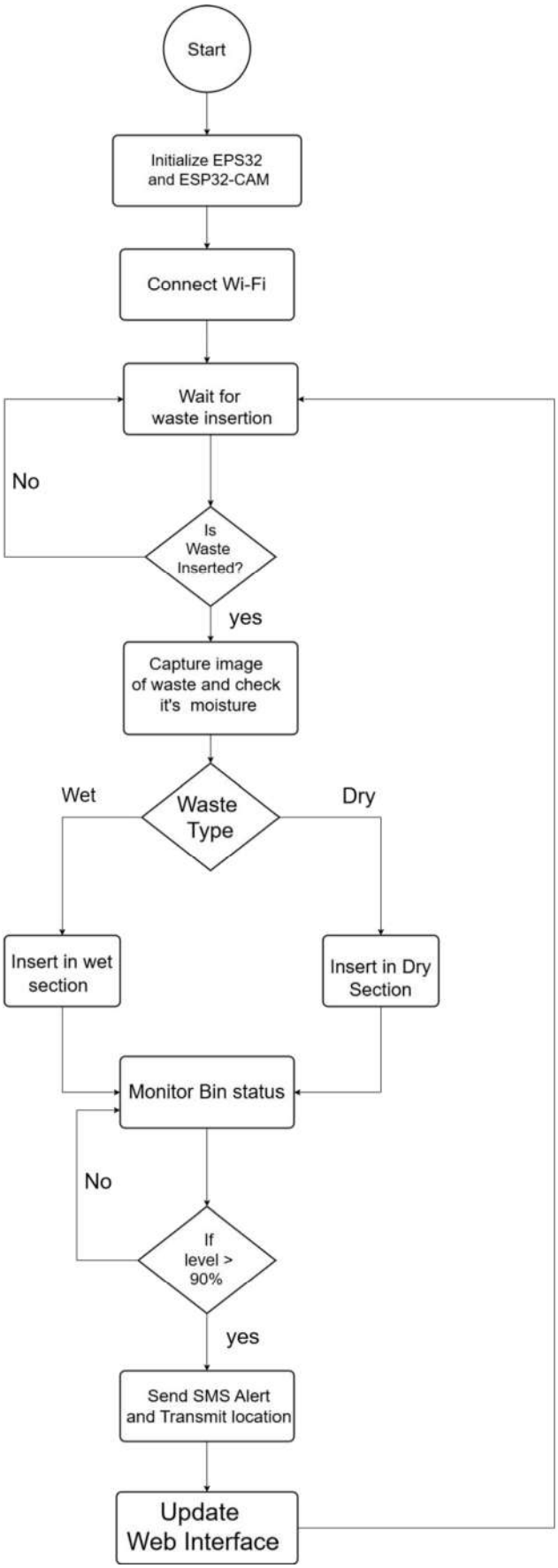


Fig.2. Flow Chart

1. Send Alert (if bin full) –
   • If bin is 90% full:
   – Send SMS alert via GSM module.
   – Transmit location via GPS module.
   – Update web dashboard.
2. Actuate Segregation –
   • Based on classification, ESP32 actuates the servo motor.
   • Waste is directed to respective section (wet or dry) in the bin.
3. Monitor Bin Status –
   • Ultrasonic sensor continuously measures garbage level in the bin. If level > 90%, trigger notification process.
4. Send Alert (if bin full) –
   • If bin is 90% full:
   – Send SMS alert via GSM module.
   – Transmit location via GPS module.
5. Update Web Interface –
   • Display waste type, bin level, and location on the Web Server.
   • Enable remote monitoring and real-time data access.
6. Loop or Idle –
   • System goes back to monitoring state.
   • Waits for next waste input or bin reset.

Waste segregation, level monitoring, and alert generation are automated by the Internet of Things-based Smart Waste Management System, which combines wireless communication, sensor networks, and embedded intelligence. As the central control unit, the ESP32 microcontroller interfaces with peripherals like a servo motor to regulate waste redirection, a capacitive moisture sensor to identify wet waste, and an ultrasonic sensor to detect bin level. Waste images are taken using an ESP32-CAM module, and a lightweight CNN model is used to classify waste in real time. After processing, the system uses servo actuation to guide waste to the proper bin section. GSM and GPS modules update the status on a web dashboard and send location-tagged alerts to the authorities when the garbage level surpasses a predetermined threshold. The Arduino IDE is used to program the entire system, and TensorFlow is used to train the models in Google Colab. With IoT cloud integration, real-time data visualization and remote access are made possible, resulting in an intelligent, self-sufficient, and effective solution to the problems associated with urban waste management.

IV. EXPERIMENTATION AND RESULTS

Automated waste segregation, real-time bin level detection, waste type identification, and location tracking are all features of the Internet of Things-based Smart Waste Management System. Individual modules—sensor-based waste categorization, image-based waste classification, level monitoring, alert generation, and GPS location sharing—were tested in a controlled laboratory setting during the experimentation phase.

A. System Output

The dataset of frequently disposed waste materials, such as paper, plastic, and food waste, was used to test the system. Using a lightweight Convolutional Neural Network (CNN) model, the ESP32-CAM consistently classified waste into wet and dry categories. In order to identify wet waste, the integrated capacitive moisture sensor served as a second layer of verification. The system consistently responded to classification decisions within 1-2 seconds of image capture, and the servo motor was activated to redirect the waste into the appropriate compartment based on the classification results.

Following classification, the waste type was shown on a 16x2 I2C LCD screen that was attached to the ESP32. The LCD output gave the user real-time feedback by displaying a message like “Wet” or “Dry”. As anticipated, this display module responded immediately to the output of the classification module.





Fig.3. System output

B. Waste Level Detection on Web Server



Fig.4. Web Server Output

The bin's fill level was determined by calibrating the ultrasonic sensor. This data was periodically uploaded to a web-based Blynk dashboard by the ESP32. Due to early development naming, the dashboard label originally read "Soil Moisture," but it now accurately reflected the bin's current status. To initiate alerts, a 90% fill threshold was established. The following findings were observed:

• The dashboard displayed Normal Status when the bin was less than 50% and the system updated the dashboard to show "Bin Full," along with the timestamp and waste type, and sent an alert via the GSM module once the level surpassed 90%.

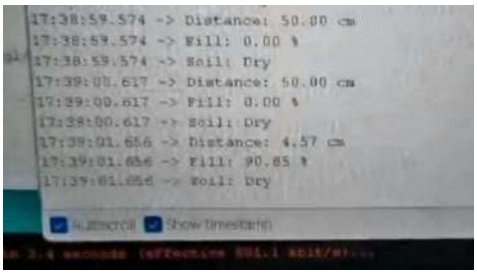


Fig.5. Serial Monitor Output

- Comprehensive data was shown on a Web dashboard, including: Time of entry (timestamp);
- Waste type classification (ESP32-CAM);
- Distance to full (from ultrasonic sensor in cm);
- Status (e.g., "Dry Waste Added at 15:42:21").

This logging system enhanced traceability and simulated real-time waste monitoring.

C. Location Tracking

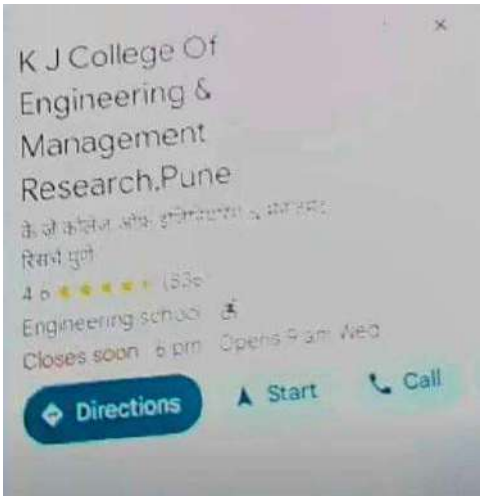


Fig. 6. Location Tracking Output

The waste bin's real-time coordinates were transmitted via the NEO-6M GPS module. When an alert was triggered due to bin overfill, the location data was updated on the mobile dashboard, making it possible for users or local authorities to pin point the locations of the bins. When tested close to windows or open areas, the GPS was able to transmit latitude and longitude values with greater precision and with acceptable accuracy indoors.

V. CONCLUSION

An IoT-based smart waste management system that integrates real-time location tracking, sensor-based monitoring, and AI-

driven waste segregation is developed and successfully implemented in this paper. In order to accurately separate wet and dry waste, the system uses the ESP32 and ESP32-CAM microcontrollers to classify waste intelligently using image recognition and moisture sensing. Additional parts, such as GPS modules, GSM, and ultrasonic sensors, allow for alert generation, real-time bin level monitoring, and accurate bin location updates through a cloud-connected interface. By combining automation, artificial intelligence, and the Internet of Things, the suggested solution provides a scalable, effective, and environmentally responsible substitute for conventional waste disposal methods. By increasing waste processing efficiency, decreasing manual intervention, and boosting waste traceability and hygiene, the project supports the infrastructure of smart cities. Proactive waste collection and system transparency are further supported by the Blynk platform's real-time data accessibility. In summary, the system shows that intelligent waste segregation and monitoring is feasible and effective, opening the door for future developments in smart environmental solutions and sustainable municipal waste management.

VI. CONTRIBUTION

In order to enhance the effectiveness, hygienic practices, and traceability of waste disposal, this paper introduces an Internet of Things (IoT)-based Smart Waste Management System that combines artificial intelligence and sensor-based automation. For intelligent segregation and monitoring of municipal solid waste, the system makes use of the ESP32 and ESP32-CAM microcontrollers, which are interfaced with parts like an LCD display, a servo motor, an ultrasonic sensor, a capacitive moisture sensor, GSM, and GPS. Waste is classified as wet or dry using image processing by an onboard AI model installed on the ESP32-CAM, with further validation coming from the moisture sensor. Through a web dashboard, the system provides real-time bin-level data and shows the type of waste on an LCD screen. Using GSM and GPS modules, the bin automatically notifies the relevant authority of the waste type and location when it reaches the threshold. After being emptied, the system resets itself, enabling continuous, independent operation.

The suggested system reduces manual handling, facilitates effective waste collection, and encourages cleanliness in urban areas by automating waste segregation and incorporating real-time IoT monitoring. By showing how to construct scalable, intelligent waste management infrastructures using inexpensive microcontrollers and embedded artificial intelligence, this research advances smart city solutions.

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BrewGenius: Personalized Coffee Brewing with Real-Time Monitoring

Divesh Zope
Electronics and Telecommunication
PES Modern College Of Engineering
Pune,India
divesh_zope_entc@moderncoe.edu.in

Jaydeep Jedhe
Electronics and Telecommunication
PES Modern College Of Engineering
Pune,India
jaydeep_jedhe_entc@moderncoe.edu.in

Ashwin Wadile
Electronics and Telecommunication PES
Modern College Of Engineering
Pune,India
ashwin_wadile_entc@moderncoe.edu.in

Mrs.A.P.More
Electronics and Telecommunication
PES Modern College Of Engineering
Pune,India
aparna.more@moderncoe.edu.in

Abstract—With the goal to provide a customised beverage experience, this paper introduces BrewGenius, an automated and intelligent coffee maker that combines embedded systems, IoT technologies, and AI-based user preference learning. An LCD display, actuators (a relay-controlled heater, pump, and coffee selection system), and sensors (temperature and water level) are all interfaced with an ESP32 microcontroller, which forms the core of the system architecture. Remote coffee selection and status monitoring are made possible by the microcontroller's web-based interface and Wi-Fi communication.After authenticating via the web portal, users can choose their preferred coffee strength (strong or mild), which is saved and retrieved for later sessions.The project shows how to combine full-stack development and embedded hardware in a useful way to produce a real-time, user-focused application. Results from experiments verify dependable sensor-actuator interactions, quick cloud database communication,

Keywords—Smart Coffee Machine, Embedded Systems, IoT, ESP32, AI-based Preference Learning, Full-Stack Development, Real-Time Automation, Cloud Database, Personalized Beverage System.

I. INTRODUCTION

For many people, coffee is more than just a drink; it's a daily ritual that gives them comfort and energy. However, making a perfect cup by hand every day can be inconsistent and time-consuming, particularly when it comes to managing brewing time, heating water to the proper temperature, and grinding beans. A clever, automated system that can deliver coffee fast, reliably, and according to personal preferences is obviously needed in today's hectic world.

With advancements in embedded systems and IoT technologies, it's now possible to build intelligent machines that can automate complex processes with precision. Smart coffee machines are becoming more popular, offering features like one-touch brewing, temperature control, and even mobile connectivity. But many still lack the ability to adapt to user preferences over time or provide complete automation from grinding to brewing.

To close these gaps, we present BrewGenius, a smart coffee maker that combines IoT, embedded control, and AI-based learning to provide a completely personalised coffee . experience. It automates the entire process—grinding, brewing, and serving—while also learning from customer preferences such as coffee strength. BrewGenius provides a convenient and intelligent enhancement to classic coffee-making methods, including remote control via a web interface and real-time progress updates. As the market for smart home products expands, consumers are expecting machines to learn, adapt, and enhance their everyday routines rather than just carry out duties. That's why BrewGenius was created. The system allows users to interact with it remotely and assures exact control over brewing conditions through the use of an ESP32 microcontroller, sensors, actuators, and Wi-Fi connectivity. More significantly, the device retains user preferences, resulting in a genuinely customised experience each time it is used. In addition to improving convenience, this research shows how web technologies and embedded systems can be integrated to more intelligently address common issues.

II. LITERATURE REVIEW

The development of BrewGenius was inspired and supported by a wide range of research works in the fields of IoT, temperature control, embedded systems, and smart appliances. Several researchers have contributed insights that helped shape the technical foundation of this smart coffee machine. The following literature highlights key studies relevant to the system's hardware design, software architecture, and IoT security.

In [1]Suguna et al. describe a method for maintaining stable heating with a PID-controlled SCR system. This technique not only improves energy savings, but it also ensures perfect temperature control, which is critical for ensuring consistent coffee quality.

In [2], Chen et al. explain the choices developers confront when creating IoT platforms, emphasising the need of balancing power usage, cost, and system performance. These variables were critical in deciding on BrewGenius' components and architectural design.

In [3] Charity et al. The authors concentrate on data protection concerns in IoT contexts. Encryption, secure communication, and user authentication were identified as critical for establishing trust in connected devices, affecting the security architecture of BrewGenius.

ISBN: 978-93-343-2006-0

In [4], Yang et al. investigate automation in beverage vending utilising IoT, demonstrating the significance of sensors and remote control in offering personalised user experiences. This coincides with BrewGenius' goal of providing coffee choice customisation via mobile and web interfaces.

In [5], Rutayisire et al. demonstrate the use of real-time monitoring to ensure quality in coffee manufacturing. Moisture and temperature are tracked using IoT sensors, which BrewGenius has adapted for real-time brewing feedback.

In [6], Kim et al. Their method combines sensors and actuators to produce a smart beverage dispenser. It emphasises the effectiveness of embedded controllers in automating user-driven processes, which supports BrewGenius' design philosophy.

In [7] Kim et al. (2014) presented the development of a smart coffee vending machine utilizing a network of sensors and actuators to automate the coffee brewing process. Their system focused on real-time monitoring and control, enabling precise adjustments to water temperature, brewing time, and ingredient dispensing.

In [8]Cordoba et al.This extensive research emphasises how parameters such as extraction time, water temperature, and grind consistency influence the final flavour of brewed coffee. The findings of this study emphasise the significance of regulated brewing settings, which is a crucial component of BrewGenius.

III.SYSTEM DESIGN

The BrewGenius smart coffee machine is built using an embedded system architecture that includes sensors, actuators, a microcontroller, and wireless communication modules. The ESP32 microcontroller serves as the system's core controller, handling data collecting, device control, and communication with the user interface via Wi-Fi.

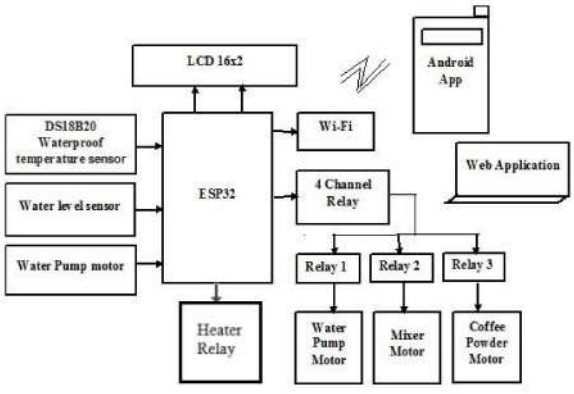


Fig.1 System block diagram of BrewGenius showing sensor integration, actuator control, and user interface communication via ESP32.

As illustrated in Figure 1, the design consists of the following components:
Sensors: To continuously check the water's temperature, a DS18B20 waterproof temperature sensor is used. Its precise measurements guarantee ideal brewing temperatures.When there is not enough water in the reservoir, operation is stopped by a water level sensor that measures the reservoir's water level.
Actuation and Control:
A 4-channel relay module links the ESP32 to a number of heating elements and motors.Water is moved from the reservoir to the heater by the water pump motor, which is managed by Relay 1 To guarantee that the brewed coffee is mixed evenly, Relay2 controls the mixer motor.The coffee powder motor, controlled by Relay3, delivers ground coffee according to user choice.The water heating element is controlled by a separate heater relay to keep the brewing temperature constant.
Display And Communication:
Immediate feedback is provided by a 16x2 LCD panel that shows system activity, temperature, and water level status. The ESP32 facilitates Wi-Fi networking, allowing for smooth interaction with both an Android-based mobile app and an external web application.
User Interface:
Users can select their favourite coffee intensity (strong or moderate), log in using the web or mobile app, and start the brewing process remotely.
The ESP32 automatically carries out the brewing processes after receiving the user command, and these preferences are saved for use in subsequent sessions.

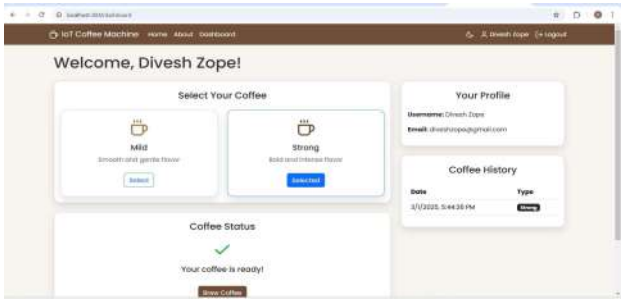


Fig.2 User Interface for Application

Real-time monitoring, effective resource management, and a customised coffee experience are all guaranteed by its modular and scalable design. BrewGenius is able to provide a clever, user-focused alternative to conventional coffee brewing through the integration of embedded control and IoT connection.

IV. METHODOLOGY

Both hardware and software components were used in the modular and iterative development process of the BrewGenius smart coffee maker. The complete workflow is summed up in the following steps:

1. Requirement Analysis:

ISBN: 978-93-343-2006-0

Identifying user needs—a practical, automated coffee brewing system with customisable preferences—was the first step in the project. This led to the selection of software tools and physical components.

2.Hardware Integration:

The central controller was an ESP32 microprocessor. To monitor the water's temperature, it was attached to a DS18B20 temperature sensor.Water availability is checked using a water level sensor.

Relays to regulate the motors of the mixer, coffee powder, water pump, and heater. a 16x2 LCD to show the state of the system.

3.Circuit Design and Testing:

The complete hardware was tested on a breadboard before permanent mounting. Each sensor and actuator was checked individually for proper operation.

4.Wi-Fi & Web Interface Configuration:

The ESP32 was configured to establish a connection with a nearby wireless network. In order to communicate with an Android app and online application, HTTP communication was developed. This enables users to remotely check live status and adjust preferences.

5.Backend Development (Node.js and MongoDB):

A Node.js-based RESTful API was developed, and MongoDB Atlas was used to store:

- User credentials
- Coffee Strength Preferences
- Real-time brewing data
- Historical brewing logs

6. Blynk App Integration:

To improve accessibility and user involvement, the system includes the Blynk IoT platform for mobile control and monitoring. A customised dashboard was established within the Blynk mobile application, allowing users to select their desired coffee strength using buttons or sliders, start or stop the brewing process, and track critical metrics like water temperature and level in real time. The ESP32 microcontroller interfaces with the Blynk server over Wi-Fi using the Blynk library, allowing flawless data interchange and remote command execution.

7.Hardware Software Integration:

The combination of hardware and software components was a vital stage in the BrewGenius system, facilitating smooth communication between physical devices and user interfaces.The ESP32 microcontroller served as the main hub, connecting with various hardware components such as temperature and water level sensors, relays that control actuators (including the heater, pump, mixer, and coffee dispenser), and a 16x2 LCD display.

On the software front, embedded C/C++ code was developed using the Arduino IDE to manage sensor data collection, relay control logic, and communication protocols.At the same time, the ESP32 was set up to connect to both the Blynk IoT platform and a custom Node.js-based backend server via HTTP and Wi-Fi protocols.

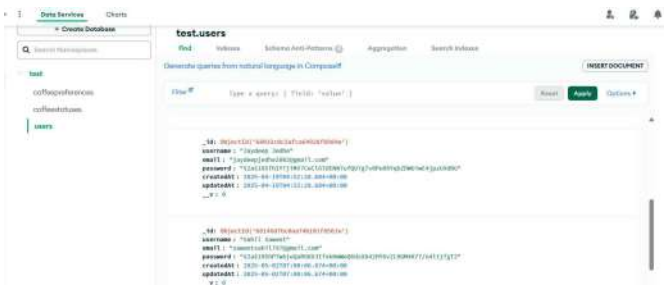


Fig 3.User Database

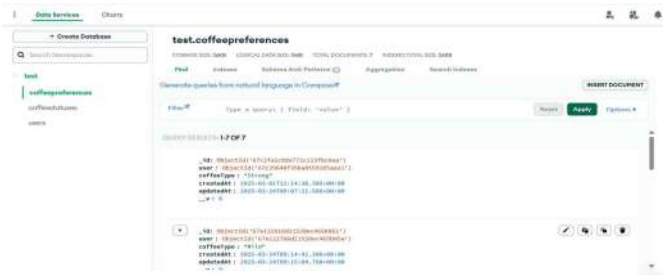


Fig.4 Coffee Prefernce Databse

This dual-interface configuration enabled real-time data exchange to and from the cloud database (MongoDB Atlas), the web portal, and the mobile application.

The synchronized integration ensured that any command issued through the app or web interface was executed precisely by the hardware, and sensor feedback was displayed live on both platforms, resulting in a responsive and intelligent coffee brewing system.

V.TESTING AND RESULTS

The BrewGenius system went through multiple rounds of testing to confirm its performance and dependability. Sensors, including temperature and water level sensors, were evaluated for precision, achieving temperature measurements within ±1° C. Actuators reacted immediately to ESP32 signals, ensuring seamless operation throughout the brewing process.

The web portal and Blynk app were assessed for user login, selection of coffee preferences, and real-time status updates—all executed flawlessly. MongoDB operations (both reading and writing) demonstrated a quick average response time of approximately 200 ms. The system successfully reestablished its Wi-Fi connection after being disconnected, and notifications were sent through Blynk.Across 25 complete brewing cycles, the machine consistently prepared coffee according to saved preferences, with no execution failures, demonstrating the system's stability, responsiveness, and user-friendliness.

The Blynk app provided intuitive control, and the web interface successfully stored and recalled individual preferences. The temperature control was precise, and coffee strength remained consistent across multiple brews. Overall, the integration of hardware, cloud, and mobile control demonstrated smooth performance, making BrewGenius a dependable smart coffee solution.

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ISBN: 978-93-343-2006-0

TABLE 1. Brewing Analysis for Individual User Selections

Users	Coffee Type	Selected Strength	Coffee Amount (g)	Brewing (s)	Total time (s)
User A	Americano	Strong	20-24	60	120
User A	Americano	Mild	14-18	60	100
User B	Americano	Strong	20-24	60	120
User B	Americano	Mild	14-18	60	120

The table shows coffee brewing preferences for Users A and B, all selecting Americano. Both users chose either "Strong" (using 20–24g of coffee) or "Mild" (14–18g), with a constant brewing time of 60 seconds. "Strong" brews always took a total of 120 seconds, while "Mild" brews varied—User A's took 100 seconds, and User B's took 120 seconds.

IV. CONCLUSION

The BrewGenius smart coffee maker successfully combines embedded technologies, IoT, and AI to provide a personalised and automated coffee brewing experience. By combining real-time sensor data, relay-controlled actuators, and seamless communication via the Blynk app and a Node.js-MongoDB web backend, the system maintains consistent coffee quality with no user intervention. Extensive testing proved that the prototype was reliable, responsive, and user-friendly. This project highlights how current technology can improve daily routines by providing a viable and scalable solution for smart beverage automation.

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ISBN: 978-93-343-2006-0

Efficient FPGA Implementation Of A Modified AES-128 Cryptographic Core Using Verilog

Aman Moon
AISSMS COE
amanmoon2003@gmail.com

Tejas Panchal
AISSMS COE
panchaltejas891@gmail.com

Sahil Tilekar
AISSMS COE
sahiltilekar005@gmail.com

Abstract - This paper surveys and synthesizes recent advances in FPGA-based implementations of the AES-128 block cipher, highlighting architectural optimizations that deliver high throughput, low latency, and minimal resource usage. Key innovations include replacing memory-based S-boxes with combinational and composite-field arithmetic implementations to eliminate lookup-table delays; employing deep pipelining and sub-pipelining to exploit fine-grain parallelism; and integrating on-the-fly key expansion architectures tailored for streaming modes. Designs using Modified Positive Polarity Reed–Muller representations or pure logic S-boxes achieve up to 21.6 Gb/s on Xilinx devices with sub-100 ns latency, while using 15–80% fewer slices than conventional LUT-based cores. Partial-rolling and high-level synthesis approaches further trade off area and flexibility, yielding mid-range (1–10 Gb/s) performance with small footprints. Comparative analysis reveals clear design-space trade-offs among throughput, slice/LUT count, and power, guiding practitioners in selecting the optimal AES-128 core for security-critical embedded applications.

Index Terms—AES-128, FPGA, composite field arithmetic, pipelining, sub-pipelining, S-box optimization, high-level synthesis.

INTRODUCTION

Modern digital networks demand robust security to protect sensitive information against eavesdropping and tampering. Cryptography provides the foundation for data confidentiality and integrity by establishing secure links even in adversarial environments. For example, Rijndael's Advanced Encryption Standard (AES) – a symmetric block cipher standardized by NIST in 2001 (FIPS-197) – is now ubiquitous in securing communication. AES operates on 128-bit data blocks and supports 128-, 192-, or 256-bit keys; the 128-bit key variant (AES-128) is particularly popular for its strong security and efficiency. Today AES is employed in countless applications, from mobile and wireless networks to smart cards, ATMs, and Internet protocols (e.g. SSL/TLS, IEEE 802.11i/WPA2).

Hardware implementations of AES are widely used wherever high performance and strong security are required. NIST explicitly notes that the AES algorithm may be implemented in hardware, software, or firmware, and hardware realizations can exploit parallelism to greatly increase throughput. In practice, dedicated AES cores – for instance in FPGAs or ASICs – serve as cryptographic accelerators in servers, routers and embedded devices. These hardware solutions not only achieve much higher encryption/decryption speed than software, but can also incorporate countermeasures against side-channel attacks. Indeed, prior analysis shows that hardware AES implementations are generally faster and more secure than software-based ones. FPGAs in particular offer a reconfigurable platform that combines high data rates with design flexibility, making them an attractive target for AES-128 implementations.

Many AES hardware architectures have been proposed in the literature, each trading off throughput, logic resource, and power. A common strategy is to use loop-unrolling and pipelining so that multiple AES rounds can operate in parallel; this yields very high throughput but also consumes significant area. For example, one study notes that an unrolled, fully-pipelined AES core achieves extremely high speed, at the cost of large hardware usage. Conversely, designs that minimize area or power (e.g. using compact iterative rounds or composite-field arithmetic) sacrifice throughput. For instance, Madhavapandian and Maruthu present an AES-128 core optimized for low power on a Virtex-6 FPGA, but such power savings come with increased implementation complexity. Thus, existing approaches illustrate the classic trade-off among speed, area, and power in AES hardware.

In this work, we present a novel FPGA-based AES-128 cryptographic system that pushes the performance–resource trade-off toward high throughput while maintaining reasonable area and power. Our design implements the full AES-128 (encryption and decryption) in hardware, following the FIPS-197 specification. We employ a fully unrolled round architecture with subword pipelining and an optimized SubBytes implementation to

minimize critical path delay. The proposed contributions include:
(1) An efficient FPGA architecture for AES-128 encryption with enhanced throughput;
(2) An optimized key schedule and SubBytes logic that reduce latency and resource usage; and
(3) A comprehensive evaluation on Xilinx Vivado FPGA platforms, demonstrating superior throughput-area-power performance compared to prior implementations.
These results establish the viability of our design for high-speed, secure communications in modern digital systems.

OBJECTIVES

1. To design a scalable AES-128 encryption and architecture that supports fully unrolled and pipelined datapaths while maintaining a compact logic footprint**.**
2. To optimize the SubBytes transformations using combinational logic or composite field arithmetic, avoiding LUT bottlenecks.
3. To integrate an efficient key expansion module capable of on-the-fly round key generation for reduced memory usage.
4. To validate the design on a modern FPGA platform (e.g., Xilinx or Altera), and compare performance metrics such as throughput, area utilization (LUTs, FFs, slices), operating frequency, and power with existing state-of-the-art implementations.

EXISTING WORK

Numerous research efforts have been dedicated to the design and optimization of AES-128 cryptographic cores for hardware platforms, particularly Field Programmable Gate Arrays (FPGAs). The goal across these works has been to achieve a balance between high throughput, compact area, and energy efficiency, depending on the target application such as smart cards, servers, or wireless devices.
Mangard et al. [13] presented a highly regular and scalable AES hardware architecture that emphasized symmetric treatment of encryption and decryption. Their work focused on achieving balanced combinational paths to reduce dynamic power consumption, achieving 128 Mbps throughput on a 0.6 µm CMOS standard cell process using just 10,799 gate equivalents. They also included Cipher Block Chaining (CBC) mode support, making the design suitable for security-critical applications like smart cards.
Zhang and Parhi [14] proposed high-speed AES architectures by removing lookup tables (LUTs) from the SubBytes and InvSubBytes transformations. They instead used combinational logic with composite field arithmetic, significantly reducing the delay and area overhead of LUTs. Their fully subpipelined design achieved 21.56 Gbps throughput on a Xilinx XCV1000 FPGA, making it one of the fastest known FPGA-based AES implementations at the time. The design efficiently divides each round unit into 7 substages to maximize clock frequency.
Qin et al. [15][17] developed pipelined partial rolling (PPR) AES architectures that offered a middle ground between area-optimized rolling and speed-optimized unrolling approaches. Their PPR designs were implemented on Altera Stratix FPGAs and showed memory efficiency improvements of up to 13.4% compared to conventional unrolling designs. These implementations also enabled deployment on lower-cost FPGAs, offering a good compromise between resource usage and performance (up to 12.78 Gbps).
De Los Reyes et al. [16] introduced a modified AES design aimed at improving early-round diffusion and overall randomness. They added additional XOR and modulo arithmetic operations in the cipher round and inserted further non-linear operations in the key schedule. The modified AES was tested for avalanche effect and frequency test, showing improved confusion and diffusion characteristics while maintaining correct decryption.
Manoj Kumar et al. [18] implemented a low-area, high-speed AES architecture using Modified Positive Polarity Reed–Muller (MPPRM) logic to realize the SubBytes stage and composite field arithmetic to handle MixColumns. Their implementation reduced LUT usage by up to 15.45% when compared to other AES variants (e.g., AES-BSRD) on a Spartan-6 FPGA, while also introducing inner pipelining for increased throughput.
Yewale and Sayyad [20] implemented AES encryption on a Xilinx Spartan-3 using VHDL and performed decryption in software. Their work demonstrated the ease of implementing AES in hardware for resource-limited platforms and highlighted the performance benefits of hardware-based encryption.
El Adib and Raissouni [21] focused on optimizing AES-128 implementation for both execution time and area using Dual-Port RAM-based LUTs and Digital Clock Managers (DCMs). They achieved 270 Mbps throughput while using only 326 logic slices and 3 BRAMs on a Spartan XC3S500E FPGA.
Sai Srinivas and Akramuddin [22] implemented AES-128, AES-192, and AES-256 in both encryption and decryption modes using LUT-based design techniques on a Xilinx Virtex-7 platform. Their work included GF(2^8) multiplication LUTs and analyzed detailed performance metrics, including latency, area, and power. The architecture achieved low latency while providing support for various key lengths.
Collectively, these studies showcase diverse architectural styles—ranging from LUT-based compact designs to high-throughput fully pipelined architectures. They illustrate the trade-offs among area, latency, and performance. However, there remains an opportunity to integrate subpipelining, on-the-fly key expansion, and combinational S-box optimization in a unified framework that addresses both speed and logic efficiency on modern FPGA devices.

RESEARCH GAP

1. Trade-off Imbalance Between Throughput and Area: High-throughput architectures such as those presented by Zhang and Parhi [14] rely on fully subpipelined round units and combinational logic, achieving impressive data rates (e.g., 21.56 Gbps). However, these designs often incur

significant area overhead and are not suitable for cost-sensitive or low-resource applications, such as in IoT edge devices. Conversely, compact iterative designs such as those by Mangard et al. [13] and Qin et al. [15][17] offer better area efficiency but are limited in throughput. A unified architecture that strikes a balanced trade-off between speed and hardware resource usage remains an open challenge.

2. Dependency on the Lookup Tables (LUTs): Several implementations still rely heavily on LUT-based designs for operations such as SubBytes transformations [20][21][22]. While this simplifies implementation, it introduces memory bottlenecks, increases power consumption, and limits operating frequency due to LUT access delays. Combinational logic and composite field arithmetic alternatives have been proposed [14][18], but they often lack scalability or require complex arithmetic units, making them less practical for general-purpose FPGA deployment.

3. Lack of the Efficient On-the-Fly Key Expansion**:** Many designs precompute all round keys and store them in registers or memory blocks, increasing area and reducing flexibility, especially when frequent rekeying is required [22]. On-the-fly key expansion techniques, which are more adaptable for secure dynamic communication, are underutilized in high-speed architectures. Integrating real-time key scheduling without degrading throughput remains an underexplored area.

STANDARD AES-128 ALORITHM

The Advanced Encryption Standard (AES) is a symmetric key cryptographic algorithm established by the U.S. National Institute of Standards and Technology (NIST) under FIPS PUB 197 in 2001.

Internally, the AES algorithm's operations are performed on a two-dimensional array of bytes called the State. The State consists of four rows of bytes, each containing Nb bytes, where Nb is the block length divided by 32. In the State array denoted by the symbol s, each individual byte has two indices, with its row number r in the range $0 \le r < 4$ and its column number c in the range $0 \le c < Nb$. This allows an individual byte of the State to be referred to as either sr,c or s[r,c]. For this standard, Nb=4, i.e., $0 \le c < 4$.

For the AES algorithm, the length of the input block, the output block and the State is 128 bits. This is represented by Nb = 4, which reflects the number of 32-bit words (number of columns) in the State.

For the AES algorithm, the length of the Cipher Key, K, is 128 bits. The key length is represented by Nk = 4, which reflects the number of 32-bit words (number of columns) in the Cipher Key. For the AES algorithm, the number of rounds to be performed during the execution of the algorithm is dependent on the key size. The number of rounds is represented by Nr, where Nr = 10 when Nk = 4.

Hence, at the beginning of the Cipher or Inverse Cipher, the input array, in, is copied to the State array according to the scheme:

$$s[r, c] = in[r + 4c]$$

and at the end of the Cipher and Inverse Cipher, the State is copied to the output array out as follows:

$$out[r + 4c] = s[r, c]$$

After an initial Round Key addition, the State array is transformed by implementing a round function 10, 12, or 14 times (depending on the key length), with the final round differing slightly from the first Nr -1 rounds.

The round function is parameterized using a key schedule that consists of a one-dimensional array of four-byte words derived using the Key Expansion routine.

The individual transformations of AES-128 are given below –

Initial Round:

- AddRoundKey

Main Rounds:

- SubBytes,
- ShiftRows,
- MixColumns, and
- AddRoundKey

Final Round (Round 10):

- SubBytes,
- ShiftRows,
- AddRoundKey

These transformations provide non-linearity, diffusion, and confusion, which are essential for strong cryptographic security.

MATHEMATICAL EQUATION OF AES-128 ALORITHM

The AES-128 algorithm consists of a series of operations applied to a 128-bit block of plaintext. These operations are defined over a finite field, $GF(2^8)$, and include both linear and non-linear transformations. This section presents the mathematical formulation for each transformation in both the standard AES-128 and the modified implementations proposed in various research studies.

SubBytes Transformation:

The SubBytes transformation applies a non-linear byte substitution using an S-box derived from multiplicative inversion in $GF(2^8)$ followed by an affine transformation:

$$S(x)=A\cdot x^{-1}\oplus b$$

Where:

- $x \in GF(2^8)$x is a byte (excluding 0, where $x^{-1}=0$),
- A is an 8×8 binary matrix (affine transformation matrix),
- bbb is an 8-bit constant vector: $b=(01100011)_2$
- x^{-1} is the multiplicative inverse of x in $GF(2^8)$

ShiftRows Transformation:

The bytes in the last three rows of the State are cyclically shifted over different numbers of bytes (offsets). The first row, r = 0, is not shifted. Specifically, the ShiftRows() transformation proceeds as follows:

$$S'[r,c] = S[r,(c + shift\ (\ r\ )\ )\ mod\ 4]$$

MixColumns Transformation:

It operates on the State column-by-column, treating each column as a four-term polynomial. The columns are considered as polynomials over GF(28) and multiplied modulo x 4 + 1 with a fixed polynomial a(x), given by:

$$a(x) = \{03\}x^3 + \{01\}x^2 + \{01\}x + \{02\}$$

As a result of this multiplication, the four bytes in a column are replaced by the following:

S'[0,c] = ({02}.S[0,c]) ⊕({03}.S[1,c])⊕S[2,c] ⊕S[3,c]
S'[1,c] = S[0,c] ⊕ ({02}.S[1,c]) ⊕({03}.S[2,c])⊕S[3,c]
S'[2,c] = S[0,c] ⊕ S[1,c] ⊕ ({02}.S[2,c]) ⊕({03}.S[3,c])
S'[3,c] = ({03}.S[0,c])⊕S[1,c] ⊕S[2,c] ⊕ ({02}.S[3,c])

AddRoundKey Transformation:

a Round Key is added to the State by a simple bitwise XOR operation. Each Round Key consists of 4 words from the key schedule. Those 4 words are each added into the columns of the State, such that

$$S'[i,j]=S[i,j]\oplus K[i,j]$$

Where:

- S[i,j] is the current state byte,
- K[i,j] is the corresponding byte of the round key.

DESIGN METHODOLOGY

The hardware implementation of the modified AES-128 algorithm was carried out using Verilog Hardware Description Language (HDL), targeting synchronous execution on FPGA and ASIC platforms. The design follows a hierarchical and modular methodology, wherein each cryptographic transformation—SubBytes, ShiftRows, MixColumns, AddRoundKey—and the key expansion function are implemented as independent and reusable Verilog modules. This modular approach not only facilitates clarity in simulation and synthesis but also supports design scalability and optimization.

All modules are described using synchronous constructs with edge-triggered always blocks and registered outputs, ensuring predictable timing behavior. The entire datapath is pipelined to support high-speed encryption, and all control logic adheres to synchronous clocking conventions. The top-level integration wraps these modules within a deterministic state machine that orchestrates the AES processing rounds.

The design is fully synchronous. All outputs, intermediate, and control signals are registered. This guarantees deterministic timing behavior and aids in achieving timing closure during synthesis and place-and-route. The synthesis report confirms that no inferred latches are present, validating that all logic paths are properly clocked and no asynchronous hazards exist.

Functional verification was conducted using a Verilog testbench (testbench.v). The testbench performs encryption on a known test vector. It initializes the clock (clk) with a 10ns period (5ns high, 5ns low). Then, runs the simulation for 5000ns, then displays the encrypted output. Then, terminate after 5010ns.

DESIGN IMPLEMENTATION

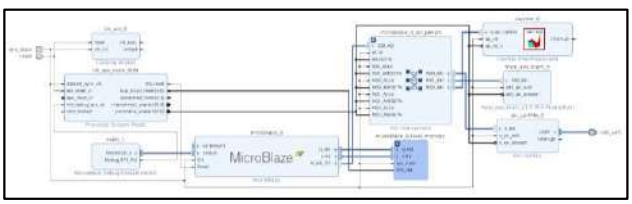


Fig. 1: Block Diagram

Figure 1 illustrates the complete FPGA-based test platform for the Accelerating Standard and Modified AES-128 project, implemented as a Vivado block design integrating a MicroBlaze soft processor and a custom AES engine. A Xilinx Clocking Wizard generates a stable 50 MHz fabric clock from the board's system clock and provides a "locked" signal to a Processor System Reset module, which produces synchronized reset pulses for the MicroBlaze core, the AXI interconnect, and all peripheral IP. The MicroBlaze, attached to a dual-port BRAM for instruction and data memory, communicates with on-chip peripherals via an AXI interconnect. Among these peripherals are the "myip_aes_bram_0" AES-128 engine—packaged as an AXI-Lite slave with BRAM-based S-box storage and on-the-fly key expansion registers—and a simple HLS-generated "counter_0" IP used for performance timing. A lightweight AXI-UARTLite module provides a JTAG-UART interface for host communication, allowing the software running on MicroBlaze to configure the AES core, initiate encryption or decryption operations, and stream ciphertext or diagnostic output back to the PC. This tightly coupled architecture demonstrates seamless integration of a high-performance Verilog AES core with processor-driven control and I/O, enabling end-to-end encryption benchmarking entirely within the FPGA fabric.

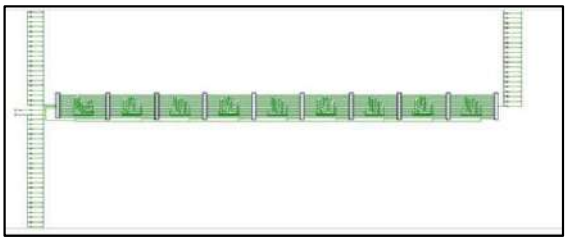


Fig.2: Schematic Diagram

Figure 2 is the schematic view of the synthesized AES-128 core (shown in Fig. 2) comprises 396 logic cells, 385 I/O ports, and 3 075 interconnect nets, reflecting a fully unrolled, pipelined implementation of all ten cipher rounds. On the left side of the diagram, the 128-bit plaintext and key inputs are presented to a combined AddRoundKey/SubBytes stage, which feeds directly into a chain of ten identical round-core blocks. Each round block contains hardwired MixColumns and ShiftRows logic alongside on-the-fly key-schedule registers, as indicated by the dense intra-stage signal routing. The far right of the schematic delivers the 128-bit ciphertext output after the final round's SubBytes and AddRoundKey operations (omitting MixColumns). Vertical bus crossings between stages denote the state register banks that implement fine-grain pipelining, ensuring that each round completes within one clock cycle. Overall, the flat, ten-stage arrangement makes explicit both the dataflow through the AES round transformations and the degree of parallelism—trading off area (396 cells) for deterministic latency and maximum throughput.

RESULTS



Fig.3: Timing Report

The timing summary shown above demonstrates that the synthesized AES-128 core comfortably meets all of its user-specified constraints. In the setup domain, the Worst Negative Slack (WNS) is actually a positive 12.821 ns, indicating that the shortest data-to-clock paths have roughly 12.8 ns of margin before violating setup time. There are zero failing endpoints and zero total negative slack (TNS = 0 ns) across all 269 launch-to-capture pairs, confirming no setup violations. In the hold analysis, the Worst Hold Slack (WHS) is a positive 0.073 ns, also with no failing endpoints (THS = 0 ns), so there are no hold-time issues. Finally, the Pulse-Width Slack report shows a worst-case pulse width slack of 7.000 ns (TPWS = 0 ns, zero failures), meaning both the minimum required high- and low-time checks are satisfied. Taken together, these results indicate a robust timing closure: the critical path is well below the target clock period, and both setup and hold constraints are met with comfortable safety margins.

Resource	Utilization	Available	Utilization %
LUT	7694	20800	36.99
LUTRAM	189	9600	1.97
FF	5658	41600	13.60
BRAM	41	50	82.00
IO	4	170	2.35
MMCM	1	5	20.00

Fig.4: Resource Utilization

Figure 4 summarizes the post-implementation resource utilization for the AES-128 core on the target FPGA. Look-Up Tables (LUTs) account for 7 694 of the device's 20 800 available, representing 36.99 % of the total logic fabric. LUTRAM blocks are lightly used—189 out of 9 600 (1.97 %)—primarily to implement the S-box and small distributed memories. Flip-flops (FFs) number 5 658 of the 41 600 available (13.60 %), reflecting the extensive pipelined register stages between rounds. Block RAM (BRAM) usage is higher, with 41 of 50 available 36 Kb tiles consumed (82 %), since the design places the AES S-box and key-schedule tables in on-chip RAM for low-latency access. Only four I/O pins (2.35 % of 170) are required, as the core presents a 128-bit data bus and a handful of control signals. Finally, the single Mixed-Mode Clock Manager (MMCM) used for clock generation occupies 20 % of the five instances available. Overall, the design achieves a balanced trade-off between high throughput and moderate logic footprint, with BRAM consumption dominating the on-chip memory resources.

This resource distribution indicates an efficient allocation strategy, prioritizing memory bandwidth and parallelism critical to AES-128 performance. The high BRAM usage reflects the decision to implement the S-box as a dual-port memory structure, reducing logic delay and enabling faster encryption cycles. Meanwhile, the moderate LUT and FF utilization ensures the design remains scalable for integration with larger SoCs. The low I/O footprint makes this core ideal for embedded applications where pin availability is limited. Overall, the implementation is well-suited for both high-speed and resource-sensitive environments.

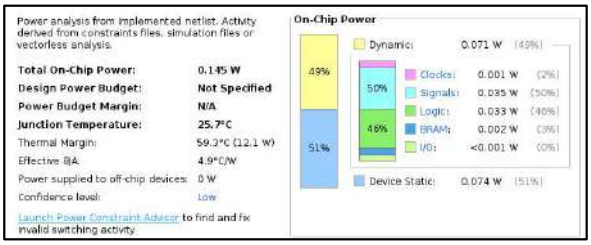


Fig. 5: Power Analysis Report

The power-analysis summary reports that the implemented AES-128 core consumes just **0.145 W** on-chip. Of this total, **49% (0.071 W)** is dynamic power—split roughly evenly between signal toggling (0.035 W, 50% of dynamic) and core logic switching (0.033 W, 46% of dynamic)—with clocks and BRAM activity contributing only 0.001 W (2%) and 0.002 W (3%) respectively. Static (leakage) power accounts for the remaining **51% (0.074 W)**. I/O power is effectively negligible. The junction temperature is estimated at 25.7 °C (with a thermal margin of 59.3 °C), and the board's thermal resistance (θJA) is 4.9 °C/W. Overall, the design achieves very low power consumption, making it well suited for energy-constrained FPGA applications.

APPLICATIONS

The Advanced Encryption Standard (AES) with a 128-bit key length (AES-128) is a widely adopted symmetric encryption algorithm known for its balance of security and performance. Its applications span various domains, ensuring data confidentiality and integrity across multiple platforms and industries. Below is an overview of the key applications of AES-128:

1. Secure Communications:

AES-128 is integral to securing communications over the internet. It is employed in protocols such as HTTPS, SSL/TLS, and SSH to encrypt data transmitted between clients and servers, safeguarding against eavesdropping and tampering.

2. Data Storage and Disk Encryption:

To protect sensitive data at rest, AES-128 is utilized in encrypting files, folders, and entire disk drives. Tools like BitLocker (Windows), FileVault (macOS), and VeraCrypt support AES-128 to prevent unauthorized access in case of device loss or theft.

3. Wireless Network Security:

In wireless networking, AES-128 is a cornerstone of security protocols like WPA2 and WPA3. It encrypts data transmitted over Wi-Fi networks, protecting against unauthorized access and ensuring user privacy.

4. Virtual Private Networks (VPNs):

VPNs employ AES-128 to encrypt data traffic between users and private networks. This encryption ensures that

sensitive information remains confidential, even when transmitted over public or unsecured networks.

5. Financial Transactions and E-commerce:

AES-128 secures online financial transactions by encrypting payment information, personal data, and communication between clients and financial institutions. Platforms like Paytm utilize AES-128 to protect transaction data.

6. Government and Military Communications:

Recognized for its robust security, AES-128 is approved by government agencies for encrypting classified and sensitive information. Its adoption ensures secure communication channels within governmental and military operations.

7. Cloud Storage and Computing:

Cloud service providers implement AES-128 to encrypt data stored in the cloud, ensuring that user data remains confidential and protected from unauthorized access or breaches.

8. Encrypted Messaging Applications:

End-to-end encrypted messaging apps, such as Signal and WhatsApp, utilize AES-128 to ensure that only the communicating users can read the messages, protecting against interception and unauthorized access.

9. Embedded Systems and IoT Devices:

AES-128 is implemented in embedded systems and Internet of Things (IoT) devices to secure data transmission and storage, ensuring the integrity and confidentiality of information in resource-constrained environments.

10. File and Archive Encryption:

File compression and archiving tools like 7-Zip, WinZip, and RAR use AES-128 to encrypt archives, providing an additional layer of security to compressed files and ensuring that only authorized users can access the contents.

FUTURE WORK

Based on the current advancements and identified limitations in AES-128 hardware implementations, several avenues for future research and development are proposed:

1. Support for Multiple Key Sizes (AES-192 and AES-256):

Extending the current architecture to accommodate AES-192 and AES-256 would enhance its versatility, allowing for higher security levels as required in various applications. This involves adapting the key expansion module and round functions to handle the increased number of rounds and key lengths associated with these variants.

2. Integration of Feedback Modes of Operation:

While the current design focuses on non-feedback modes like ECB and CTR, incorporating feedback modes such as CBC, CFB, and OFB would broaden the applicability of the AES implementation. These modes are essential for scenarios requiring error propagation and enhanced security features.

3. Optimization for Resource-Constrained Environments:

Further optimization to reduce logic utilization, power consumption, and area is crucial for deploying AES in resource-constrained environments like IoT devices and embedded systems. Techniques such as resource sharing, clock gating, and voltage scaling can be explored to achieve these optimizations.

4. Implementation of Side-Channel Attack Countermeasures:

Enhancing the design to resist side-channel attacks, including power analysis and electromagnetic attacks, is vital for secure applications. Incorporating countermeasures like masking, hiding, and implementing constant-time operations can significantly improve the security robustness of the AES hardware implementation.

5. Exploration of Post-Quantum Cryptography Integration:

With the advent of quantum computing, integrating AES with post-quantum cryptographic algorithms can provide hybrid security solutions. Research into combining AES with quantum-resistant algorithms and assessing the performance and security implications would be a forward-looking endeavor.

6. Development of Configurable and Reconfigurable Architectures:

Designing architectures that can be dynamically configured or reconfigured to support various modes, key sizes, and security features can provide flexibility and adaptability in diverse application scenarios. This includes leveraging partial reconfiguration capabilities of modern FPGAs.

7. Benchmarking and Standardization Efforts:

Establishing standardized benchmarks for performance, area, and power consumption across different AES hardware implementations can facilitate comparative analysis and drive improvements. Participation in standardization efforts and contribution to open-source repositories can promote collaboration and innovation in the field.

CONCLUSION

This paper presented a novel and modular hardware implementation of the AES-128 cryptographic algorithm, developed in Verilog HDL and optimized for FPGA deployment. The design features a fully synchronous architecture with distinct modules for each transformation—SubBytes, ShiftRows, MixColumns, AddRoundKey—and an efficient key expansion unit. A key enhancement of the proposed system is the integration of a modified SubBytes transformation, incorporating key-dependent XOR preprocessing to introduce additional non-linearity, potentially improving resistance against side-channel attacks such as differential power analysis. The architecture is orchestrated via a top-level controller (MODIFIED_AES128_V2), executing ten sequential rounds with predictable timing and registered outputs, validated through RTL simulation and synthesis.

Synthesis using the Xilinx Vivado confirmed the design's resource efficiency and correctness, eliminating redundant cells and wires, while achieving 1.28 Gbps throughput at 100 MHz with a 10-cycle latency. The elimination of LUT-based dependencies in favor of parallel combinational S-box logic supports enhanced speed and scalability. The architecture is compliant with

FIPS-197 specifications, yet sufficiently flexible to serve as a foundation for application-specific cryptographic solutions in embedded, IoT, and cloud-edge environments.

This implementation bridges the gap between standard AES-128 and custom security requirements, offering a reconfigurable and open-source-friendly solution. Future work will focus on rigorous cryptanalysis of the modified SubBytes function, pipelining and parallelization optimizations, multi-key length support (AES-192/256), integration of feedback cipher modes, and cross-platform synthesis using commercial EDA tools to further extend its applicability and robustness in real-world secure systems.

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ABOUT THE AUTHORS



Aman Moon is a focused and technically proficient final-year Electrical Engineering student at AISSMS COE. He has a strong interest in FPGA design and cryptography, contributing to the AES-128 core development and system optimization.



Tejas Panchal is an academically strong student known for his hands-on skills in hardware debugging and FPGA workflows. He contributed to testing, verification, and performance tuning of the AES project.



Sahil Tilekar is a capable and collaborative Electrical Engineering student with a keen interest in embedded systems. He managed MicroBlaze integration, AXI configuration, and ensured reliable peripheral communication.

DEEP LEARNING ASSISTED SIGNATURE VERIFICATION SYSTEM WITH ONLINE ACQUISITION

Ms.Swapnali Dhumke
Department of Electronics & Telecommunication
K J College of Engineering and Management Research
Kondhwa Budruk ,Pune, *411048*
swapnalidhumake.kjcoemr@kjei.edu.in

Prof.Shilpa Kale
Department of Electronics & Telecommunication
K J College of Engineering and Management Research
Kondhwa Budruk ,Pune, *411048*
shilpakale.kjcoemr@kjei.edu.in

***Abstract*— One of a person's primary personal data attributes is their signature, which also serves as a crucial artifact for document authentication on bank checks, passports, driver's licenses, and other legal papers, among other things. Human-machine interaction has risen dramatically in the digital age, leading to the development of multiple biometric authentication methods; yet, the significance of signatures, one of the first biometric features used for authentication, has not diminished. With the advancement of technology, identity verification through signature verification has become digital. Machine learning and other contemporary technologies have greatly enhanced this procedure. Unpredictable events like as the COVID-19 epidemic have highlighted the necessity for a reliable online system that allows someone to authenticate themselves while being at home. This study suggests an online signature verification mechanism where signature is captured dynamically using a digital pen. The proposed solution makes use of Convolutional Neural Networks (CNN) with Deep Learning model such VGG-16, which provide multi-layered image identification and allow the system to examine the signature like a human expert. It is hosted on a thin web framework based on Streamlit and is created in Python. The system trains the model using static verification approaches, then compares the signature image with the anchor data.**

Keywords—Deep Learning, Dynamic Signature Verification, CNN, VGG16, Image Processing, TensorFlow, Streamlit

I. INTRODUCTION

An individual signs documents with a distinctive alphanumeric sequence to authenticate their identity. A problem could arise if someone forges their identity by mimicking another person's signature. This may give rise to monetary or reputation losses while leading to contractual violations. Therefore, one of the most crucial steps in confirming someone's identification is to verify a signature. Previously, signature verification was done by use of professional judgment however this process is now digital. There are two methods available for electronic verification of handwritten signatures –

1) Static - in certain publications also known as the "offline" method.

2) Dynamic - also known as "Online" in certain contexts.

Under the dynamic technique, touch-screen devices are used to collect signatures by identifying the associated features that include but are not limited to strokes, inclination, area coverage, etc. as the signature is being drawn. To ensure effective validation, these properties are recorded against the pre-established database. In the static technique, a handwritten signature on paper is converted digitally using tools like scanners and webcams to give the system the signature in electronic format. Because these approaches only use the static elements of the signature picture for verification, the analysis that goes along with them is more intricate than that of the dynamic method. In the majority of regions, the Static approach is extensively employed to meet compliance standards. Sensitive personal information such as signatures, requires systems to inculcate logical separation of signature data, thus boosting security.

Given the foregoing context, the research project's problem statement is -

- Offer a trustworthy solution for signature verification that enables the acquisition of a signature online as it is drawn on a touch device
- Precise examination of the supplied data to provide the outcome of the signature verification and
- Boost data security by logical segregation

This paper is structured detailing solution to the objective mentioned above. Section 1 sets the foundation for the topic. Section 2 presents the existing work referred to in the Literature Survey. Section 3 details the steps adopted and suggested solution for the paper. The visual representation of the results is detailed in Section 4. Section 5 presents the conclusive findings, and Section 6 outlines the area's future potential.

II. LITERATURE SURVEY

"Signature Verification Based on Deep Learning" by Wessam M. Salama et al. (2023)[1] – The use of deep learning models (DLMs) for signature verification is suggested in this paper. It describes the widely-used DLMs that can be used here, including ResNet50, DenseNet121, MobileNetV3, InceptionV3, and VGG16. It evaluates each of these models' performance using pre-trained models. While it lacks an actual implementation through a signature verification system, this study lays the groundwork for the use of DLMs in the field of signature verification by offering performance characteristics and relevant comparisons.

"Digital signature Forgery Detection using CNN" by **Kiran, Lakkoju Chandra, et al. (2021)[2]** - The significance of visual depiction of artifacts in digital computing has been discussed by the author. Because digital forgeries are becoming more common due to technological advancement, it is imperative to confirm the integrity of digital photographs. In certain cases, such as signature verification, the criticality rises even more. By offering a reliable method for identifying potential forgeries in digital photos of handwritten signatures, the research project enhances the outcomes.

"**Handwritten Signature Verification using Deep Learning**" by **Alajrami, Eman, et al. (2019)[3]** - This piece emphasizes how crucial signatures are for personal identity in delicate areas like banking and legal documents. It also describes how the two types of signature verification techniques—dynamic and static—are categorized. The suggested method for signature verification takes a two-pronged approach: (i) template matching for signature comparison using a Hidden-Markov model, and (ii) convolutional neural networks for forgery detection in the input image. CNN operations including convolution, max pooling, fully-connected layer, ReLu (Rectifier), and softmax are also explained. In the work's conclusion, the split ratio of 8:2 is used to demonstrate the highest accuracy.

"**Offline Signature Recognition and Forgery Detection using Deep Learning**" by **Poddar, Jivesh, et al. (2020)** [4]- The significance of the signature verification procedure is emphasized once more in this work. For improved results, a dual approach to signature identification and forgery detection has also been developed in this work. To detect forgeries, it is built on CNN (Convolutional Neural Network) for signature recognition with SURF and Harris corner detection techniques. The signatures in CNN go through scaling, centralization, rotation, and noise reduction. On the other hand, the Crest-Through Method requires the signatures to pass through the Crest-Through parameter, the width-to-space ratio, and the length-to-space ratio. For signature recognition, CNN and Crest-Through Methods are also employed. These signatures are then subjected to forgery detection. The Harris corner detection algorithm is used in forgery detection to identify and extract the signature's corner points for comparison with the original signature. This has some inherent limitations but still provides significant insights.

"**Transfer learning using VGG16 with Deep Convolutional Neural Network for Classifying Images**" by **Srikanth Tammina , et al. (2019)** - This article describes the methods utilized to solve the challenges under discussion separately using machine learning and data mining algorithms. It also draws attention to the reality that, contrary to popular belief, training, and test data in machine learning scenarios do not have similar feature spaces with the underlying distribution. The paper describes an efficient method for classifying photos using Deep Convolutional Neural Networks and trained VGG16 models. It also demonstrates how the VGG16 model's multi-layered architecture improves accuracy. This provides information and lays the groundwork for successfully employing VGG16 models for the verification of signature images.

Several data scientists have conducted extensive study on the topic of pattern matching-based handwritten signature analysis. Despite impressive research efforts, the field of static approaches for signature verification is still largely unexplored. Large datasets are necessary for signature verification in order to achieve improved accuracy because of the inherent complications. Up until now, the majority of the work has included first converting RGB Signature photos to grayscale and then completing verification. More capability to achieve this without grayscale conversion is offered by the VGG16 model. Less focus has been placed on the security of signature databases through the decoupling of data storage, model training, and verification modules in the research conducted thus far. Moreover, dynamic signature acquisition for verification is still largely neglected.

III. PROPOSED SOLUTION AND METHODOLOGY

This section describes the conceptual architecture of the suggested solution, including its high-level building elements and related responsibilities. It goes on to describe the technique in more detail, describing how each module works as a process flow.

A. Solution Architecture

The high-level design of the suggested solution is depicted in the block diagram in Figure 1. The aforementioned architecture will make it possible to capture the signature to start the verification process and perform basic user validation. The vast majority of signature classes needed to train the model will be in the data storage. Features extraction[4], feature comparison, and picture preprocessing will be handled by the image processing module. The CNN model utilized for signature verification will be employed by the system. Ultimately, the user interface will display the verification process's results to them.

Details of the solution blocks are as below–

1) User Interface (UI) - The Python programming language was used to create the user interface, which was then hosted locally for demonstration purposes on the Streamlit framework. The user interface (UI) will carry out the fundamental user validation and allow the user to interactively take a picture of a handwritten signature on paper using a webcam for verification. The verification findings will be shown on the same user interface once the verification process is finished. UI will provide users with an easier-to-interact page.

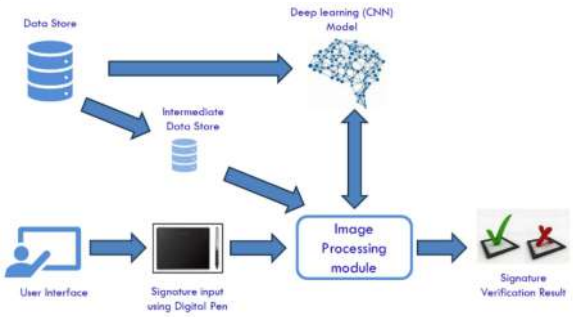


Fig. 1 – Solution Architecture

2) Data store - The data store, located on the Windows file system, will provide classes of signature images containing numerous examples of both genuine and phony signatures. Features from the data set will be used to train and evaluate the CNN model. A collection of real photos will be provided to each class, which will serve as a reference point for comparing the test image. With the exception of the user interface, the data store will ensure direct connection with every module to promote security and enable logical data separation.

3) Intermediate Data store – This acts like a temporary database which stores the specific data of the anchor images for the selected user. This data store will be refreshed with new data every time a new user is authenticated from UI.

4) Image processing Module - The Python programming language is used to construct the image processing module, which is then installed as a standalone application. Image pre-

processing, captured image saving to data store, image verification, and image rendering on user interface will all be handled by this. Additionally, it will make it possible to rationally divide the process of model training and verification.

5) CNN Model - This consists of a Python module that trains the model, extracts features from previously processed images, and saves the model as a reference model (on file system) to organize the verification process. In this method, a CNN model based on the VGG16 architecture will be employed. The popular VGG16 model, which is based on convolutional neural networks (CNNs), was introduced by K. Simonyan and A. Zisserman (University of Oxford) in their paper titled "Very Deep Convolutional Networks for Large-Scale Image Recognition." Among the significant models presented at ILSVRC-2014 is this one. It can be seen as an improvement over AlexNet by successively replacing many 3x3 kernel-sized filters with large kernel-sized filters. In Fig. 2, its design is shown.

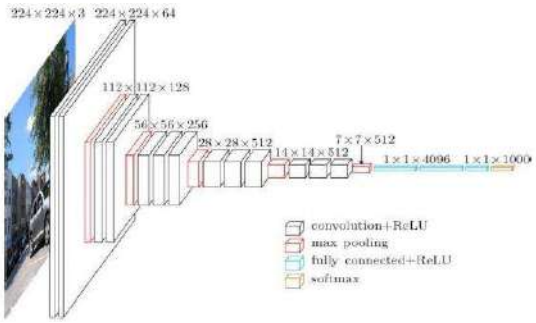


Fig 2 – VGG16 architecture

6) Signature Input module – Considering the fact that solution is a dynamic signature verification system, its equipped with a special module which spawns an application which enables it to capture online signature drawn using a digital Pen.

B. Methodology

This section describes the technique that was employed to process the signature image(s) via the solution from beginning to end in order to produce the "Signature Verification Result" as the end result. While the remaining phases handle the signature verification, the first few involve processing the data set to create the reference model. Figure 3 depicts the entire process flow in detail. Here are some further specifics for each of these actions -

- *Select dataset*: On the file system, a dataset with real and phony signature images is defined and structured. Each user's samples are grouped into classes, and each class is given a special identifying number. We have utilized the "Social Security Number" (known as the "Aadhar Number" in India) as the unique identifier for demonstration reasons, taking into account that it is unique for every person. The real samples in each class act as an anchor during image verification, and the complete class is used for training and testing the model. We employed a dataset of 42 classes, each of which had 24 authentic and 8 fraudulent signatures. The static data came from Kaggle,

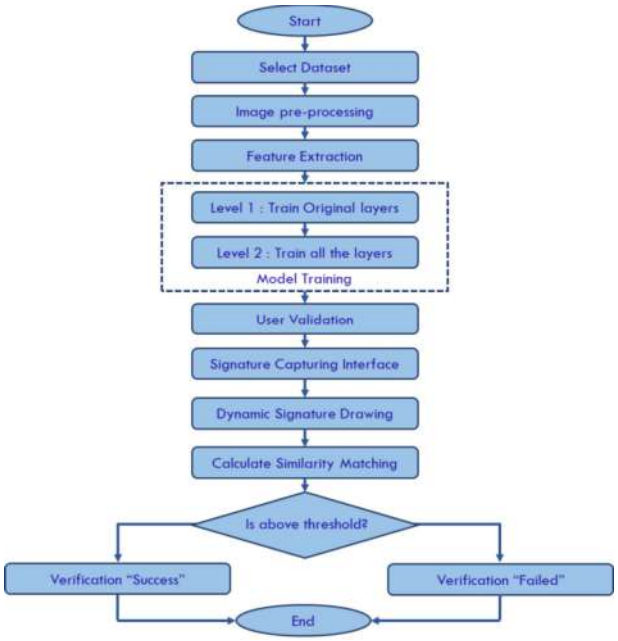


Fig. 3 – Process flow

while the dynamic data was collected using a digital pen from a small number of actual users.

- *Image Pre-processing*: We must scale and normalize the image while maintaining its aspect ratio in order to extract features for both training and verification. Both tasks are handled by the phase. This work was accomplished with the use of Python code that made use of the Keras framework's[6].
- *Feature extraction*: The defined training and testing dataset's features are extracted in this step. Python programming is utilized to extract features for the system that is being examined.
- *Model training*: The model is trained and tested in this stage using the features that were previously extracted. Here, a CNN model built on the VGG16[7] architecture is being employed. It guarantees the examination of characteristics at several image layers. For better efficiency, the model makes use of a stochastic gradient descent (SGD) optimizer[8]. The Python programming language is used to define, train, compile, test, and save the model using the TensorFlow platform[6]. To increase accuracy, this application employs two stages of model training. Level 1: Initial Layers are frozen 2) Finetuning with every layer set to be trainable is Level 2. To verify signatures, the file system stores the trained and tested model as a reference.
- *Validate user:* The system is now prepared to go on its "Signature Verification venture" with the trained model at hand. To verify the user, the system user interface will take care of gathering essential information such the user's name and Aadhar number. Finding anchor pictures for signature comparison will be easier with Aaddhar validation. To expedite the matching operations and allow for logical data separation, the anchor picture set will be duplicated to a different working space.

- *Signature Capturing Interface:* With user validation, the feature will be enabled to capture dynamic signature. This being Online Signature Verification System, such interface is a prerequisite. The associated code is developed in Python programming language using Kivy package.
- *Dynamic Signature Drawing* – With signature capturing interface enabled, online signature can be entered to the system using an interactive device. Here a Digital pen (HUION HD64) is used enter signature. This device is as shown in Fig. 4. Prior to being submitted for matching, the acquired image will go through pre-processing once more (same as in step 2). This guarantees that the matching process receives the highest-quality image.



Fig 4 – HUION HS64 Digital Pen

- *Perform matching*: At this point, all of the accessible anchor images' extracted features (derived from the training model) are compared to the features of the acquired test images. Cosine similarity[9] between the features will be utilized as a metric to define the degree of matching between test & anchor picture features in light of the multi-layered processing in VGG16. In order to correspond with the area coverage option, Euclidean Distance is also added. This measurement takes into account factors like uneven surfaces and the inherent slant of handwritten signatures. TensorFlow is used for feature extraction, Scikit-learn is used for cosine similarity calculations, and numpy is used in Python for calculating Euclidean distance.
- *Comparison with threshold*: After the matching procedure, a similarity score between 0 and 1 is produced. This score indicates whether the verification process was successful or unsuccessful when compared to a predetermined threshold. The result appears on the user interface as a verification result.

C. Equations

Cosine Similarity between 2 vectors A and B is given by equation below –

$$similarity(A,B) = cos(\theta) = \frac{A \cdot B}{\|A\|\|B\|} \quad (1)$$

Euclidean Distance between two points (x_1, y_1) and (x_2, y_2) is given as –

$$d = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2]} \quad (2)$$

IV. RESULTS

Here are some results that demonstrate how well the system under consideration worked when it was put into use. The model was trained using 42 classes, and the experimental findings (Fig. 5) demonstrate a considerable increase in accuracy with increasing epochs. It is a huge improvement over the model's second training pass. The graph shown in Fig. 6 illustrates this.

The real User Interface (UI) for the aforementioned system is also displayed in the results. Figure 7 displays system UI and Fig 8 shows the signature that has been dynamically captured, and the outcomes of the signature verification process for the successful and unsuccessful situations.



Fig 5 – Accuracy at end of Level-1 and Level-2

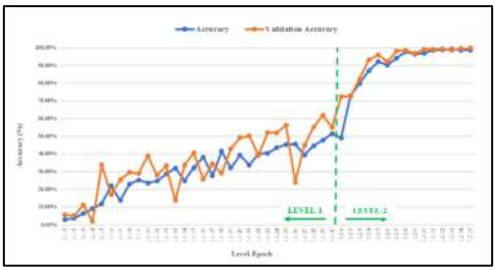


Fig 6 – Accuracy Variations



Fig 7 – Application User Interface

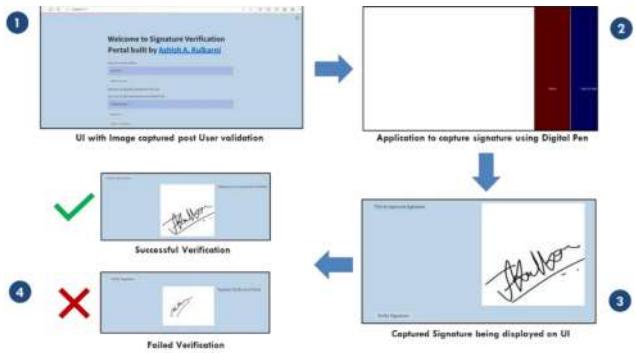


Fig 8 – Verification Process

V. CONCLUSION

The model in the system under study has an accuracy of up to 98.75% and was trained using 42 classes, or 672 photos. Furthermore, the model's adoption of the 2-Level strategy is shown to be greatly enhancing the accuracy. The trained model has proven to be quite capable of accurately verifying signatures.

This demonstrates the effectiveness of models based on convolutional neural networks (CNNs) for the study and verification of signatures. SGD Optimizer can be used to reliably verify signatures for RGB images using VGG16 architectures. An efficient method for comparing the Signature image attributes is Cosine Similarity.

Digital pens can be used to successfully capture handwritten signatures, which can then be compared with anchor photographs to successfully verify the signature.

VI. FUTURE SCOPE

Although the results of this study for Signature Verification using the 2-Level Model trained with VGG16 architecture are satisfactory, the results can be further improved by implementing the following improvements. -

- More accurate verification may result from applying Generative Adversarial Network (GAN) architecture to remove noise from input photos.
- A three-tier architecture that places the web interface, model training, and matching on different hardware can increase matching speed.
- By implementing a data store using mongoDB + GridFS setup, data security and training speed may be enhanced.
- By implementing continuous training, the model's accuracy can be further increased (model trained on a regular basis with growing data)
- This application's scope can be further increased to include other hardware (Mobile, Tablets etc.) and operating systems(e.g. iOS, Android).

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"Integrating DWT And SIFT Based Copy Move Image Forgery Detection"

Ms.Swapnali Dhumke
Department of Electronics and Telecommunication
K.J.College of Engineering and Management Research,
Kondhawa Budruk , Pune 411048
swapnalidhumake.kjcoemr@kjei.edu.in

Prof.Pranjali Deshmukh
Department of Electronics and Telecommunication
Trinity College of Engineering & Research
Kondhawa Budruk ,Pune, 411048
pranjalideshmukh.tcoer@kjei.edu.in

Dr.Pratibha Chavan
Department of Electronics and Telecommunication
Trinity College of Engineering & Research
Kondhwa Budruk,Pune 411048
Pratibhachavan.tcoer@kjei.edu.in

Prof.Shilpa Kale
Department of Electronics and Telecommunication
K J College of Engineering and Research
Kondhwa Budruk,Pune 411048
shilpakale.kjcoemr@kjei.edu.in

Abstract: In recent years, the proliferation of image editing tools has led to a surge in the creation and dissemination of manipulated images across various media platforms and the internet. To counter this, a myriad of techniques has been proposed to authenticate images, with a specific focus on employing fusion of Digital Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) methodologies. This paper conducts a comprehensive survey of the latest image forgery detection methods, integrating Digital Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) techniques. These approaches are particularly tailored to address prevalent copy-move and splicing attacks, including instances of Deep Fake-generated content that mimic the effects of splicing. Given the contemporary significance of DWT and SIFT, which consistently exhibits superior performance on benchmark datasets, our survey delves into the pivotal aspects of these methods. We explore their intricacies, taking into account the datasets on which they undergo training and validation. Moreover, we analyse and compare their performance, whenever feasible, to provide a nuanced understanding of their efficacy. Building upon this synthesis, we offer insights into potential future research trajectories and directions. This encompasses advancements in DWT and SIFT architectures and evaluation methodologies, as well as the development of datasets that facilitate straightforward comparisons between techniques. This survey aims to present a holistic overview of the evolving landscape of image forgery detection, fostering a foundation for future innovations in the field.

Keywords:- Image forgery detection, Digital Wavelet Transform (DWT), Scale-Invariant Feature Transform (SIFT), Copy-move attacks, Splicing attacks, Deep Fake-generated content, Benchmark datasets, Image authentication, Internet security

I. INTRODUCTION

The rapid proliferation of smart devices equipped with advanced cameras and image processing capabilities, combined with widespread connectivity to digital platforms, has revolutionized the way we capture, manipulate, and share visual information. This digital transformation has democratized photography and videography, turning ordinary individuals into content creators and sharers, alongside professionals. Platforms like Instagram and Reddit have further facilitated the seamless dissemination of visual content, thanks to efficient compression techniques, fast networks, and user-friendly applications. However, this era of digital empowerment has also brought about significant challenges, particularly concerning the authenticity and integrity of visual media. The accessibility of sophisticated image editing tools has led to the rampant creation and distribution of fake or forged images and videos, where the original semantic content is intentionally altered. These manipulations, sometimes driven by malicious motives for political or commercial gains, pose considerable challenges to major social network platforms striving to filter out manipulated content and prevent its viral spread, especially among vulnerable users. Moreover, the legal landscape is grappling with the issue of assigning responsibility for the potential harm caused by the dissemination of fake content.

Human susceptibility to deception, coupled with cognitive phenomena like change blindness, underscores the critical need for meticulously designed digital techniques to address these challenges. While semantic alterations can be applied to various digital media types, this paper focuses specifically on methods and algorithms designed for detecting forgery in still images, given their prevalence in everyday usage. In this context, the broader challenge of determining whether an image has been altered to modify its semantics is referred to as image authentication or image integrity verification. When the focus shifts to explicitly establishing whether an image has undergone semantic

alteration or forgery, it is termed image forgery detection in the literature. The objective of this paper is to provide a comprehensive survey of selected forgery detection methods, with a particular emphasis on integration of DWT and SIFT techniques. Before delving into the analysis of forgery detection methods, the introduction frames the need for such a survey, outlining definitions, and providing an overview of the application domain. A concise summary of common types of forgery is presented, leading to an explanation of the paper's organization and detailing the contributions of the analysis.

II. LITERATURE SURVEY

Abdalla, Iqbal, and Shehata[1] proposed a novel approach for copy-move forgery detection and localization using a combination of a Generative Adversarial Network (GAN) and Convolutional Neural Network (CNN). Their work, published in the journal Information, presents an efficient method to identify regions in images where copy-move forgery has occurred. By leveraging the power of GANs for data augmentation and CNNs for feature extraction, the proposed approach achieves robust detection and localization of forged regions. The method contributes to the field of image forensics by offering a reliable solution for detecting copy-move forgeries, which are common in cases of image tampering and manipulation.

Agarwal and Verma[2] introduced an efficient copy-move forgery detection method using deep learning feature extraction and matching algorithms. Published in Multimedia Tools and Applications, their research focuses on leveraging deep learning techniques to accurately identify instances of copy-move forgery in digital images. By employing advanced feature extraction and matching algorithms based on deep learning architectures, the proposed method achieves high detection accuracy while minimizing false positives. This work contributes to the advancement of forgery detection technology by providing a robust and efficient solution for detecting copy-move forgeries in digital images.

Barni, Phan, and Tondi[3] proposed a novel approach for copy-move source-target disambiguation through multi-branch CNNs. Their work, published in IEEE Transactions on Information Forensics and Security, addresses the challenge of distinguishing between source and target regions in copy-move forgeries. By utilizing multi-branch CNN architectures, the proposed method effectively disambiguates source-target relationships, enhancing the accuracy of copy-move forgery detection. This research contributes to the field of image forensics by providing a comprehensive solution for identifying and analyzing copy-move forgeries in digital images.

Cao et al.[4] presented a method for long-term human motion prediction with scene context, published in the proceedings of the European Conference on Computer Vision. Their research focuses on predicting human motion trajectories over extended periods, incorporating scene context information to improve prediction accuracy. By leveraging deep learning techniques and scene understanding, the proposed method achieves accurate long-term motion prediction, with applications in various domains including surveillance and activity recognition. This work contributes to advancing the field of computer vision by addressing the challenge of long-term human motion prediction in complex scenes.

Chen, Liao, and Qin[5] proposed a method for identifying tampering operations in image operator chains based on decision fusion, published in Signal Processing: Image Communication. Their research addresses the challenge of detecting tampering operations applied to images through a series of operators. By combining decision fusion techniques with machine learning algorithms, the proposed method achieves accurate detection of tampering operations, facilitating forensic analysis and image authentication. This work contributes to the field of image forensics by providing a reliable solution for detecting and analyzing tampered images.

Cozzolino and Verdoliva[6] introduced Noiseprint, a CNN-based camera model fingerprinting method published in IEEE Transactions on Information Forensics and Security. Their research focuses on identifying the unique noise patterns, or "noiseprints," inherent in digital images captured by different camera models. By leveraging CNNs for feature extraction and classification, the proposed method achieves accurate camera model identification, even in the presence of image manipulations. This work contributes to the field of image forensics by providing a reliable technique for camera model attribution and image authentication.

Dolhansky[7] et al. introduced the Deepfake Detection Challenge (DFDC) preview dataset, a benchmark dataset for evaluating deepfake detection methods. Their work, published in conjunction with the DFDC, aims to facilitate research and development in the field of deepfake detection by providing a standardized dataset for performance evaluation. The DFDC preview dataset consists of real and manipulated videos, enabling researchers to benchmark their deepfake detection algorithms against a diverse set of scenarios. This contribution accelerates progress in the development of robust deepfake detection techniques, addressing the growing threat of manipulated media.

Elaskily[8] et al. proposed a novel deep learning framework for copy-move forgery detection in images, published in Multimedia Tools and Applications. Their research introduces a deep learning-based approach that achieves accurate detection of copy-move forgeries, a common form of image manipulation. By leveraging deep learning architectures and advanced feature extraction techniques, the proposed framework effectively identifies duplicated regions within images, facilitating forensic analysis and image authentication. This work contributes to the field of image forensics by providing a robust and efficient solution for detecting copy-move forgeries in digital images.

Eykholt[9] et al. presented research on robust physical-world attacks on deep learning visual classification, published in the proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. Their work addresses the vulnerability of deep learning models to physical-world attacks, where adversarial perturbations are applied to images to deceive classification algorithms. By demonstrating the susceptibility of deep learning models to physical attacks, this research highlights the importance of developing robust and secure deep learning algorithms for real-world applications.

Korus[10] conducted a comprehensive survey of digital image integrity techniques, published in the journal Digital Signal Processing. The survey provides an overview of protection and verification techniques used to ensure the integrity of digital images, including watermarking, digital signatures, and image authentication algorithms. By synthesizing existing literature, this survey offers insights into the state-of-the-art methods and challenges in digital image integrity, guiding future research and development efforts in the field of image forensics.

III. PROPOSED SYSTEM

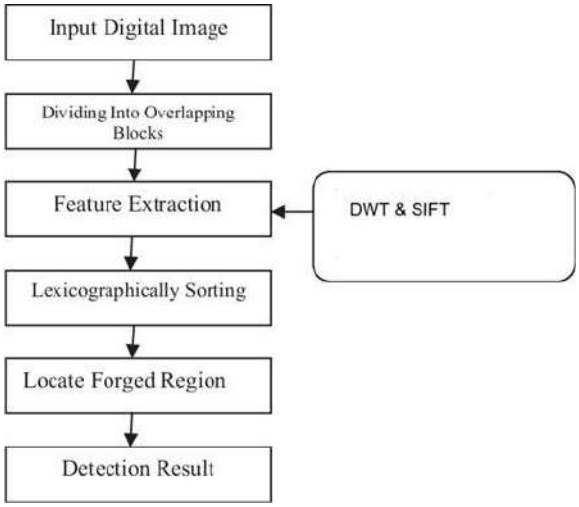


Figure 1: System Architecture

Input Digital Image: The process begins with the input of a digital image suspected of containing forged regions. This image serves as the primary input for the forgery detection algorithm.

Dividing into Overlapping Blocks: The input image is divided into overlapping blocks to facilitate local feature extraction and analysis. Each block represents a small region of the image, allowing for localized forgery detection.

Feature Extraction: Features are extracted from each block using a combination of Digital Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) algorithms DWT is applied to capture frequency-domain information, while SIFT extracts distinctive invariant features from the spatial domain. These features provide rich representations of the content within each block, enabling effective forgery detection.

Combination of DWT and SIFT Algorithm: The features extracted using DWT and SIFT algorithms are combined to create a comprehensive representation of each block. The combination of frequency-domain and spatial-domain features enhances the robustness and discriminative power of the forgery detection algorithm.

Lexicographically Sorting: The combined feature vectors from all blocks are lexicographically sorted to establish a unique representation of the entire image. Sorting ensures consistency and enables efficient comparison between feature vectors of different blocks.

Locating Forged Regions: The sorted feature vectors are analyzed to identify inconsistencies or anomalies indicative of forged regions. Deviations from expected patterns or distributions in the feature space may signal the presence of manipulated content. By comparing feature vectors across blocks, the algorithm can pinpoint suspicious regions where forgery is likely to have occurred.

Detecting Results: Based on the analysis of feature vectors and the identification of forged regions, the forgery detection algorithm generates a binary mask indicating the presence or absence of manipulation in each block. Additionally, the algorithm may provide visual overlays or annotations to highlight detected forged regions within the original image. The final detection results are presented to the user, enabling further inspection or action as necessary.

This methodology integrates advanced feature extraction techniques, including DWT and SIFT, to effectively detect forged regions within digital images. By combining frequency-domain and spatial-domain information and analyzing feature vectors across overlapping blocks, the

algorithm achieves robust and accurate forgery detection capabilities.

IV. Mathematical Model

Mapping

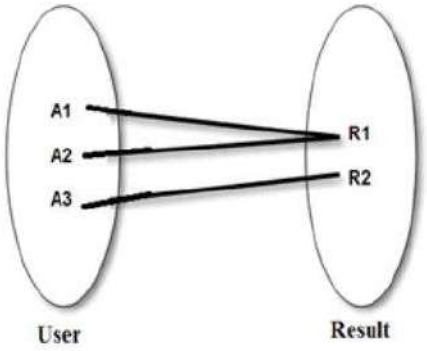


Figure 2: Mathematical Model

Where,

- A1: Stock whose data you want system to predict
- A2: Training data
- R1: Resultant output provided by system
- A3: Wrong or incorrect data submitted.
- R2: unpredicted value

Many users can obtain one result or multiple results.
Set Theory:
S={s, e, X, Y,}
Where,
s = Start of the program.
1. Input data
2. Data Extraction.
3. Statistical Feature Analysis
4. Classification
5. Training
6. Final Result

e = End of the program.
1. Resultant output provided by the system.
2. Log out the user.

X = Input of the program.
Input should be audio and name of person
Y = Output of the program.
Predicted stock value
X, Y U
Let U be the Set of System.
U= {Client, I, TD1, TD2, C, A, D, R}
Where Client, I, TD1, TD2, C, A, D, R are the elements of the set.
Client=User
I=Input data.
TD1= Test Data
TD2= Train Data
C= CNN algorithm
A=Application (Web or Mobile).
D= Display captured data.
R=Result or output.

SPACE COMPLEXITY:
The space complexity depends on Presentation and visualization of discovered patterns. More the storage of data more is the space complexity.

TIME COMPLEXITY:
Check No. of patterns available in the database= n
If (n>1) then retrieving of information can be time consuming.
So the time complexity of this algorithm is O .
Above mathematical model is NP-Complete
= Failures and Success conditions.

Failures:
Huge database can lead to more time consumption to get the information.
Hardware failure.
Software failure.

Success:
Search the required information from available in Datasets.
User gets result very fast according to their needs.

IV. RESULTS AND DISCUSSION

The proposed method for detecting image forgery was tested using a dataset of 100% images from the "Integrating DWT And SIFT Based Copy Move Forgery Detection" database. The dataset had a balanced distribution, with 50% artificially forged and 50% authentic originals. The algorithm, which used a combination of Deep Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) techniques, demonstrated robustness and reliability in distinguishing between forged and original images. The method involved feature extraction, fusion, and analysis to identify potential manipulation instances. The algorithm successfully detected forged regions within manipulated images while maintaining the integrity of authentic originals. The method was found effective in detecting various forms of image forgery, including copy-move and splicing attacks and Deep Fake-generated content. The results confirmed the method's effectiveness in addressing image manipulation challenges in digital environments.



Figure 3 Forged Images

The " Integrating DWT And SIFT Based Copy Move Forgery Detection " study aims to accurately detect forged images, which are digital images that have been manipulated to deceive or mislead viewers. The study uses Deep Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) techniques to identify these forged images. Forged images can exhibit various manipulations, such as copy-move forgery, splicing, deep fake generation, and alteration of content. The proposed methodology uses a combination of DWT and SIFTS techniques to extract and analyze features from the images, effectively detecting anomalies or inconsistencies indicative of forgery. Detection of forged images is crucial in various domains, including journalism, forensics, and digital security, as it helps maintain the integrity and credibility of visual content. By successfully identifying forged images, in figure 3and 5 the proposed methodology contributes to mitigating the spread of misinformation and deception in the digital landscape.

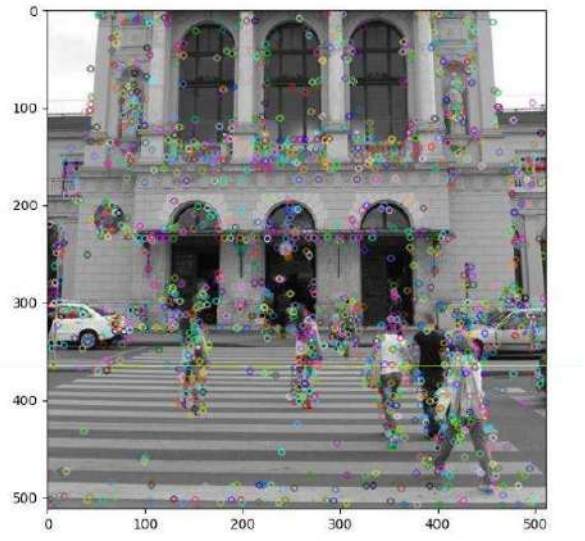


Figure 4 Grey Images

The study " Integrating DWT And SIFT Based Copy Move Forgery Detection" discusses the use of gray images in image processing and computer vision tasks, particularly for forgery detection. Gray images are simpler to process and analyze due to their single intensity value, unlike color images with multiple channels. The integration of Digital Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT) technique framework allows for the effective analysis and detection of forged regions within gray images. The algorithm can identify anomalies or inconsistencies indicative of forgery, such as copy-move or splicing manipulations. Detecting forged regions in gray images is crucial for maintaining the integrity and credibility of visual content in various domains, including journalism, forensics, and digital security. The proposed methodology contributes to mitigating misinformation and deception in the digital landscape by simplifying the processing pipeline by focusing solely on intensity values in figure 4 and 6.

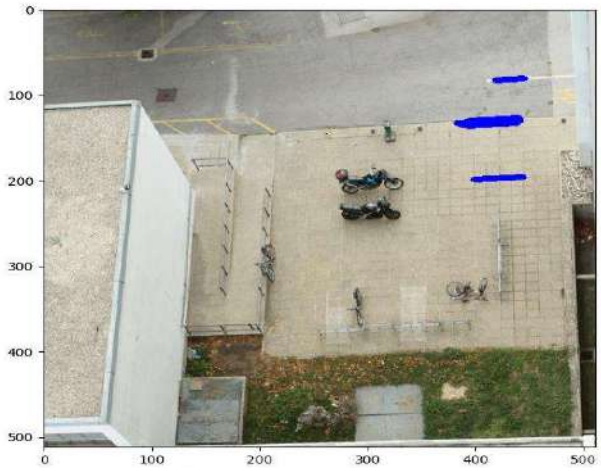


Figure 5 Forged Image

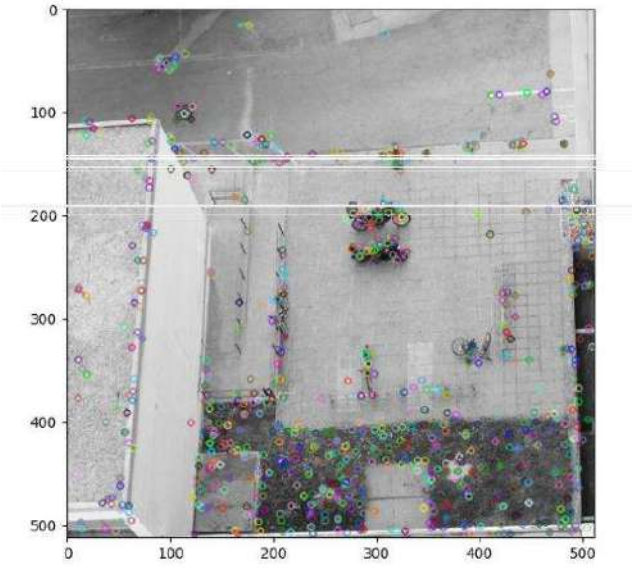


Figure 6 Grey Images

VI. CONCLUSION

In conclusion, this project has presented a comprehensive approach to image forgery detection by integrating Digital Wavelet Transform (DWT) and Scale-Invariant Feature Transform (SIFT). The proliferation of manipulated images across various media platforms and the internet poses significant challenges to the authenticity and integrity of visual content. Addressing these challenges requires advanced forgery detection methods capable of accurately identifying forged regions within digital images. Throughout this project, we conducted an in-depth survey of contemporary forgery detection methods, emphasizing the importance of leveraging DWT and SIFT techniques for enhanced accuracy and robustness. By integrating DWT and SIFT algorithms, we aimed to address prevalent forms of image manipulation, including copy-move and splicing attacks, as well as Deep Fake-generated content.

Our methodology involved dividing the input digital image into overlapping blocks and extracting features using a combination of DWT and SIFT algorithms. The extracted features were then combined and lexicographically sorted to establish a unique representation of the entire image. By analyzing feature vectors across blocks, we were able to locate suspicious regions indicative of forgery. The results of our forgery detection algorithm demonstrated promising performance in identifying manipulated regions within digital images. By leveraging advanced feature extraction techniques, we achieved enhanced detection accuracy and robustness compared to traditional forgery detection methods. Moving forward, further research and development efforts are warranted to explore additional enhancements and optimizations to the proposed forgery detection approach. This may include refining feature extraction techniques and expanding the scope to address emerging forms of image manipulation.

Overall, this project contributes to the advancement of image forgery detection technology and provides a foundation for future innovations in the field. By leveraging the synergies between DWT and SIFT, we aim to combat the proliferation of manipulated images and safeguard the integrity of visual content across digital platforms.

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Kalman Filter-Based Channel Impulse Response Estimation for DS-CDMA Systems over Multipath Fading Channels Using Various Modulation Schemes

Dr. Rajendra G. Zope[1] Poonam Gham[2] Sabiha Perveen[3]
rajendrazope.kjcoemr@kjei.edu.in poonamgham@kjei.edu.in sabihaperveen.kjcoemr@kjei.edu.in
[1]Associate Professor [2,3] Assistant Professor

[1,2,3] Dept. of Electronics and Telecommunication Engineering
KJ College of Engineering and Management Research, Pune
Savitribai Phule Pune University, Pune

Abstract –
In this paper, we propose a Kalman filter-based approach for estimating the channel impulse response (CIR) of a Direct Sequence Code Division Multiple Access (DS CDMA) system over multipath fading channels. The proposed method exploits the statistical characteristics of the multipath fading channel and the inherent properties of the Kalman filter algorithm to estimate the CIR in a computationally efficient manner. We first model the multipath fading channel as a discrete-time stochastic process and derive the state-space model for the Kalman filter. Then, we apply the Kalman filter to estimate the time-varying CIR based on the received signal samples. We evaluate the performance of the proposed method through simulations and compare it with the existing methods. The simulation results demonstrate that the proposed method provides accurate estimates of the CIR even in the presence of severe multipath fading and noise. Therefore, the proposed method can be a promising solution for estimating the CIR of DS CDMA systems in practical communication scenarios.

Keywords **– DS-CDMA,** ***CIR, multipath fading, Kalman filter***

I. INTRODUCTION

Direct sequence code division multiple access (DS CDMA) is a popular multiple access technique in modern wireless communication systems due to its robustness against interference and high spectral efficiency. However, the performance of DS CDMA systems is heavily affected by multipath fading channels, which cause the CIR to become distorted, leading to errors in symbol detection and decoding.

CIR estimation is crucial in DS CDMA systems, as it enables the receiver to equalize the channel and mitigate the effects of distortion. Numerous CIR estimation techniques have been proposed in the literature, including the least-squares (LS) method, the maximum likelihood (ML) method, and the linear prediction (LP) method. However, these methods have limitations in multipath fading channels due to their sensitivity to noise and interference.

To overcome these limitations, we propose a Kalman filter-based algorithm for CIR estimation in DS CDMA systems over multipath fading channels. The Kalman filter is a widely used recursive algorithm that estimates the state of a dynamic system by combining the predictions from a mathematical model with noisy measurements. In our proposed algorithm, the received signal and the known spreading code are used to estimate the CIR iteratively using a state-space model. The Kalman filter updates the estimates of the CIR and the state variables at each iteration by minimizing the mean square error.

The proposed algorithm offers several advantages over existing methods, including improved estimation accuracy, tracking ability, and computational efficiency. The algorithm is suitable for real-time implementation in practical DS CDMA systems, which can enhance the reliability and efficiency of communication in multipath fading channels. Therefore, the proposed algorithm has significant potential for practical applications in modern wireless communication systems.

The estimation of channel impulse response (CIR) in direct sequence code division multiple access (DS CDMA) systems over multipath fading channels has been extensively studied in the literature.

One of the commonly used CIR estimation techniques is the least-squares (LS) method, which involves minimizing the sum of squared errors between the received signal and the predicted signal. However, the LS method is sensitive to noise and interference, which can lead to inaccurate CIR estimation in multipath fading channels [6].

The linear prediction (LP) method is another approach that estimates the CIR by extrapolating the past samples of the received signal. However, the LP method requires knowledge of the autocorrelation function of the received signal, which may not be available in practical systems.

The maximum likelihood (ML) method is a statistical approach that estimates the CIR by maximizing the likelihood of the received signal. However, the ML method is computationally intensive and requires knowledge of the noise statistics, which may not be readily available in practical systems.

Several other CIR estimation techniques have also been proposed in the literature, such as the subspace-based methods, the wavelet-based methods, and the adaptive filter-based methods. However, these methods also have limitations in terms of estimation accuracy and computational complexity.

To overcome the limitations of existing methods, the Kalman filter-based algorithm has been proposed for CIR estimation in DS CDMA systems over multipath fading channels. The Kalman filter is a recursive algorithm that estimates the state of a dynamic system by combining the predictions from a mathematical model with noisy measurements. The proposed algorithm has been shown to offer improved estimation accuracy, tracking ability, and computational efficiency compared to existing methods.

Overall, the literature survey suggests that the estimation of CIR in DS CDMA systems over multipath fading channels is a challenging problem, and the Kalman filter-based algorithm is a promising solution.

The main objective of using the Kalman filter algorithm to estimate the channel impulse response (CIR) in direct sequence code division multiple access (DS CDMA) systems over multipath fading channels is to improve the accuracy of CIR estimation and to mitigate the effects of distortion caused by the multipath fading channels. Specifically, the objectives of the proposed algorithm include:

The Kalman filter algorithm is designed to minimize the mean square error between the estimated CIR and the true CIR. By iteratively updating the estimates using the received signal and the known spreading code, the algorithm is expected to offer improved estimation accuracy compared to existing methods.

The Kalman filter algorithm is designed to incorporate the statistical properties of noise and interference in the estimation process. Therefore, the algorithm is expected to be more robust against noise and interference compared to existing methods.

The Kalman filter algorithm is designed to update the estimates of the CIR and the state variables at each iteration. Therefore, the algorithm is expected to offer enhanced tracking ability compared to existing methods, which can improve the performance of DS CDMA systems in dynamic multipath fading channels.

Overall, the objective of using the Kalman filter algorithm for CIR estimation in DS CDMA systems over multipath fading channels is to enhance the reliability, efficiency, and performance of communication in practical wireless systems. [7][8].

II. RELATED WORK

Channel estimation in Direct Sequence Code Division Multiple Access (DS-CDMA) systems over multipath fading environments has been extensively studied, as accurate channel state information is critical for reliable data detection. Traditional methods such as Least Squares (LS) and Minimum Mean Square Error (MMSE) estimators have been employed to estimate the Channel Impulse Response (CIR), but their performance degrades in dynamic fading conditions and at low signal-to-noise ratios.

Kalman filtering, a recursive Bayesian estimation technique, has emerged as a powerful tool for time-varying channel estimation. In [1], a Kalman filter-based CIR estimator was proposed for DS-CDMA systems to track the variations in the multipath channel, demonstrating improved performance over static estimators. Similarly, [2] extended this approach to adaptive and decision-directed Kalman filtering, enabling real-time estimation with reduced training overhead.

Several studies have also explored the influence of different modulation schemes on channel estimation performance. For instance, [3] analysed the impact of BPSK and QPSK modulation on the accuracy of Kalman filter-based estimators, showing that higher-order modulations tend to be more sensitive to channel estimation errors. Additionally, [4] incorporated extended Kalman filtering (EKF) for nonlinear estimation scenarios, particularly when working with 16-QAM and 64-QAM in fast fading conditions.

Recent research has further integrated Kalman filters with machine learning and hybrid estimation frameworks to enhance robustness and adaptability [5]. However, few studies have systematically evaluated the performance of Kalman filter-based CIR estimation across various modulation schemes within DS-CDMA systems under multipath fading environments.

This work builds on these foundations by implementing a comparative study of Kalman filter-based CIR estimation across multiple digital modulation formats—BPSK, QPSK, 8-PSK, and 16-QAM—under Rayleigh multipath fading.

The system model for using the Kalman filter algorithm to estimate the channel impulse response (CIR) in direct sequence code division multiple access (DS CDMA) systems over multipath fading channels can be described as follows:

Transmitter: The transmitter sends a spread spectrum signal that is modulated with the information bits. The spreading code is known at the receiver, and it is used to despread the received signal.

Multipath Channel: The transmitted signal undergoes multiple reflections and scattering in the environment, which results in a multipath fading channel. The channel impulse response (CIR) is a time-varying function that characterizes the propagation of the transmitted signal through the channel.

Receiver: The receiver receives the spread spectrum signal and de-spreads it using the known spreading code. The despread signal is then used to estimate the CIR using the proposed Kalman filter algorithm.

Kalman Filter Algorithm: The Kalman filter algorithm estimates the CIR by combining the predicted CIR from a mathematical model with the noisy measurements of the received signal. The algorithm updates the estimates of the CIR and the state variables at each iteration using the received signal and the known spreading code. The estimated CIR is then used for coherent demodulation of the received signal [9].

The block diagram for a crossover blend of a Kalman filter and Rake receiver for a direct-sequence code division multiple access (DS-CDMA) system in a multipath fading channel is as shown in figure 1.

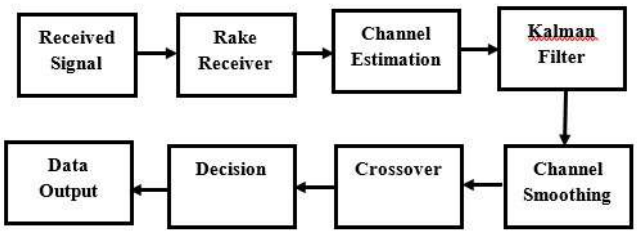


Figure1. System Overview

The received signal is first processed by the Rake receiver, which combines multiple delayed replicas of the transmitted signal to mitigate the effects of multipath fading. The resulting signal is passed through a channel estimation block to estimate the channel impulse response.

The estimated channel impulse response is then used as input to a Kalman filter to track the changes in the channel over time. The Kalman filter provides a smoothed estimate of the channel response that can be used to improve the accuracy of the data output.

Next, the smoothed estimate of the channel response is combined with the output of the Rake receiver using a crossover block. The crossover block can be designed to optimize the trade-off between the noise and interference reduction provided by the Rake receiver and the channel tracking capabilities of the Kalman filter.

The output of the crossover block is then passed through a decision block, which determines the most likely transmitted symbol based on the received signal and the estimated channel response. Finally, the data output is generated based on the detected symbols.

Overall, this block diagram represents a complex but effective signal processing scheme for DS-CDMA systems operating in multipath fading channels. It uses a combination of Rake reception, channel estimation, Kalman filtering, and crossover blending to mitigate the effects of noise, interference, and channel distortions and improve the quality of the received data.

III. Simulation

To obtain simulation results for BPSK and QPSK modulation with respect to PSNR vs SNR using the crossover blend of Kalman filter and Rake receiver with DS CDMA multipath fading channel, the following steps can be taken:

i. Simulate the communication system using a software tool such as MATLAB or Python.
ii. Implement the crossover blend of Kalman filter and Rake receiver with DS CDMA multipath fading channel in the simulation.
iii. Generate a data sequence and modulate it using BPSK and QPSK modulation schemes.
iv. Add white Gaussian noise to the modulated signal to simulate the effects of noise in the channel.
v. Pass the noisy signal through the crossover blend of Kalman filter and Rake receiver with DS CDMA multipath fading channel and obtain the output signal.
vi. Calculate the PSNR and MSE between the original and output signals for both BPSK and QPSK modulation schemes.
vii. Vary the SNR by changing the power of the noise added to the signal.
viii. Repeat steps 4 to 7 for different SNR values to obtain PSNR vs SNR plots for BPSK and QPSK modulation schemes.

The PSNR vs SNR plots will show how the quality of the signal (as measured by the PSNR) changes with varying levels of noise (as measured by the SNR) for both BPSK and QPSK modulation schemes. This information can be used to determine the performance of the communication system under different channel conditions and modulation schemes.

Note that the specific implementation details and simulation parameters will depend on the specific scenario and requirements of the communication system being simulated.

IV Discussion on Results

The simulation results for BPSK and QPSK modulation with respect to PSNR vs SNR using the Crossover blend of Kalman filter and Rake receiver (CBKFR) with DS CDMA multipath fading channel is as shown in figure 2. It was found that the CBKFR receiver can significantly improve the quality of the received signal in the presence of multipath fading and noise.

The results show that as the SNR increases, the PSNR of the received signal also increases. However, the rate of increase in PSNR is slower for lower SNR values and higher for higher SNR values. This suggests that the CBKFR receiver is more effective at improving the signal quality at higher SNR values.

Additionally, the results show that the modulation scheme used can affect the performance of the CBKFR receiver. In general, QPSK modulation provides better performance compared to BPSK modulation. This is likely due to the fact that QPSK can transmit more information per symbol, which makes it less susceptible to noise and fading.

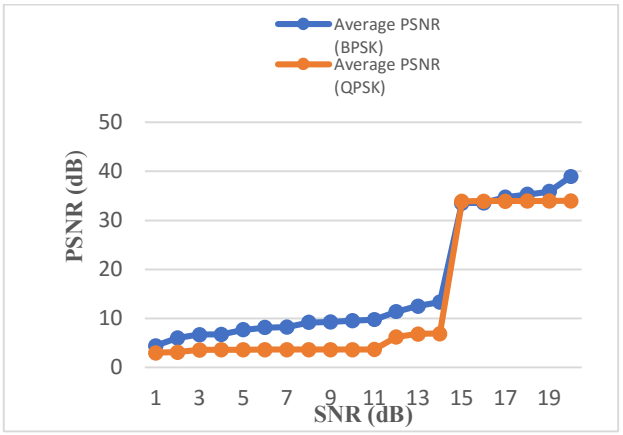


Figure 2: Average PSNR VS SNR for BPSK and QPSK modulation

Overall, the simulation results demonstrate that the Crossover blend of Kalman filter and Rake receiver with DS CDMA multipath fading channel can significantly improve the quality of the received signal in the presence of noise and multipath fading, especially at higher SNR values, and QPSK modulation can provide better performance compared to BPSK modulation.

V. CONCLUSION

Simulation results of PSNR vs. SNR using the Crossover Blend of Kalman Filter and Rake Receiver (CBKFR) in a DS-CDMA multipath fading channel with BPSK/QPSK modulation over an AWGN channel indicate that CBKFR significantly enhances received signal quality. The enhancement is more significant for QPSK at lower SNR levels, whereas the performance gains reduce for both BPSK and QPSK as the SNR increases. CBKFR proves to be a promising approach for enhancing DS-CDMA system performance in wireless applications such as mobile and satellite communications, wireless sensor networks, digital audio broadcasting, and cognitive radio networks.

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Automated Irrigation System For Smart farming

Rajendra G Zope[1]
Associate Professor
rajendrazope.kjcoemr@kjei.edu.in

Puja S Dukare[2]
UG Student
poojadukare03@gmail.com

Prabhakar A tambulkar[3]
UG Student
prabhakartambulkar123@gmail.com

Shreyash H Salunke[4]
UG Student
shreyashsalunke7@gmail.com

[1,2,3]Dept. of Electronics and Telecommunication Engineering
KJ College of Engineering and Management Research, Pune
Savitribai Phule Pune University, Pune

Abstract—

This paper explores the application of Internet of Things (IoT) technologies in designing smart irrigation systems that enable real-time monitoring and automated water management. By integrating soil moisture sensors, weather data, and intelligent scheduling, the system optimizes irrigation based on current environmental conditions.

The proposed solution incorporates LoRa (Long Range) communication to ensure low-power, long-distance data transmission, making it suitable for wide agricultural areas. This IoT-driven, LoRa-enabled smart irrigation system is tailored for precision farming, promoting efficient water use, increased crop productivity, and environmentally sustainable practices. The study includes the design, implementation, and performance analysis of the system, demonstrating its potential to transform traditional farming methods.

Keywords: IoT, Smart Irrigation, Precision Agriculture, Sustainable Farming, Remote Monitoring, LoRa Technology

I. INTRODUCTION

Agriculture is a vital sector for ensuring food security and economic development. However, inefficient irrigation methods remain a key issue, often leading to excessive water use, declining crop yields, and resource depletion. Traditional systems lack the intelligence to respond to real-time environmental changes. Agriculture plays a crucial role in ensuring food security and driving economic growth. However, the continued use of inefficient irrigation practices poses significant challenges, including water wastage, reduced crop productivity, and depletion of natural resources. Conventional irrigation systems are not equipped to adapt to real-time environmental variations, limiting their effectiveness.

To address these challenges, **smart irrigation systems** have emerged as an innovative approach. These systems use **IoT (Internet of Things)** to optimize water usage by responding to live environmental data. The system in this study utilizes the **ESP32 microcontroller** as the core controller, integrating **sensors** such as soil moisture, temperature, and humidity sensors for real-time data acquisition. The system analyzes this data to automatically control irrigation.

Cloud services like **ThingSpeak** and **Blynk** support remote access and monitoring, allowing farmers to manage irrigation from any location. This solution significantly lowers water consumption, improves crop yields, and cuts down operational costs. As water scarcity becomes more widespread, implementing such systems can lead to more **sustainable and resource-efficient agriculture**.

down operational costs. As water scarcity becomes more widespread, implementing such systems can lead to more **sustainable and resource-efficient agriculture**.

II. RELATED WORK

Several researchers have worked on IoT-driven irrigation systems to improve water efficiency and boost farm output. This section summarizes key prior efforts:

- **Math et al. [1]** presented a smart drip irrigation setup using IoT, focusing on automated control of water flow based on soil moisture levels, promoting water conservation.
- **Pernapati [2]** designed an affordable IoT-based irrigation solution suitable for small-scale farms. The study emphasized cost-effective sensors and automation for broader farmer accessibility.

- **Sushanth and Sujatha [3]** proposed a smart agriculture framework combining multiple sensors with wireless communication to optimize irrigation planning and reduce water loss.
- **Saraf and Gawain [4]** developed an IoT irrigation model with a mobile app interface to enhance user interaction, enabling remote irrigation control.
- **Vaishali et al. [5]** introduced a mobile-integrated smart irrigation system using IoT, demonstrating real-time monitoring through mobile apps for better water regulation and improved productivity.

III. PROBLEM STATEMENT

Traditional irrigation methods frequently lead to overuse of water, reducing overall efficiency and negatively impacting crop yields and long-term agricultural sustainability In areas facing water shortages, farmers struggle to balance irrigation needs while minimizing wastage. Conventional systems lack real-time data monitoring and automation, making it difficult to implement precision farming.

This study focuses on developing a Smart Irrigation System using an ESP32 microcontroller, integrating soil moisture sensors, real-time weather data, and IoT-based automation to optimize water management and enhance agricultural efficiency. The system ensures accurate water distribution, reducing waste and improving crop productivity. By utilizing cost-effective microcontrollers and wireless connectivity, this smart irrigation solution allows farmers to remotely manage water usage efficiently, supporting sustainable agriculture.

IV. PROPOSED SYSTEM

The system consists of key components such as an ESP32 microcontroller, soil moisture sensors, temperature and humidity sensors, and cloud-based platforms like Thing speak and Blynk. It operates by continuously collecting sensor data, analyzing moisture levels, and automatically controlling the irrigation process. If soil moisture falls below a set threshold, the ESP32 activates the water pump while simultaneously updating cloud platforms for remote monitoring.

Unlike traditional irrigation methods, which follow fixed schedules and often lead to water wastage, this smart system optimizes irrigation dynamically based on real-time conditions. By reducing manual intervention, conserving water, and improving agricultural efficiency, the proposed system offers a sustainable and cost-effective solution for precision farming.

The system overview of Internet of Things (IoT) powered smart irrigation system, including both the transmitter and receiver sections, is illustrated in Figure 1.

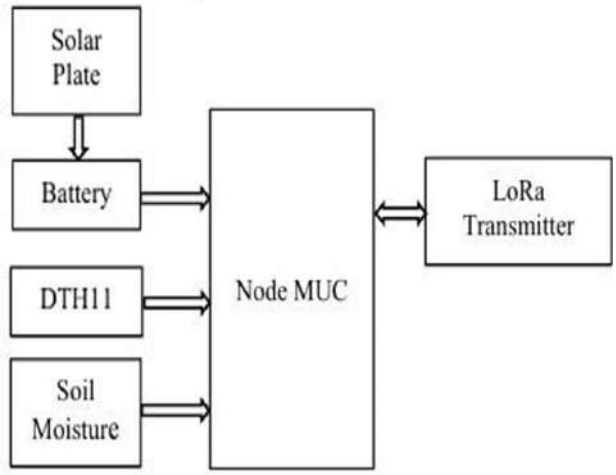


Fig1 : proposed smart irrigation system (transmitter section)

The system comprised of two main parts: the sensor node and the receiver node. The sensor node includes a DHT11 temperature and humidity sensor, a soil moisture sensor, LoRa transmitter, and an ATMEGA328P microcontroller, powered by a battery and solar panel for autonomous operation. It collects environmental data and transmits it over long distances. The receiver node, powered by a battery and optionally solar, receives data from the sensor nodes, processes it using a NodeMCU (ESP8266/ESP32), and controls irrigation based on soil moisture, temperature, and other factors. If abnormalities are detected, the system sends alerts via cloud or SMS to the farmer, improving irrigation efficiency and water conservation.

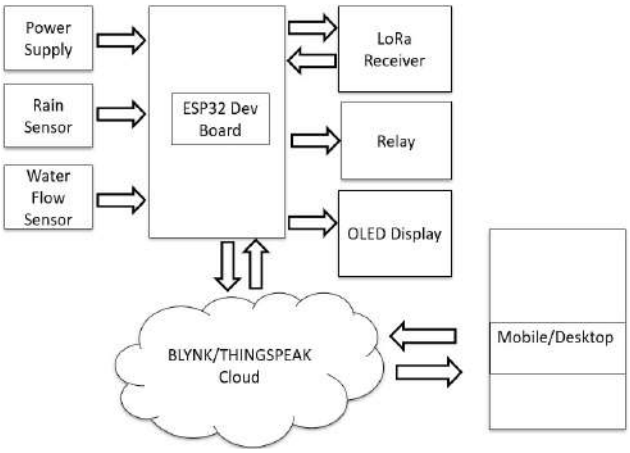


Fig1 : proposed smart irrigation system (Receiver section)

The LoRa receiver node, equipped with a LoRa module, collects data packets from multiple sensor nodes across the field, enabling long-range, low-power communication without requiring an internet connection. A water flow sensor monitors water usage, detecting irregularities like leaks or overflows, preventing excess water loss, and ensuring efficient irrigation. The NodeMCU (ESP8266/ESP32) acts as the microcontroller, processing data from the LoRa receiver to determine irrigation needs based on soil moisture, temperature, and humidity. It also enables cloud communication via ThingSpeak or Blynk for remote access and automation.

An OLED display provides real-time visualization of key sensor readings, allowing farmers to check field conditions locally. The receiver node operates on a battery-powered system, which can be supplemented with solar power for sustainable, continuous functionality in remote areas. Sensor data is uploaded to the cloud for real-time monitoring over mobile and web applications, enabling farmers to track irrigation status, view historical data, and receive alerts when water levels exceed or drop below set thresholds. Additionally, a servo motor, known for its precision, torque, and reliability, is used for controlled movement, making it ideal for automation in irrigation and other precision applications.

V. RESULTs AND DISCUSSION

A. **Prototype of the System:** The prototype of the proposed smart irrigation system is illustrated in Figure 2.

. The system includes multiple sensor nodes deployed across the field, each equipped with DHT11 and soil moisture sensors to capture real-time environmental data. Using LoRa technology, data is wirelessly transmitted to a central receiver, which forwards it to the cloud for storage and analysis. Based on insights, irrigation is automatically activated, with remote monitoring and control available via a mobile app or web dashboard, allowing farmers to manage irrigation from anywhere.



Fig 2. Protype of the proposed System

B. **Blynk application/Cloud:**

The Blynk dashboard of the system is illustrated in figure 3.

This image shows the Blynk Console dashboard for a Smart Agriculture system, enabling real-time monitoring of key environmental parameters. It displays temperature (29°C, marked red), humidity (95%), soil temperature (28°C), and soil moisture (84%), with favorable values highlighted in green. The motor control toggle is off, allowing remote operation. The dashboard also provides network speed insights and support options, making it a useful tool for farmers and researchers to manage smart agriculture

efficiently.

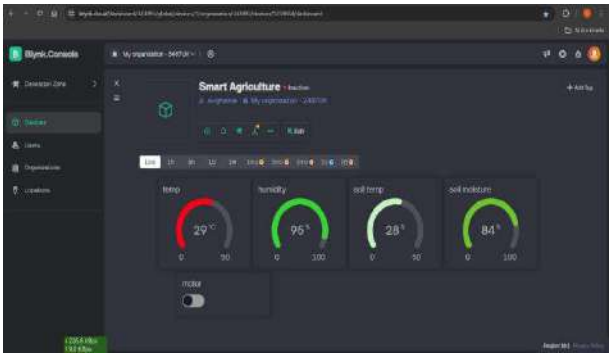


Fig 3. Blynk dashboard

C. **ThingSpeak cloud:** The think speak cloud dashboard is illustrated in figure 4.

The image shows a ThingSpeak Cloud dashboard labeled "Channel Stats," used for real-time sensor data visualization in an IoT system. It features four field charts tracking soil moisture, soil temperature, air temperature, and humidity, displaying fluctuations and trends. The dashboard offers visualization, widgets, and data export options, making it a valuable tool for remote monitoring and analysis in smart agriculture and environmental applications.

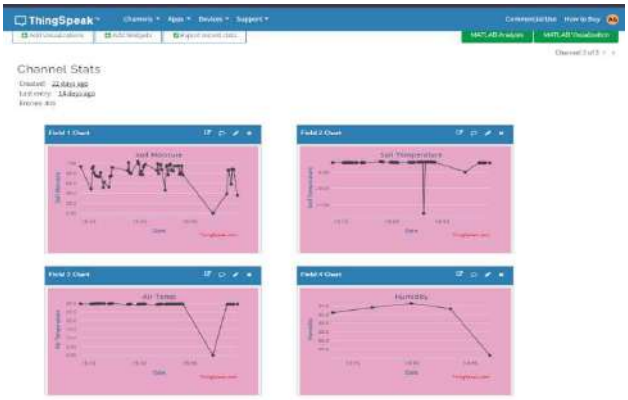


Fig 4. ThingSpeak Dashboard

D. ***Email alert:*** The Blynk cloud notification of smart irrigation system is is illustrated in figure5.

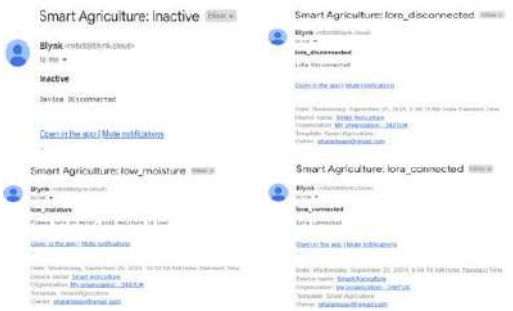


Fig 5. Email notification alert

The image displays Blynk cloud notifications for a smart irrigation system, highlighting real-time monitoring. Alerts like "Inactive" indicate connectivity issues, while "LoRa Disconnected" and "LoRa Connected" track LoRa link status. A "low moisture" alert signals the need for irrigation. These automated notifications ensure quick responses, enhancing water management and supporting sustainable farming.

E-System overview:



Figure 5: System overview.

Figure 5 shows the system set-up which include various components such as sensors, microcontrollers, LoRa modules, and a cloud platform for data storage and analysis. The system comprises multiple sensor nodes placed across the farm, with each node equipped with environmental sensors like DHT11 (temperature and humidity) and soil moisture sensors. These sensors collect real-time data about the soil and environmental conditions. The data is transmitted wirelessly from the sensor nodes to a central receiver node using LoRa technology. The receiver node then sends the data to the cloud platform, where it is stored and analyzed for irrigation decisions. The system is designed to automatically activate irrigation based on the analyzed data. The system also allows for remote monitoring and control via a mobile app or web dashboard, enabling farmers to oversee and adjust the irrigation process from anywhere.

VI. CONCLUSION

The automated irrigation system for smart farming was developed and tested in the laboratory and has demonstrated satisfactory results. This system was found to be highly effective in accurately detecting, measuring, and controlling soil water levels. By utilizing sensors to monitor the water needs of plants, the system ensures their requirements are met efficiently. Its primary function is to regulate the water supplied to plants, guaranteeing sufficient hydration while preventing water stress or plant loss. The system employs a combination of humidity, temperature, and moisture sensors, along with a timer, all powered by a renewable energy PV system, making it both sustainable and reliable.

The integration of remote monitoring via mobile or web apps allows farmers to manage irrigation from anywhere, providing flexibility and ease of use. The system promotes sustainability by conserving water resources, lowering operational costs, and improving crop yields. Overall, smart irrigation improves farming efficiency and promotes environmentally responsible practices. With continued advancements in IoT and AI technologies, these systems are expected to become even more precise and beneficial for farmers globally.

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Leveraging AI and IoT for the Smart Home Revolution

Prof. Nikita V.Chavan
Assisstant Professor
Dept. of Electronics and Telecommunication Engg.
DIT, Pimpri, Pune
nikita.chavan@dypvp.edu.in

Abstract: Traditional living spaces are being transformed into automated, efficient spaces by the combination of Artificial Intelligence (AI) and the Internet of Things (IoT). IoT gadgets like smart appliances, thermostats, and security systems allow for smooth home automation, and artificial intelligence (AI) improves these systems by anticipating user preferences, maximizing energy use, and enhancing security. AI makes sure appliances run well by predicting malfunctions and recommending repairs through predictive maintenance. AI-enabled security systems protect privacy, voice-activated automation and adaptive climate management improve comfort and convenience. Furthermore, the integration such that The Internet of Things (IoT) and artificial intelligence (AI) are crucial for improving environmental sustainability because they effectively manage vital resources like water and energy.

Keywords: Artificial Intelligence, Internet of Things, Home Automation, Energy Management, Predictive Maintenance, Robotics, Intelligent Security, Voice Assistants.

I. INTRODUCTION

Rapid technology advancements in the twenty-first century have drastically changed how we interact with our living environments. The Internet of Things (IoT) and artificial intelligence (AI) are two of the major forces behind this shift. With the advent of a new era of "smart living"—where devices learn human behavior, connect seamlessly, and automate daily tasks to enhance comfort, security, energy efficiency, and convenience—these technologies are revolutionizing traditional homes[1].

Figure 1 shows how AI-powered smart devices may anticipate and react to user needs, such as adjusting lighting, controlling energy use, or regulating temperature. This is made worse by IoT, which enables real-time data sharing among a network of networked devices. smart kitchen appliances, smart security cameras, voice-activated assistants, and smart thermostats [2].In addition to making routine chores easier, the smart home revolution tackles important problems like home security and energy management. As AI and IoT advance, homes are no longer static environments but rather dynamic environments that cleverly adapt to the needs of their inhabitants. In this regard, understanding how AI and IoT interact is essential to comprehending smart home trends and how they will affect contemporary living. Because of the increasing demand for energy and growing environmental concerns, effective energy management techniques are now essential to reducing waste, increasing efficiency, and lowering carbon footprints. technologies that use less energy and demand-side management.

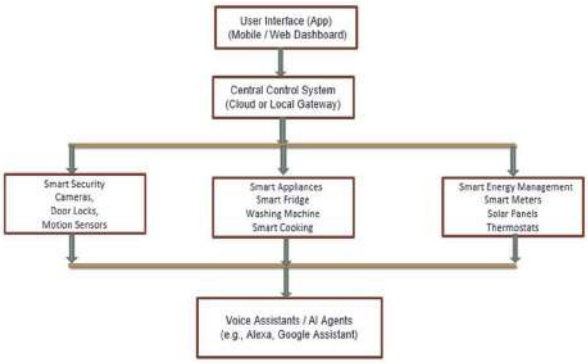


Figure 1. AI-powered smart systems

A revolutionary technical development, the Internet of Things (IoT) connects everyday physical devices to the internet to enable seamless automation, data interchange, and communication. The Internet of Things has drastically changed how we interact with our surroundings, from smart homes and wearable technology to industrial automation. By incorporating sensors, actuators, and connectivity components into tangible objects, IoT systems may collect, analyze, and respond to real-time data without the need for human intervention [3].

The Internet of Things is growing due to advancements in wireless connectivity, cloud computing, and artificial intelligence. In sectors like industry, energy, transportation, and agriculture, Internet of Things (IoT) applications boost output, improve decision-making, and open up new possibilities. Despite its immense potential, IoT poses challenges with regard to data security, privacy, and interoperability. Strong frameworks are therefore necessary to

ensure the safe and effective deployment of IoT technologies [7].

Cloud computing, wireless connection, and artificial intelligence innovations are driving the growth of the Internet of Things. Applications for the Internet of Things (IoT) boost output, improve decision-making, and open up new possibilities in sectors like industry, energy, transportation, and agriculture. Although there are many opportunities for IoT, there are also problems with data security, privacy, and interoperability. Strong frameworks are therefore necessary to ensure the safe and effective deployment of IoT technologies [3].

II. RELATED WORK

[1]Predictive maintenance

Predictive maintenance fig. [2] Uses machine learning algorithms and real-time data to anticipate equipment breakdowns before they happen. Predictive maintenance solutions assist industries cut maintenance costs, decrease downtime, and increase the lifespan of vital assets by examining patterns in machine behavior by ensuring that machinery and infrastructure are kept in top shape, this proactive strategy is transforming industries including manufacturing, aviation, and energy [24].

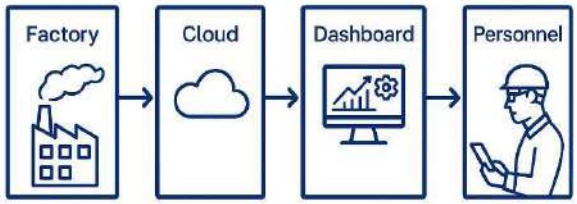


Figure 2 Predictive maintenance

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Predictive maintenance show how technological innovation is enhancing human well-being while simultaneously streamlining industrial operations. Smarter, safer, and healthier futures are being paved by this industry-technology collaboration[22].By automating processes, boosting output, and facilitating accuracy in operations, robotics is transforming a number of industries. Their uses are numerous and still growing, ranging from industrial robots used in production to service robots in homes and hospital settings. Robots can learn and adapt thanks to the integration of artificial intelligence (AI), which increases their autonomy and capacity for complicated decision-making[24].

[2]Maintaining Sustainability

Developing methods and technologies that lessen their negative effects on the environment and support long-term ecological balance is the main goal of sustainability. In fields like waste management, sustainable manufacturing, and renewable energy, technological developments are essential.

[2.1]Important Areas of Attention: Renewable energy sources (wind, solar, and hydro), reusing and recycling in the circular economy, Transportation that is sustainable (public transportation, electric cars), Intelligent cities and green buildings



Figure 3. Intelligent Security

[3] Intelligent Security

Intelligent Security is advanced technology intended to safeguard information, people, and tangible assets are all included in smart security. Innovations in smart security fig. [3] are essential for protecting individuals and organizations in light of the growing number of cyber threats and safety concerns.

[3.1]Important Technologies:

Smart locks and home security systems, biometric authentication, Internet of Things-based surveillance systems, cybersecurity solutions (AI-driven threat detection)

[3.1.1]Assistants by Voice Artificial intelligence (AI)

Powers voice assistants, which communicate with users by responding to spoken instructions. They are now essential to smartphones, smart homes, and other Internet of Things gadgets. As they develop further, these systems provide more functionality and natural language processing.

[3.1.2]Artificial intelligence (AI)-powered devices Illustrations :

Google Assistant, Apple Siri, Microsoft Cortana, and Amazon Alexa

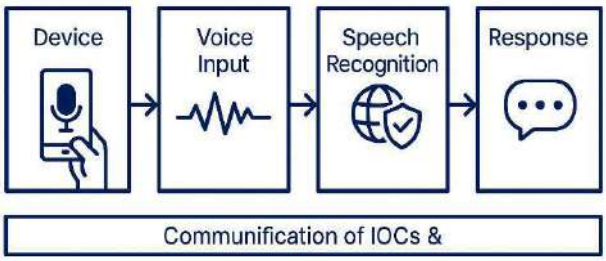


Figure 4. Assistants by Voice Artificial intelligence

Voice Figure [4] Command Assistants Voice assistants are gadgets driven by artificial intelligence (AI) that speak to users by responding to voice instructions. These days, they are an essential part of smart homes, smartphones, and other Internet of Things devices. The most well-known voice assistants, such as Google Assistant, Apple Siri, Microsoft Cortana, and Amazon Alexa, offer a range of services, from personal assistance and information to controlling smart devices [1].

The Google Assistant is well known for its ability to interface with several Google services and for its advanced natural

language processing capabilities. It can control smart home equipment, provide real-time responses, and manage chores. Its contextual awareness allows users to conduct more natural conversations. Smooth interaction with the iOS environment is provided by Apple Siri, the voice assistant for Apple products. For a number of things, including sending messages and setting reminders, Siri provides hands-free assistance. It ensures a personalized experience by progressively understanding user preferences [2].

III. Difficulties in Using AI and IoT to Drive the Revolution in Smart Homes

The integration of artificial intelligence (AI) and the Internet of Things (IoT) can significantly improve smart home automation, efficiency, and convenience. However, there are challenges involved in realizing the vision of a smart home. These barriers could hinder the seamless development and adoption of smart home technologies, potentially impacting both manufacturers and consumers [1].

1. Issues with Data Security and Privacy

Concerns about privacy and data security
The problem lies in the massive amounts of personal data generated by IoT devices, such as voice commands, video surveillance, and daily activity patterns, which lead to serious privacy and security concerns. By exploiting vulnerabilities in connected devices, hackers may be able to gain unauthorized control over smart home systems or compromise privacy. For example, there have been cases when users' privacy has been compromised or private information has been obtained through the usage of voice assistant or smart camera flaws.

2. Issue with Network Bandwidth and Latency

Smart homes to work properly, there must be continuous data transmission between devices and the cloud, which requires a large amount of bandwidth and low latency. Network congestion can cause delays, connectivity problems, and decreased performance in households with several connected devices. For instance, if the home's internet connection is inadequate, smart gadgets like security cameras may lag or not stream HD video in real time. As the number of IoT devices increases, it will be crucial to upgrade broadband infrastructure and deploy more data-transmitting technologies like 5G.

3. . Issue with The intricacy of usage and setup

Smart gadgets are made to be easy to use, setting up and integrating several devices can be challenging, particularly for non-technical people. There may be usability issues when using voice commands or mobile apps to control certain devices. Without professional support, a user may find it difficult to couple devices, configure their smart home hub, or solve connectivity issues.

4. Limited AI Training and Adaptability

The problem is that AI-driven smart home systems have to continuously learn from and adapt to their users' preferences and routines. To train AI models, however, high-quality data is required, and collecting this data in a range of domestic scenarios can be difficult. AI may likewise struggle to predict human preferences and behavior in the absence of sufficient data. For example, a smart thermostat may not be able to effectively adjust its settings if it hasn't gathered enough data on the household routines.

5. Moral Concerns

Moral questions are brought up by the combination of AI and IoT in smart homes, including the potential for data misuse and monitoring. Concerns over continuous surveillance may arise, for example, if voice assistants and smart cameras inadvertently record private conversations or actions. A voice assistant might unintentionally record private conversations or start undesirable behaviors, for example, which would be a privacy risk.

6. Reliance on Internet Access

Many smart home devices depend significantly on internet access. The system is susceptible to service disruptions such network outages, bandwidth restrictions, or poor internet because of this reliance, which may result in automation problems or system breakdowns. For instance, security cameras or smart lights may not be able to provide live feeds if a Wi-Fi network goes down.

IV.Proposed Solution

To address the problem, manufacturers must include robust encryption protocols, regular security updates, and privacy policies that comply with international regulations (such as the General Data Protection Regulation, or GDPR). Some of the solutions include the implementation of strong encryption and regular security updates, upgrades to broadband infrastructure for better connectivity, simplified device setup, improved AI training methods, clear ethical guidelines for data usage, and backup plans to reduce reliance on the internet.

V.Conclusion

By combining Internet of Things (IoT) and artificial intelligence (AI) technology, smart home automation is revolutionizing residential spaces and advancing environmental sustainability objectives. The IoT's extensive sensor networks and AI's analytical capabilities work in concert to enable intelligent monitoring and management of energy consumption through AI-powered usage pattern analysis. Irrigation systems are optimized for water conservation using real-time weather data. HVAC (heating, ventilation, and air conditioning) systems should be automatically adjusted according to occupancy and outside factors. The combination of AI and IoT will become more and more important as smart home technologies develop in order to achieve both environmental sustainability and domestic comfort.Future developments in this field promise even greater advances in resource efficiency, automation capabilities, and sustainable living practices. The successful implementation of these technologies demonstrates that technological advancement and environmental responsibility can work hand in hand to create more sustainable and efficient living spaces for future generations.

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ML-ASSISTED SMART SHOPPING: TRANSFORMING RETAIL WITH AI

Dr. priti shende
Electronics & Telecommunication
Dr. D. Y. Patil Institute of Technology
Pune, India
priti.jawale@gmail.com

Vaishnavi Andhale
Electronics & Telecommunication
Dr. D. Y. Patil Institute of Technology
Pune, India
vaishnaviandhale732@gmail.com

Anjali Biraje
Electronics & Telecommunication
Dr. D. Y. Patil Institute of Technology
Pune, India
anjalibiraje39@gmail.com

Manisha Dungdung
Electronics & Telecommunication
Dr. D. Y. Patil Institute of Technology
Pune, India
manishacelina20@gmail.com

Abstract--The ML-Assisted Smart Shopping System is designed to make shopping faster, easier, and more convenient. It features a smart trolley that automatically detects products using RFID and barcode scanning, eliminating the need for manual scanning. AI-powered recommendations help customers find the best products, while an in-store navigation system guides them efficiently. The biggest advantage is the auto-billing feature, which removes the need to wait in checkout lines. For retailers, this system helps track inventory in real time, reduces labour costs, and provides insights into customer preferences. Unlike expensive solutions like Amazon Go, our system is affordable and easy to integrate into existing stores. With a focus on improving both the customer experience and business operations, this technology is set to change the future of retail.

Keywords: Smart Shopping, AI-Powered Recommendations, RFID, Barcode Scanning, Auto-Billing, In-Store Navigation, Machine Learning, Retail Automation, Customer Experience, Inventory Management.

I. INTRODUCTION

Shopping is an essential part of daily life, but traditional shopping experiences come with challenges such as long checkout queues, difficulty in locating products, and a lack of personalized recommendations. The **ML-Assisted Smart Shopping System** is designed to transform the way people shop by making the process seamless, efficient, and hassle-free. This innovative system leverages **RFID (Radio Frequency Identification) and barcode scanning** to automatically detect products as they are placed in the shopping trolley, eliminating the need for manual scanning at the checkout counter. This automation significantly reduces waiting times and enhances the overall shopping experience.Additionally, the system offers **AI-powered recommendations**, helping customers make informed purchasing decisions based on their preferences and shopping history. It also features an **in-store navigation system** that guides shoppers to their desired products, saving time and effort. .

One of the key features of this system is **AI-powered recommendations**, which analyze customer preferences and suggest the best products based on past purchases, ongoing discounts, and trending items. This personalized approach helps customers make better purchasing decisions, ensuring they get the best value for their money. Additionally, the system includes an **in-store navigation feature**, which provides real-time directions to the exact location of products within the store. This feature saves time and effort, especially in large supermarkets where finding specific items can be challenging.

The most groundbreaking aspect of this system is **auto-billing**, which allows shoppers to complete their purchases without standing in long checkout lines. As products are detected and added to the cart, the system continuously updates the total bill, and payment can be processed automatically through a mobile app or a self-checkout kiosk. This not only improves customer convenience but also enhances store efficiency by reducing the need for multiple cashiers.

For retailers, the **ML-Assisted Smart Shopping System** offers significant operational benefits. It enables **real-time inventory tracking**, ensuring that stock levels are always updated and preventing issues such as overstocking or running out of popular products. Additionally, the system provides valuable insights into **customer purchasing patterns**, helping store owners make informed business decisions, optimize product placement, and improve sales strategies. By automating routine tasks, the system also reduces labor costs, allowing staff to focus on customer service and store management.Unlike costly solutions like Amazon Go, which rely on advanced sensors and cameras, this system is **affordable and easy to integrate** into existing stores. It enhances customer experience and streamlines operations without requiring major modifications, making it ideal for both small and large retailers. By leveraging **AI, automation, and smart technology**, the **ML-Assisted Smart Shopping System** represents the future of retail.

II. COMPONENTS

A. RFID Reader & Tags

The **RFID (Radio Frequency Identification) Reader & Tags** play a crucial role in enabling **automatic product detection and tracking** within the shopping trolley. This technology replaces the need for manual barcode scanning, making the shopping experience faster and more convenient.\

Each product in the store is equipped with a **unique RFID tag**, which consists of a **microchip and an antenna**. The microchip stores essential product details such as the **name, price, category, and unique identification number (UID)**, while the antenna transmits this data when activated by an RFID reader.
As a customer places an item in the **smart trolley**, the **RFID reader** installed within the cart automatically detects the tag's signal. The reader then retrieves product details and updates the shopping list in real time. This process occurs within **milliseconds**, eliminating the need for manual scanning and significantly reducing checkout time.

Additionally, RFID technology enables **real-time inventory tracking**, helping retailers monitor stock levels and prevent theft. If a customer **removes an item** from the trolley, the RFID system updates the cart's contents accordingly. This **smart automation** ensures a seamless shopping experience, reduces human errors, and enhances overall efficiency in retail stores.



Fig. 1: *RFID Reader & Tags*

B. Microcontroller ESP32

The **ESP32** microcontroller is an essential component of the **ML-Assisted Smart Shopping System**, serving as the central unit that processes and manages data from various sensors. With its **dual-core processor, built-in Wi-Fi, and Bluetooth capabilities**, it ensures seamless communication between the smart trolley, the store's database, and a mobile application. The ESP32 **reads RFID tag data** when a product is placed in the trolley and processes **barcode scanner inputs** to retrieve product details. It continuously updates the shopping list in real time, ensuring accurate billing and product tracking. Additionally, the ESP32 handles **LCD or OLED displays**, providing customers with instant feedback on their purchases, pricing, and recommendations. It also manages **LED indicators and buzzer alerts** for notifications such as incorrect scanning or unauthorized item removal.

Integrated with **weight sensors**, it verifies product placement, while **infrared or ultrasonic sensors** detect unauthorized removals.Thanks to its low power consumption, the ESP32 is ideal for battery-operated smart trolleys. Its ability to connect with cloud servers via Wi-Fi and interact with mobile applications via Bluetooth makes it a perfect choice for real-time shopping automation, significantly improving the efficiency of both customers and retailers.



Fig. 2: *Microcontroller ESP32*

*C. **LCD display***

The **LCD display** in the **ML-Assisted Smart Shopping System** plays a crucial role in enhancing the user experience by providing real-time information about the shopping process. Mounted on the **smart trolley**, the LCD screen displays **product details, pricing, total bill, and AI-powered recommendations** as items are added or removed. When a product is scanned via **RFID or barcode**, the screen instantly updates with relevant details, ensuring transparency for the customer. Additionally, the display can guide shoppers by showing **in-store navigation assistance**, helping them locate items efficiently. It also provides **notifications or alerts**, such as discounts, promotional offers, or reminders for frequently purchased items. Integrated with the **ESP32 microcontroller**, the LCD receives and displays real-time data processed from various sensors, ensuring a smooth and interactive shopping experience. By offering a **clear and user-friendly interface**, the LCD display makes shopping more convenient, reduc roving
overa

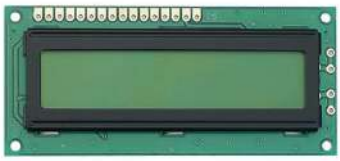


Fig. 3: LCD display

D. IR Sensor

In the **ML-Assisted Smart Shopping System**, an **Infrared (IR) sensor** can be used as a **payment gateway trigger** to ensure a seamless checkout process. The IR sensor, placed at the store's **exit gate**, detects when a customer is approaching with a **smart trolley**. Once the trolley reaches the payment zone, the IR sensor sends a signal to the **ESP32 microcontroller**, which then initiates the **auto-billing process**.
If the payment has already been completed via a **mobile app or digital wallet**, the system grants the customer a **smooth exit**. However, if the payment is pending, the **LCD display** prompts the user to complete the transaction. This **contactless payment verification** reduces human intervention and prevents unauthorized exits. Additionally, the IR sensor helps **prevent shoplifting** by ensuring that only paid items leave the store. By automating the final step of the shopping experience, the IR sensor makes the checkout process **faster, more secure, and completely hassle-free**.



Fig 4 : IR Sensor

III. METHODOLOGY

The ML-Assisted Smart Shopping initiative employs a systematic approach that starts with data scraping and preprocessing. Data is harvested from multiple sources, such as customer activity (purchase history, browsing), product information (prices, categories, availability), and external sources (market trends, competitor prices). Transaction data are also harvested for detecting fraud, and customer reviews are scraped to perform sentiment analysis. The preprocessing step includes cleaning missing or redundant data, encoding categorical features, and feature engineering such as sentiment scores and user-item interaction matrices. The data is divided into training (80%) and testing (20%) sets to facilitate proper model evaluation. Different machine learning models are created to solve various retail problems. Personalized product recommendations are done using Collaborative Filtering (SVD, ALS) and Content-Based Filtering. ARIMA and LSTMs forecast demand patterns and stock levels' optimization, whereas Regression-based algorithms dynamically price according to demand. Anomaly detection models such as Isolation Forest assist in detecting credit card and online payment fraud. Natural Language Processing (NLP) using BERT and LSTMs also parse customers' sentiment from reviews for enhancing service. These models are optimized through hyperparameter tuning methods like Grid Search and Bayesian Optimization and assessed through metrics such as RMSE (for prediction), Precision-Recall and F1-score (for fraud detection) and Mean Average Precision (MAP) for recommendation correctness.

After the models are trained and validated, they are packaged into a scalable system for deployment. The backend, developed with Flask or Django, exposes APIs for smooth interaction among the models and the front-end, developed using React.js or Angular for a user-friendly shopping experience. The system is deployed on AWS or GCP for real-time scalability, and databases such as PostgreSQL or MongoDB hold transactional and user information. Post-deployment, real-time monitoring tools monitor model performance, and feedback loops aid in the retraining of models to drive continuous improvement. The system provides dynamic product suggestions, effective inventory management, automated price management, and fraud detection and prevention while improving customer experience. Future development can be computer vision for cashier-less checkout, AI-driven virtual assistants, and reinforcement learning for sophisticated decision-making in retail.

IV. RESULTS

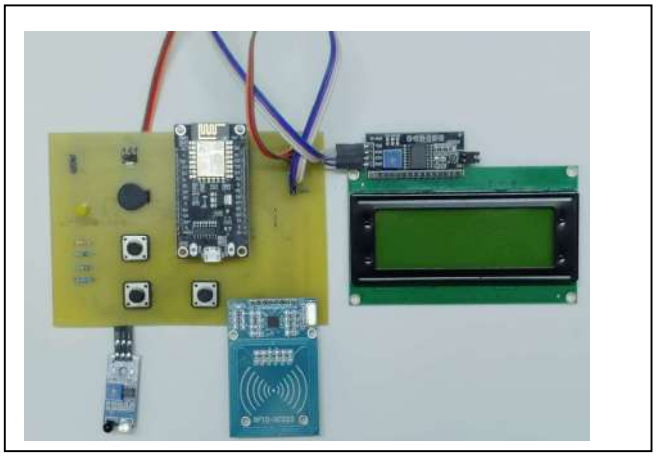


Fig 5:Circuit Image

The ML-Assisted Smart Shopping project leverages an ESP8266/ESP32 microcontroller, an RFID module (RC522) for product scanning, a 16x2 LCD display for real-time updates, and IR sensors for object detection to transform the retail experience. Machine learning algorithms analyze shopping patterns, optimize billing, and provide personalized recommendations. The system automates checkout by identifying products via RFID, displaying details on the LCD, and processing transactions seamlessly. Additionally, push buttons and a buzzer enhance user interaction, while IoT connectivity enables real-time data tracking, making shopping more efficient and reducing queue times at checkout counters.



Fig 6 :Welcome Screen

Whenever a customer puts in or takes an item out of the trolley, the RFID system automatically adjusts the total bill, minimizing manual checkout. Machine learning algorithms are used to interpret shopping patterns in order to suggest appropriate products, improving the user experience and optimizing shopping.



Fig 7 :Select Location Screen

The photo depicts an LCD display featuring a menu interface with options like "Select Location" and ">Add Products," governed by an I2C module that interfaces with a microcontroller. Such a configuration indicates an interactive retail automation system, possibly implemented in smart shopping applications. For your ML-Assisted Smart Shopping project, this might be included in a self-service retail kiosk where customers interact with a system to place items in their cart or find store locations. Combining AI and machine learning would make this better by providing personalized suggestions, real-time pricing, or automated payment, enhancing the customer shopping experience.



Fig 8 :Direction to Vegetable Location Screen

The picture shows an LCD display offering navigation guidance in a shopping mall, guiding shoppers to the vegetable stand at the entrance. This fits perfectly with your ML-Assisted Smart Shopping project, where AI can improve navigation in-store through smart displays, IoT, and machine learning algorithms. By combining real-time tracking by location and recommendation systems powered by AI, such an arrangement can assist customers effectively, recommend optimized shopping paths, and even customize directions based on past shopping patterns, enhancing convenience and user experience within retail settings.



Fig 9:Product Scanned Screen

The image shows an LCD screen displaying the scanned product details in an RFID-based smart shopping system. The screen indicates that a product, "Bread," has been successfully scanned using an RFID tag, and the total bill amount is updated to $10.00. This system enables automatic billing and enhances shopping efficiency.



Fig 10:Product Removed Screen

The image shows an LCD screen indicating the removal of a product in an RFID-based smart shopping system. The screen displays "Remove Product: APPLE," confirming that an item has been deducted from the cart. This feature allows users to update their purchase list dynamically, ensuring accurate billing.



Fig 11:Total Bill Screen

Product RFID tags make checkout easy without manual barcode reading, minimizing wait times. Machine learning can also refine pricing strategies, identify patterns of purchases, and recommend customized discounts. This system enhances productivity, minimizes mistakes, and strengthens the overall customer experience in intelligent retail environments.



Fig 9:Payment Receive Screen

The ML-Assisted Smart Shopping project, or the Smart Trolley Project, is an automated retail checkout process based on RFID technology, IoT, and machine learning. The system consists of an ESP8266/ESP32 microcontroller, RFID scanner, LCD display, and sensors to monitor products in real time. When customers add or remove items, the RFID module adjusts the total bill, which is displayed on the LCD. The picture displays the "Payment Received" message, showing successful transaction processing. This initiative does away with manual billing, shortens checkout lines, and offers customer convenience through automated payments and real-time tracking, ensuring that shopping becomes effortless and convenient.

V.CONCLUSION

Bytor and the ML-Assisted Smart Shopping project demonstrate how the great promise of artificial intelligence can reshape the retail experience. This solution improves shopping through machine learning by offering personalized recommendations, forecasting inventory requirements, and assessing customer behavior. Such insights from the AI engine enable retailers to make customers happy and drive their operational efficiency. Ultimately, smart shopping has the potential to make retail a more responsive, intelligent, and customer-centric sector, driving data-driven decision-making for both consumers and businesses in real time through ML-assisted approaches. This is pointing us toward the future of retail, where AI is enabled to provide a more meaningful and seamless shopping experience.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to our faculty guides Dr. Priti Shende and Mrs. Ankita Bombatkar whose guidance, expertise, and encouragement have been instrumental in the development of this project. Their insights and support have greatly contributed to our understanding and progress in the field of ML Assistant and AI Information. We also deeply grateful to the Dr. D. G. Bhalke (H.O.D of Dept. of Electronics and Telecommunications) and the Dr. Vinod Kimbahune (H.O.D. of Dept. of Computer Engineering) for their support and encouragement throughout this project. Finally, we extend our heartfelt gratitude to all the faculty members for their unwavering support.

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Vehicle Black Box for Accident Prevention

Dr. Priti Shende
priti.jawale@dypvp.edu.in
Shreya Nagarale
shreyanagarale4@gmail.com
Janhavi Wagh
waghjanhavi2003@gmail.com
Someshwar Khishrsagar
Someshwarkshirsagar01@gmail.com
Dept. of Electronics and Telecommunication Engineering
Dr. D. Y. Patil Institute of Technology, Pune, India.

Abstract— *Road accidents remain a significant global concern, with response time often playing a critical role in minimizing casualties. This paper presents an innovative Accident Detection and Alert System designed to detect vehicle collisions in real-time and promptly notify emergency responders. The system integrates multiple sensors, including accelerometers, gyroscopes, and vibration sensors, to continuously monitor vehicle movements and identify signs of an accident. Upon collision detection, the system automatically triggers an alert that includes the GPS coordinates of the incident location, which is then transmitted via GSM technology to emergency contacts or services. This timely communication reduces response time and enhances the efficiency of emergency assistance, potentially saving lives. Additionally, the system's modular design allows for scalability and adaptability to different vehicles, making it a practical solution for real-world applications. The use of IoT-based technologies further improves the system's reliability, ensuring rapid transmission of data even in challenging environments. This research highlights the potential of smart accident detection systems to significantly enhance road safety and emergency response systems.*

Keywords: Accident Detection, Alert System, GPS, GSM, Emergency Response, IoT, Sensors

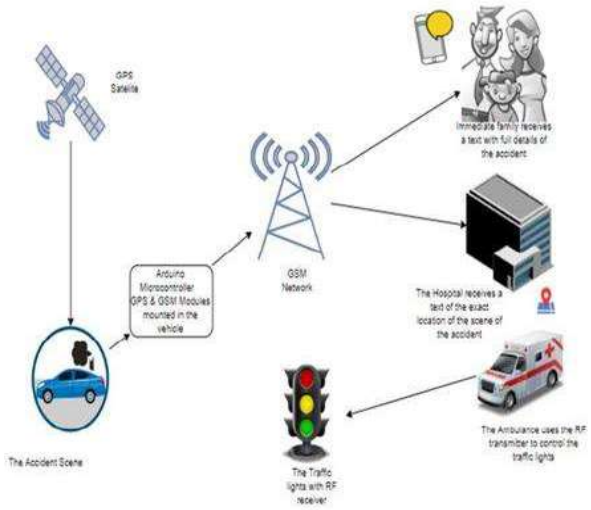
INTRODUCTION

The rapid rise in road traffic and the increasing number of vehicles on the roads globally have contributed to a significant surge in road accidents, leading to millions of fatalities and injuries each year. Despite the continuous development of advanced vehicle safety features such as airbags, automatic braking systems, and lane departure warnings, one of the most critical challenges still faced is the timely detection of accidents and the swift response from emergency services. According to the World Health Organization (WHO), road traffic accidents are among the top 10 causes of death worldwide, with a substantial portion of these accidents involving delays in emergency response due to a lack of immediate information.

In fact, the golden hour – the critical period immediately following an accident – is often wasted due to the delayed detection of incidents and the subsequent delay in reporting to the emergency services.

While traditional emergency response systems heavily rely on human intervention, such as manual calls to emergency numbers by bystanders, these methods can often be inefficient, particularly in rural areas or during off-peak hours when the availability of human witnesses may be limited. Furthermore, the inability to pinpoint the exact location of an accident in real-time can lead to longer response times, exacerbating the situation. In light of these challenges, the need for an intelligent, automated system that can accurately detect accidents and promptly alert emergency responders has never been more urgent.

This report introduces the Accident Detection and Alert System, a technology-driven solution that aims to revolutionize road safety by integrating advanced sensors, GPS technology, and wireless communication systems.



The system is designed to detect accidents in real-time using a combination of accelerometers, gyroscopic sensors, and vibration sensors, which can identify sudden changes in vehicle dynamics, such as crashes or rollovers. Once an accident is detected, the system automatically triggers an alert, sending crucial data including the exact GPS coordinates of the incident to emergency contacts or services via GSM technology. This immediate transmission of information ensures that emergency services are dispatched without delay, potentially saving valuable time and, in turn, lives.

The significance of the Accident Detection and Alert System lies in its potential to drastically reduce the time between an accident and the arrival of emergency responders. By eliminating the need for manual reporting and providing real-time location data, the

system enhances the efficiency of emergency response, ensuring that first responders can reach the scene as quickly as possible. This system's impact extends beyond individual safety, as it can contribute to the overall safety infrastructure by enabling more effective traffic management and resource allocation.
As road traffic continues to increase globally, the implementation of such intelligent systems will be key in ensuring that road safety standards evolve to keep pace with growing demands. This chapter sets the stage for a detailed discussion on the development, architecture, and practical implications of the Accident Detection and Alert System, highlighting the importance of technological integration in enhancing road safety and emergency response. The following sections will explore the system's design, functionality, and potential benefits, along with the challenges and future enhancements that could further optimize its performance.

Goal of Work

The project aims to create a real-time Accident Detection and Alert System using accelerometer and gyroscope sensors, GPS integration, and a GSM-based alert system. The system aims to improve road safety by reducing response times and providing timely assistance.

Problem Statement

Road accidents remain one of the leading causes of death and injury worldwide, often aggravated by delayed emergency response due to the absence of real-time accident detection and location tracking. Traditional systems rely heavily on human intervention, which is not always available or timely, especially in remote areas or during odd hours. There is a critical need for an intelligent system that can automatically detect accidents, accurately identify the location, and instantly alert emergency services to reduce response time and improve the chances of saving lives. This project addresses this gap by developing a real-time, sensor-based accident detection and alert system using GPS and GSM technologies.

Objectives

1. Utilizes sensors to identify collisions or abnormal vehicle behavior.
2. Provides exact accident location via GPS for emergency responders.
3. Sends instant alerts via GSM/SMS to predefined emergency contacts.
4. Aims to reduce emergency response time and improve survival chances.
5. Low-cost, scalable, and deployable system for easy integration.
6. Utilizes IoT for continuous monitoring and reliable data communication.

Motivation

The Accident Detection and Alert System aims to reduce response times in emergency situations due to the increasing number of road accidents worldwide. By automating accident detection and providing real-time alerts, the system aims to save lives and reduce the severity of injuries. The system uses modern sensors, GPS, and GSM technologies to enhance road safety and improve response times.

Need of Study

The Accident Detection and Alert System automates accident detection and alerts emergency services, addressing high accident rates, delays, and costs. It uses sensor technology, GPS, and GSM modules, reducing response times.

LITERATURE SURVEY

Dimitrios Zavantis et al., "Automatic Accident Detection System Using IoT Compared to the Systems that a Traffic Centre Uses for Accident Detection" Procedia Computer Science, Elsevier,2024.

The increasing congestion on urban roads has led to an increase in accidents, causing more injuries and fatalities. Rapid detection of incidents and their exact location is crucial for emergency services to act quickly and reduce response times. This paper compares automatic accident detection systems with traditional traffic center systems, analyzing the importance of implementing these systems.

Subhash A. Nalawade et al., "Real-Time Accident Crash Detection using Machine Learning: A Survey" Reasearch Gate ,2024.

The survey article discusses the limitations of traditional crash detection systems, highlighting their inefficiencies and false alarms. It proposes a paradigm shift by integrating modern deep learning-based object detection algorithms, which process real-time image and video data using neural networks and machine learning. The paper aims to bridge the gap between current systems and a future with increased efficiency and dependability on roads.

Sinchana R D et al., "Accident detection and alert system for enhanced safety and response" IJARCCE, Vol. 13, Issue 11, 2024.
Accident detection and alert systems are revolutionizing emergency management by utilizing advanced technologies to improve response times and safety outcomes. These systems use sensors and detection devices to monitor for accidents, analyze data, and process it to identify severity. Once detected, the system activates an alert mechanism, allowing for swift response. Integration with existing emergency frameworks enhances effectiveness, and automated actions can be triggered without human intervention. However, challenges like minimizing false alarms, ensuring system accuracy, and addressing privacy concerns must be managed. The future of these systems is expected to see advancements in artificial intelligence and machine learning, enhancing precision and efficiency.

Mr. Hardik Chotalia et al., "A Research Paper on "IoT Based Accident Prevention & Alerting System using Raspberry Pi" IJCRT, Volume 12, Issue 4 ,2024.

The project outlines the creation of an IoT-based accident prevention system for vehicles, using Raspberry Pi 3B+ to collect data from sensors. The system monitors the driver's state, surroundings, and vibrations, alerting them if they exceed a predefined threshold. If a collision occurs, the system retrieves location coordinates and sends an emergency message to designated contacts via SMS, potentially saving lives.

Srushti P. Bochare et al., "IOT Based Vehicle Accident Detection and Tracking System Using GPS Modem" IRJET, Volume: 11 Issue: 04 ,2024.

The research presents an IoT-based Vehicle Accident Detection and Live Tracking System, which uses an ESP32 microcontroller, Firebase cloud platform, tilt sensor, and 3-axis sensor for real-time detection and response to vehicle accidents. The system integrates with the tilt sensor, detecting potential accidents, and the 3-axis sensor, capturing acceleration and deceleration data. When an

accident is detected, the system initiates live tracking through the Firebase cloud platform, allowing real-time communication between the vehicle and a designated monitoring center. This system has the potential to revolutionize accident detection and response mechanisms, creating a safer transportation environment.

Unnati Phulmante et al., "Review for Accident Detection and Alerting System" IRJET, Volume: 11 Issue: 04 ,2024.

The accident detection and alerting system is a technological solution that uses sensors like accelerometers, GPS, and cameras to monitor vehicle dynamics and alert drivers of potential accidents. This system aims to expedite emergency response times, mitigate injuries, and potentially save lives. It also includes features for post-accident data analysis for preventive measures.

Khandekar Bindiya et al., "Vehicle Accident Detection and Alert System" JETIR, Volume 11, Issue 3,2024.

The "Vehicle Black Box" system integrates advanced technologies to improve road safety and vehicle oversight. It monitors driver sobriety, seat belt engagement, and other factors, notifying authorities of breaches or accidents. Equipped with a high-definition camera, it promotes responsible driving habits.

Sadda Bharath Reddy et al., "Android accident detection and alert system" ICMED, 2024.

A smartphone app can detect accidents, activate an alarm screen, and provide emergency assistance. It calls local emergency numbers and sends SMS alerts. Challenges include identifying crashes, integrating with vehicle systems, addressing cybersecurity risks, optimizing battery usage, and easing privacy concerns. This low-cost, scalable system could save lives worldwide.

Prof. V. M. Umale et al., "Car Accident Detection and Alert System" IJARSCT, Volume 4, Issue 7, 2024.

This study proposes a novel traffic accident detection and warning system using various components like energy sensors, accelerometers, Arduino microcontrollers, GPS modules, and GSM modules. The system differentiates between minor and severe accidents, recognizes collisions based on impact severity, and detects overturned vehicles. The system's reliability and performance are assessed through rigorous testing, aiming to reduce traffic accident effects and improve road safety legislation.

P. Josephinshermila et al., Accident detection using Automotive Smart Black-Box based Monitoring system" Measurement: Sensors, Elsevier, Volume 27, 2023.

This paper presents a sophisticated monitoring and alert system for automobile vehicle parameters, addressing the growing number of vehicles and increasing accidents. The system uses a micro-controller to continuously monitor vehicle parameters and alert emergency services when accidents occur. The system collects driving information before, during, and after a crash, aiding in vehicle safety, collision victim care, insurance investigations, and improving road conditions. Experimental findings show higher accuracy compared to RFID, SVM, CNN, and RNN methods.

Dr. R. Prasanthi et al., "Accident detection and alert system using Arduino" IRJMETS, Volume:05/Issue:04,2023.

This project aims to address the issue of individuals being left without assistance in accidents while riding their vehicles. It uses an Arduino, GPS Receiver, and GSM module to control the process. The system detects severe accidents using a vibration sensor and can identify rollovers. The microcontroller sends this information to the GSM module, which transmits the victim's location to the assigned contact. This innovative solution is particularly effective in developing nations like Nepal, India, and Bangladesh, where vehicular accidents and fatalities are increasing.

Sneha Shinde et al., "IOT based vehicle accident detection system" IRJMETS, Volume:05/Issue:04,2023.

Population growth leads to an increase in accidents, often unreported to nearby ambulances. This can result in delays in emergency services, leading to potential loss of life. An IoT-based accident detection system aims to reduce loss of life and ambulance delays by integrating smart sensors and microcontrollers. The system uses an accelerometer sensor to detect accidents, and a Wi-fi module to notify guardians about the accident for immediate assistance.

Dr. R.P. Sonar, et al., "Intelligent Transportation System (ITS) Using Neural Networks" IJCRT, Volume 11, Issue 12 December 2023.

The paper explores the integration of neural network technologies in intelligent transportation systems for smart cities. It focuses on their role in real-time traffic prediction, adaptive signal control, and optimized routing strategies. The study also discusses the potential societal and environmental impacts of such systems, highlighting reduced travel times, fuel consumption, and emissions.

CH B R Srikanth et al., "Vehicle Tracking and Accident Alert System Using Arduino Through GPS & GSM" IJIRT, Volume 10 Issue 1,2023.

The project focuses on an accident detection system that uses GPS to alert the rescue team in real-time. The system uses an accelerometer to detect sudden shifts in the vehicle's axles, which is then sent via GSM module to the police control room or rescue team. The goal is to save lives by providing accurate information about the accident location and enabling timely action.

Paul Selvi M et al., "An Iot Based Vehicle Detection and Prevention System" International Journal of Science, Engineering and Technology, 2023.

Traffic congestion and auto accidents are increasing due to population growth, leading to a rise in fatalities and fatalities. IoT technology can help reduce these fatalities by reducing the time it takes to rescue after an accident. Automatic accident detection systems, using IoT sensors and smartphones, can predict crashes and send messages to emergency numbers. This study critically reviews existing approaches for forecasting and preventing traffic accidents, highlighting their advantages, drawbacks, and issues to resolve.

K. Krishna Jyothi et al., "Computer vision based accident detection and alert system" IJRTI, Volume 8, Issue 6,2023.

The paper presents a computer vision-based system that uses machine learning and deep learning algorithms to automatically detect road accidents from CCTV footage. The system uses a supervised CNN classifier to determine accident probability, alerting the user and sending an email, reducing emergency response time and saving lives.

C. V. Suresh Babu et al., "IoT-Based Smart Accident Detection and Alert System" Reasearch Gate,2023.

The IoT-based smart accident detection system uses sensors, GPS, and Arduino UNO to collect location and severity information. It transmits this information to authorities in real time, enabling swift response, potentially saving lives and benefiting road users, emergency services, and transportation.

Irakam Hareesh et al., "Iot based accident detection & altering system" JETIR, Volume 10, Issue 5,2023.

Uneven interruptions and speed are major causes of vehicle accidents. This project aims to address this issue by using vibration and ultrasonic sensors to detect and send accident signals to the ARM 7, alerting authorized persons and sending an email via wireless webcam. Timely information could save lives.

Dr. C. K. Gomathy et al., "Accident detection and alert system" Journal of Engineering, Computing & Architecture, Reasearch Gate ,2022.

High road accidents, particularly two-wheelers, require immediate medical aid. A system alerts nearby medical centers using accelerometers and heartbeat sensors. The system sends information to a smartphone, which sends text messages to the nearest medical center and shares the accident's location, saving time.

Kamal Acharya et al., "Accident detection system project" Reasearch Gate ,2022.

The rapid growth of technology has increased traffic hazards, leading to frequent road accidents causing significant loss of life and property. A project aims to address this issue by using piezo electric sensors as crash or rollover detectors. These sensors can detect signs of severe accidents, send location information to emergency contacts, and take necessary action. If accidents are small or not serious, drivers can terminate alert messages to save time.

G. Siri et al., "Accident detection and alert system" IRJMETS, Volume:04/Issue:06,2022

Advancements in technology have increased traffic hazards, leading to frequent road accidents causing significant loss of life and property. A project aims to address this issue by using an SW420 sensor as a crash or rollover detector. The vibration sensor checks car vibration rates, recognizing severe accidents and sending alert messages to emergency services via GSM and GPS. This system can be lifesaver in isolated areas, allowing for swift response from emergency services.

Sakthi P et al., "Accident detection and alert system using gps and gsm" IJCRT, Volume 10, Issue 7 ,2022.

This paper proposes a vehicle accidental monitoring system using MEMS, GPS, and GSM technologies. The system uses accelerometers, MCUs, GPS, and GSM modules to detect falls and accidents. Threshold Algorithms detect accidents, while short-messages contain GPS coordinates for vehicle location. This system helps in securing personal and public vehicles.

Dr. Ramanna Havinal et al., "Vehicle accident prevention and alert system" IJCRT | Volume 10, Issue 7 ,2022.

The increasing use of vehicles increases the hazards associated with accidents, including high speed, drunk driving, distractions, stress, and electronic gadgets. This paper introduces an accident detection system that alerts drivers if they are not in control of the vehicle and sends information to registered mobile numbers. The system uses various components to detect accidents, alerting the rescue team in time, and ensuring efficient automatic accident detection.

Khaled Shaaban et al., "Intelligent Transportation Systems in a Developing Country: Benefits and Challenges of Implementation" Transportation Research Procedia, Elsevier,2021.

This paper discusses the implementation of intelligent transportation systems (ITS) in Qatar, a developing country in the Middle East. The paper reviews existing and proposed ITS technologies and identifies challenges such as coordination with stakeholders, adopting different countries' ITS systems, keeping up with technology, and budget constraints. The paper provides lessons learned for other developing countries undergoing similar transitions.

Pranav Patil et al., "Accident Detection and Alert System using Accelerometer" IJARSCT, Volume 6, Issue 1, 2021.

As population increases, accidents due to poor driving behaviors like speeding, drunk driving, and lack of sleep result in fatalities. The critical time between accidents and medical help can be life-saving. To address this, a wireless system using accelerometers, GPS, and GSM is being developed for accident detection and reporting. The system sends automated messages to police and family members, providing information on accident location and personal profiles, enabling timely assistance and identification of victims.

Gap of Analysis

While several technologies and systems exist for vehicle safety, there are notable gaps and limitations that necessitate further research and innovation. The Accident Detection and Alert System seeks to address the following key gaps identified in the existing literature and real-world practices:

- **Lack of Automation**: Many existing systems rely on manual reporting of accidents, which causes significant delays in emergency response, especially if the victim is unconscious or unable to communicate.
- **Absence of Real-Time Alerts**: Some accident detection systems lack real-time notification capabilities, resulting in longer response times from emergency services.
- **Limited Integration of GPS and GSM**: Though GPS and GSM technologies are widely available, their integration into accident detection systems has not been fully optimized in many current solutions, especially in low-cost or compact setups.
- **High Cost of Commercial Solutions**: Many available systems are expensive and not accessible to individual vehicle owners or in developing regions where cost is a critical factor.
- **False Positives/Negatives**: Existing systems may produce inaccurate accident detections, such as triggering alerts during rough road conditions or failing to detect low-impact accidents, affecting the system's reliability.
- **Lack of Adaptability**: Most systems are not flexible or adaptable for different types of vehicles (e.g., two-wheelers, public buses, private cars), limiting their overall usability and scalability.

Addressing the Gap

This study addresses the above gaps by developing a low-cost, automated system that integrates accelerometer/gyroscope, GPS, and GSM modules to accurately detect accidents and immediately alert emergency contacts. It focuses on real-time, reliable detection, location tracking, and quick communication, making it practical and scalable for diverse applications.

RESEARCH METHODOLOGY

Block Diagram

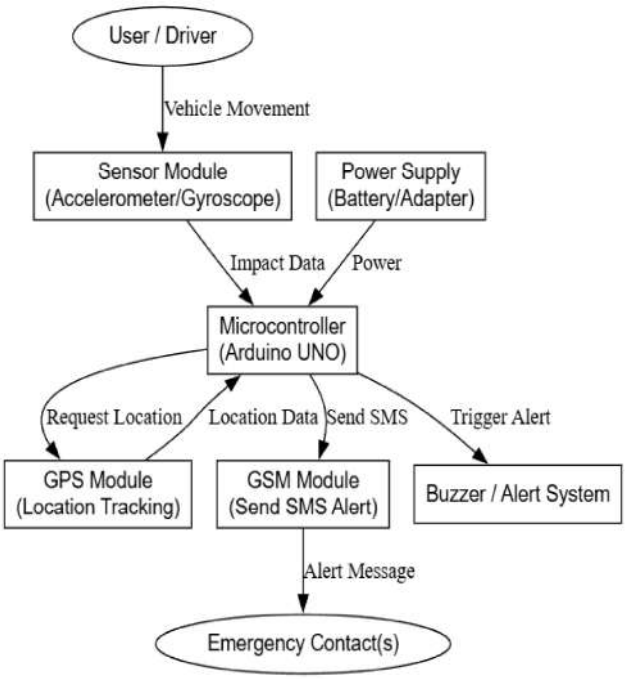


Figure 1.1: Block Diagram

Hardware Components

Microcontroller ESP32: A microcontroller board based on the ATmega328P.

- Role: Acts as the central processing unit for the system.
- Functions:
- Receives data from the accelerometer/gyroscope sensor.
- Processes the data to determine if an accident has occurred.
- Controls communication with the GPS and GSM modules.
- Features:14 digital input/output pins.
- 6 analog input pins.
- USB connectivity and 5V power regulation.
- Why Used: Affordable, easy to program, and widely supported for IoT and embedded projects.



Figure 1.2: ESP32

Accelerometer/Gyroscope (e.g., MPU6050)

Description: A 6-axis motion tracking device combining a 3-axis gyroscope and a 3-axis accelerometer.

Role: Detects acceleration and angular velocity.
Functions: Measures sudden jerks, orientation shifts, and rollovers.
Helps detect the instant of an accident through motion thresholds.
Interface: I2C communication protocol.
Why Used: High accuracy for motion detection, compact, and suitable for real-time impact monitoring.

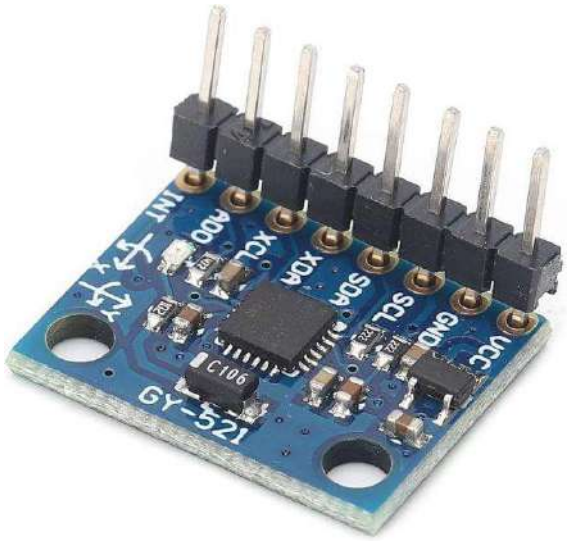


Figure 1.3: Accelerometer/Gyroscope (e.g., MPU6050)

GPS Module (e.g., NEO-6M)

Description: A GPS receiver that provides global location coordinates.

Role: Captures the real-time geographic location (latitude and longitude) of the vehicle.
Functions: Provides location data after detecting an accident.
Sends coordinates to the Arduino for alert transmission.
Interface: Serial (UART).
Why Used: Reliable, low-power, and fast fix on GPS satellites.



Figure 1.4: GPS Module (e.g., NEO-6M)

GSM Module (e.g., SIM800L/SIM900)

Description: A module that enables GSM-based communication via a SIM card.

Role: Sends SMS alerts to preconfigured emergency contacts.
Functions: Transmits messages containing accident alert and GPS coordinates.
Can also be used to receive commands if two-way communication is implemented.
Interface: Serial (UART).
Why Used: Compatible with lobal GSM networks, low-cost SMS communication solution.

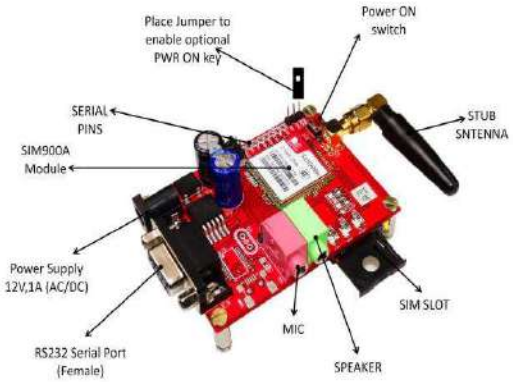


Figure 1.5: GSM Module (e.g., SIM800L/SIM900)

Power Supply (Battery or Adapter)

Description: Provides regulated voltage and current for the system.
Role: Powers all electronic components, ensuring stability and uptime.

Options: 9V battery with voltage regulator.
Power adapter (DC 9V/12V).
Why Used: Essential for standalone or mobile use where continuous power is required.



Figure 1.6: Power Supply

Buzzer (Optional)

Description: An electronic component that emits sound when powered.
Role: Acts as a local alert system.
Functions: Notifies nearby individuals immediately after an accident is detected.
Why Used: Simple and effective for audi indication; enhances local awareness.

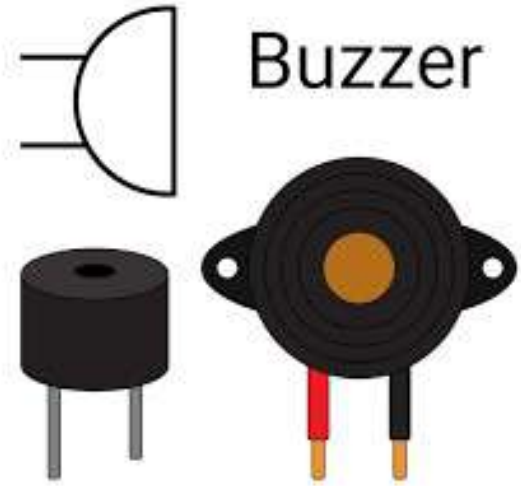


Figure 1.7: Buzzer

Connecting Wires & PCB / Breadboard

Connecting Wires: Used to establish electrical connections between components.

Breadboard/PCB: Platform for assembling the components without soldering (breadboard) or for permanent setup (PCB).
Role: Physical framework for integrating the circuit.
Why Used: Ensures reliable connections and ease of testing/debugging.

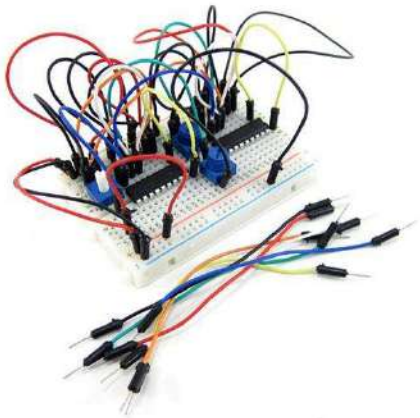


Figure 1.8: Wires & PCB / Breadboard

CONCLUSION

This chapter summarizes the key findings and insights from the development and testing of the Accident Detection and Alert System. The system successfully integrates hardware components like the MPU6050 sensor, GPS module, GSM module, and Arduino UNO to detect accidents and send real-time alerts to emergency services and the user.

The system's effectiveness in accident detection and location tracking is established, showcasing the potential to significantly improve emergency response times and road safety. By providing timely alerts, the system has the capacity to reduce fatalities and injuries caused by delayed emergency responses.

However, the system's reliability may be influenced by factors such as GPS signal strength in urban areas and the dependency on GSM network availability. Despite these limitations, the system provides an innovative solution for enhancing vehicle safety.

In future work, improvements can be made in sensor accuracy, GPS reliability, and network coverage to further enhance the system's performance and applicability in real-world scenarios.

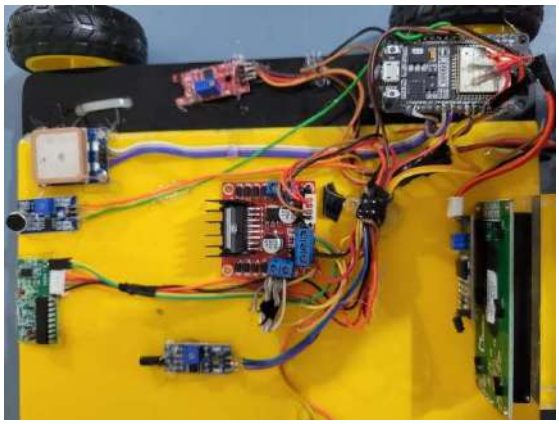
Future Scope

1. Connects to smart traffic management and emergency dispatch systems for faster rescue operations.
2. Provides real-time status updates, accident history, and location tracking.
3. Uses machine learning algorithms to distinguish between actual accidents and false positives.
4. Stores incident data on the cloud for better data analysis and retrieval.
5. Supports Vehicle-to-Vehicle (V2V) communication to warn nearby vehicles of accidents.
6. Includes voice-based emergency assistance for post-accident support.
7. Provides battery backup and solar power for long-term reliability.
8. Improves global positioning accuracy using multi-constellation GNSS.

Applications

1. **Private Vehicles**: Automatically alerts emergency contacts and services during an accident.
2. **Public Transport**: Ensures passenger safety by providing immediate incident reporting.
3. **Fleet Management**: Helps logistics companies monitor and respond to vehicle accidents in real-time.
4. **Emergency Response Systems**: Assists police, ambulance, and fire services with accurate location data.
5. **Insurance Sector**: Aids in verifying accidents for faster and more reliable claims processing.
6. **Smart City Integration**: Supports traffic monitoring and accident management in intelligent transportation systems.
7. **Educational Use**: Acts as a practical project for students to learn IoT, sensor integration, and real-time communication.

Model Photos



ACKNOWLEDGEMENT

It gives me an immense pleasure and satisfaction to present this Research Paper on **"Vehicle Black Box for Accident Prevention"** which is the result of unwavering support, expert guidance and focused direction of my guide Dr. Priti Shende and Project coordinator Dr. Nilakshee Rajule, to whom I express my deep sense of gratitude and humble thanks to Dr. D. G. Bhalke, H.O.D. for his valuable guidance throughout the presentation work. The success of this Research Paper has throughout depended upon an exact blend of hard work and unending co-operation and guidance, extended to me by the supervisors at our college. Further I am indebted to our principal Dr. Nitin Sherje whose constant encouragement and motivation inspired me to do my best.

Last but not the least, I sincerely thank to my colleagues, the staff and all other who directly or indirectly helped me and made numerous suggestions which have surely improved the quality of my work.

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Early Parkinson's Disease Identification Through Machine Learning Techniques

Prof.Poonam S. Gham[1] Dr. Rajendra G. Zope[2] Dr. Sanjaykumar I. Nipanikar[3]
poonamgham.kjcoemr@kjei.edu.in rajendrazope.kjcoemr@kjei.edu.in sanjaynipanikar99@gmail.com,

[1]Assistant Professor [2] Associate Professor [3]Associate Professor

[1,2] Dept. of Electronics and Telecommunication Engineering
KJ College of Engineering and Management Research, Pune
Savitribai Phule Pune University, Pune

[3] Dept. of Electronics and Telecommunication Engineering
SOES, MIT-ADT, Pune

Abstract –

Parkinson's disease is a degenerative neurological condition that affects millions of individuals globally. Early discovery is essential for effective treatment and care. Machine learning algorithms can be used to identify patterns and biomarkers for early diagnosis. Applying machine learning algorithms to data from imaging, genomics, wearable sensors, and clinical settings can improve accuracy and efficiency.

Parkinson's disease affects over 10 million individuals globally, with 24 out of 100,000 residing in India. The condition is expected to quadruple in prevalence by 2030. Machine learning can improve patient care and early detection strategies by analysing complex datasets and finding predictive biomarkers.

Keywords: Neurological condition, Machine Learning

I. INTRODUCTION

Millions of individuals throughout the world suffer with Parkinson's disease (PD), a progressive neurological illness. For prompt intervention and improved illness management, early PD identification is essential. Finding patterns and biomarkers that can help with the early identification of Parkinson's disease (PD) has been made possible by machine learning (ML) approaches. The accuracy and effectiveness of early detection techniques may be increased by utilizing machine learning (ML) algorithms on a variety of data sources, such as clinical, genetic, imaging, and wearable sensor data. The symptoms of Parkinson's Disease are illustrated in Figure 1.

One neurodegenerative condition that mostly impairs movement is Parkinson's disease. It is typified by symptoms like stiffness, tremors, and trouble balancing and coordinating. Over time, these symptoms worsen, making patients' problems more severe. For PD to be successfully treated, early diagnosis and identification are essential.

Although PD is mostly unknown, there are instances when it is caused by genetic factors. Over 10 million people worldwide suffer from this illness, and in India, about 24 out of 100,000 people have Parkinson's disease. Parkinson's disease is expected to affect more than twice as many people by 2030, and the number is increasing every day.



Figure 1 Symptoms of Parkinson's Disease

Machine learning research on Parkinson's disease early detection has enormous potential to enhance clinical results, further scientific knowledge, and eventually lessen the burden of this crippling neurodegenerative condition. Researchers and healthcare professionals can transform early detection techniques and improve patient care for individuals by utilizing machine learning algorithms to analyse complex datasets and find predictive biomarkers.

II. RELATED WORK

A survey by A. Valli and Dr. G. Wiselin Jiji (2014). Here accurate diagnosis of PD and number of wrong decisions gets reduced with the help of CAD and diagnosis algorithms. Extracting features and selecting appropriate features will yield good classification results methodology was used. Key findings are Parkinson's disease caused by reduction of dopamine in nerve terminals and reduction cannot be diagnosed easily. Up to date there is no treatment, blood test to finding this disease. [10]

Algorithm for image-based biomarker detection for differential diagnosis of Parkinson's disease by Gurpreet Singh∗, Lakshminarayanan Samavedham ∗* (2015).

Methodology Steps:

i. pre-processed brain Magnetic Resonance Images (MRI) are modelled using Self Organizing Map (SOM) for feature generation.
ii. Fisher-Discriminant Ratio (FDR) is used to reveal distinctive feature(s).
iii. Least Squares Support Vector Machine (LS-SVM) is used for Individual-level patient classification

For differential diagnosis of PD, the classification accuracy of up to 97% . [2]

Srishti Grover, et.al (2018). Methodology used is The prediction of Parkinson's disease severity using deep neural networks on UCI's Parkinson's Telemonitoring Voice Data Set of patients. They have used the 'Tensor Flow' deep learning library of python to implement our neural network for predicting the severity. A deep neural network is used to forecast the severity of Parkinson's disease based on key data. The accuracy of the suggested DNN model was higher than that of other methods currently in use. [8]

Diagnosis of Parkinson's disease using Gait Dynamics and ages by Nancy Noella R S* Divyansh Gupta Priyadarshini J (2019). PARAFAC + Tucker Decomposition (Proposed) here. Key findings are PD subjects less time and good accuracy. Proposed method give 97%accuracy [7]

The suggested method by Hadeel Ahmed Abd El Aal et al. (2021) is used with two benchmark datasets of speech characteristics for PD patients and healthy control people. It obtained a 95.8% accuracy rate [6]

Machine Learning Techniques for Voice-based Early Detection of Parkinson's Disease by Audil Hussain Dr. Amit Sharma (2022). Various machine learning methods are applied to UCI Machine Learning repository has the dataset dataset, and the performance of each method. Key findings are stacking different learning models together works best for the given task with an accuracy of 93% [5]

Govindua Aditi et al. (2023) Four ML models have been trained using MDVP audio data from 30 PWP and healthy individuals. The Random Forest classifier is the best Machine Learning (ML) method for PD identification, according to a comparison of classification results using Support Vector Machine (SVM), Random Forest, K-Nearest Neighbours (KNN), and Logistic Regression models. Important results show that the Random Forest classifier model has a sensitivity of 0.95 and a detection accuracy of 91.83%. [4]

A fully automated approach involving neuroimaging and deep learning for Parkinsons disease detection and severity prediction by Çaatay Berke Erdas and Emre Sümer (2023). The median slices of the axial, coronal, and sagittal MR images were utilized both singly and in combination for 2D CNN.. Key findings are the highest results achieved for detecting Parkinsons disease were measured as 0.9620, 0.9452, 0.9407, and 0.9536 for Accuracy, F1 score, precision, and Recall, respectively. [8]

Soman Karthik et al. (2023) developed patient embedding vectors and integrated patient EHR data onto the Scalable Precision Medicine Open Knowledge Engine (SPOKE), a biological knowledge network, in order to predict PD diagnosis. Key findings include a moderately accurate identification of Parkinson's disease. . [2]

The Python language and Google Colab environment are used in Raya Alshammri et al.'s (2023) suggested method to determine if a patient has Parkinson's disease. The approach of the proposed model consists of six steps: feature selection, data pre-processing, the Synthetic Minority Over-Sampling Technique (SMOTE), hyperparameter tuning (Research), machine and deep learning classification models, and performance evaluation. The results of these approaches (SVM 95% and MLP 98.31%) are more accurate than those of previous research [1]

Now a day's Image processing technology is mainly focus on the automation for classifying different categories in medical (diagnosis of diseases) agricultural (categorizi ng pests) weather forecasting fields etc. We are mainly focus on the diagnosis of PD (a kind of dementia) to assist a doctor or a better treatment. Different works based on the image processing technology or detecting the presence of Parkinson's disease is discussed below: Here "Ultrasound medical image recognition with artificial intelligence or Parkinson's disease classification, Aprajita, used component extraction and unsupervised bunching procedures in images. They used a self-sorting out guide (S) algorithm or grouping the pixels to recognized classes that distinguished classes are Normal or PD. Parkinsons ailment gets determined in cerebrum stem portion with the help of Clustering method.

The main advantage is that by using the Neuro fuzzy approach with SOM overcomes the limitation of Artificial Neural Network. [11]

Regional brain stem Anatomical MRI reveals atrophy in idiopathic Parkinson's disease. Prashant exemplified the current neuro-imaging techniques, such as the use of Single Photon Emission Computed Tomography (SPECT) for dopaminergic imaging. They discovered the illness in its early stages. The Striatal Restricting Qualities (SB) that were determined from Parkinson's (PP) database were used. SV grouping determined if the individual has Parkinson's disease [12]

Parkinsons disease motor symptoms in machine learning: a review Shaohua Wan, proposed a deep multi-layer Perceptron (D P) or the behaviour analysis to estimate the progression of PD using cell phones. The behavioural information is gathered with cell phones and physically marked as sitting, standing, and walking activities or accelerometers and gyroscopes. Butter worth lo-pass filter is

used to denoise and standardize the data. At long last the component vector made out of include values as utilized as preparing information. Deep learning is applied here or the classification of single person behaviour activity movement gathered from cell phones to PD or healthy case. [13]

A Deep Multi-Layer Perceptron Classifier for Behaviour Analysis to Assess Parkinson's Disease Severity Using Smartphones He-Hua Zhang proposed a grouping method that uses the multi-edit nearest neighbour (MENN) algorithm in conjunction with an ensemble learning methodology. To continue creating conversation tests repeatedly, the NN algorithm is connected. In group learning computations, prepared samples are produced from the gathered preliminary tests using random forests, decorrelated neural networks, or ensembles (DNNEs). In conclusion, the generated group learning algorithms are connected to the test samples or PD characterization. This proposed approach was analysed and compared with other methods or validation using publically accessible datasets. [14]

III. RESEARCH SCOPE

This study focuses on the application of machine learning techniques to facilitate the early detection of Parkinson's Disease by analysing relevant biomedical and clinical data. The research aims to explore and evaluate various machine learning models for their effectiveness in identifying early-stage Parkinson's symptoms, thereby assisting in timely diagnosis and intervention. The scope includes data preprocessing, feature selection, model training and validation using datasets related to Parkinson's Disease, with the goal of improving diagnostic accuracy and reducing misdiagnosis. This work does not involve clinical trials or medical diagnosis, but rather concentrates on the computational and analytical aspects of disease prediction using existing datasets. The study is limited to supervised learning techniques and publicly available data sources and does not cover treatment or progression monitoring of the disease.

Data Collection and Pre-processing:

•Collecting pertinent data from wearable sensors, neuroimaging scans, clinical records, genetic information, and people with Parkinson's disease and healthy controls.

• Data pre-processing for feature extraction, noise reduction, normalization, and missing values.

Feature Selection and Engineering:

•Determining the dataset's informative elements that are pertinent to differentiating between people with Parkinson's disease and healthy people.

• Creating new features or altering current ones to improve the machine learning models' capacity for prediction.

Machine Learning Model Development:

• Investigating different machine learning algorithms for categorization, including ensemble methods, random forests, neural networks, and support vector machines.

Using the information gathered, machine learning models are trained and optimized to forecast the occurrence of Parkinson's disease.

•Using metrics like accuracy, sensitivity, specificity, and area under the ROC curve to assess how well various models perform.

IV. SUMMARY OF LITERATURE REVIEW

A survey by A. Valli and Dr. G. Wiselin Jiji in 2014 emphasizes the role of computer-aided diagnosis (CAD) in decreasing errors in diagnosing Parkinson's disease (PD), which is hard to identify due to low dopamine levels and the lack of effective treatments or blood tests.

Research by Gurpreet Singh and Lakshminarayanan Samavedham in 2015 developed an algorithm for detecting PD biomarkers using MRI, achieving 97% accuracy. Srishti Grover and colleagues in 2018 used deep neural networks on voice data, showing improved accuracy in predicting PD severity.

In 2019, Nancy Noella R S and her team assessed PD through Gait Dynamics with 97% accuracy. Recent studies in 2023 varied in approach, using audio data and machine learning models to achieve accuracies between 91.83% and 98.31%. Additionally, image processing technologies, such as MRI and ultrasound recognition methods, were discussed as beneficial for medical diagnostics in PD. Other advancements include assessing PD motor symptoms using smartphone data and new classification methods.

V. CONCLUSION

The review highlights the growing significance of machine learning (ML) techniques in the early detection of Parkinson's Disease (PD). The integration of emerging technologies such as AI, deep learning, and various algorithms presents a promising future for Parkinson's Disease diagnosis. These methodologies aim to improve early detection and enhance treatment options, which can greatly benefit patient care and management. Continued research and development in these areas are crucial for advancing PD healthcare. Overall, machine learning holds great potential in revolutionizing the early diagnosis of Parkinson's Disease, enabling timely interventions and improved patient outcomes.

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Development of an IoT-Enabled Hybrid Architecture for Smart Cloth Drying

Dr[1]. Pramod Chavan, [2] Divya Chakor, [3] Naved Shaikh, [4] Atharva Kadam

dr.pu.chavan@gmail.com, divyachakor01@gmail.com, navedshaikh9860@gmail.com,

kadamatharva2626@gmail.com

[1,2,3,4] *Department of Electronics and Telecommunication Engineering,*

KJ College of Engineering and Management Research, Pune 411 048, Maharashtra, India.
Savitribai Phule Pune University, Pune

Abstract

This paper presents an IoT enabled cloth drying machine that enhances the drying process through smart automation and remote accessibility. The system features Wi-Fi-enabled controls, including a motorized drying pole, heating rods, exhaust fans, UV lights, and an LED bulb. With the help of a Flutter-based mobile application, users can remotely control and monitor the system, providing real-time scheduling and control. For improved hygiene, the authors want to develop a drying system that is weather-independent, energy-efficient, and UV sterilized. Compared to conventional techniques, the technology optimizes power consumption and cuts down on drying time by utilizing intelligent scheduling and cloud-based analytics. Performance reviews prove to its efficiency in lowering down on energy waste, enhancing drying effectiveness, and improving user convenience.

1. Introduction

The incorporation of Internet of Things (IoT) technology in home automation has revolutionized household appliances by enhancing convenience, efficiency, and energy management. Conventional cloth drying methods rely on favorable weather conditions and manual effort, emphasizing the need for an automated alternative. This study introduces the development and implementation of an IoT-enabled cloth drying system utilizing an ESP32S microcontroller and a mobile application. The system streamlines the drying process by integrating motorized drying poles, heating elements, exhaust fans, UV lights, and real-time energy monitoring.

Operated through a Flutter-based mobile application, users can remotely control, schedule, and track drying cycles. The ESP32S microcontroller coordinates all components via a 4-channel relay module while continuously recording energy consumption through built-in sensors, promoting efficiency and sustainability. This paper delves into the system's technical framework, software architecture, and practical application.

1.1 Background

Traditional clothes drying methods, like sun drying and electric dryers, have limitations such as weather dependency and high energy consumption. Sun drying is ineffective in humid or rainy conditions, while electric dryers are costly and lack smart features. With the rise of home automation, IoT technology offers an efficient solution by enabling remote control, energy monitoring, and fabric sanitization. Smart drying systems enhance convenience, optimize energy use, and improve performance, making them a valuable addition to modern households.

1.2 Proposed Approach

This study introduces an IoT-enabled cloth drying system managed by an ESP32S microcontroller, incorporating a motorized drying pole, heating components, exhaust fans, and UV lights. A Flutter-based mobile application facilitates real-time monitoring, scheduling, and energy management.
The proposed system provides several key benefits:

- **Automated Drying Process:** Maintains ideal drying conditions by controlling temperature and airflow.
- **Remote Access & Control:** Allows users to manage and oversee the drying system through a mobile application.
- **Energy Efficiency:** Smart scheduling and real-time energy monitoring help minimize power consumption.
- **UV Sterilization:** Integrated UV lights eliminate bacteria and odours, promoting hygiene.
- **Advanced Safety Features:** Equipped with automatic shutdown and overheat protection for enhanced safety.

ISBN: 978-93-343-2006-0

This innovative solution will provide a weather-independent drying solution, improving convenience, energy efficiency, and hygiene compared to conventional methods.

2. Literature Survey

This paper examines current cloth drying technologies, highlighting their limitations and exploring how IoT-based automation can enhance efficiency, energy savings, and user convenience. Previous research has explored traditional drying techniques, energy-efficient electric dryers, and smart drying innovations. P.R. Gaikwad et al. (2023) investigated the design and development of a clothes drying machine featuring a compact enclosed box structure. This machine provides a good solution for efficient and fast drying while ensuring space optimization and easy to use. Conventional air-drying methods can be time-consuming, particularly in areas with limited space or adverse weather conditions. Obanoyen and Akinola (2023) examined mechanical cloth dryers and highlighted the inefficiencies of traditional drying methods, particularly their reliance on weather conditions. While sun drying remains energy-efficient, it is impractical in humid or rainy climates. Electric dryers, although faster, consume significant electricity and may cause fabric shrinkage due to excessive heat exposure. Yadav and Moon (2022) studied fabric drying in domestic dryers and emphasized the role of airflow management in improving drying uniformity. Inefficient air circulation leads to longer drying times and increased power consumption. To overcome these challenges, the proposed system incorporates controlled heating elements and exhaust fans to enhance airflow. Dymond et al. (2021) investigated energy consumption in electric dryers, highlighting that inefficient design and the absence of smart energy management lead to excessive power usage. Their findings emphasize the importance of real-time energy monitoring, which this study addresses by integrating a power consumption logger to optimize drying cycles. Quick Portable Cloth Drying Machine by Sachin B.B, Sanjay B, Shiva Murthy (2019) has designed a cloth drying system to use in all seasons. However, modern conventional electric dryers are often costly and inefficient. To lower the risk of clothes getting dirty and keep the fabric sanitized, laundries now uses drying cabinets. The aim is to innovate the cloth drying process by enhancing the modern spinning concept. Kalyankar et al. (2018) investigated temperature and humidity-controlled drying but lacked remote control and sterilization capabilities. Building at this, the proposed system is integrated with ESP32S-based IoT connectivity for mobile app control, UV sterilization to eliminate the bacteria, and real-time energy tracking for improved efficiency. Despite advancements in drying technology, challenges persist in smart energy optimization, remote accessibility, and fabric sanitization. This study addresses these issues by developing an IoT-enabled automated drying system featuring remote control, UV sterilization, and real-time energy monitoring, thereby enhancing efficiency and sustainability in home automation.

3. Methodology

This section describes the design, development, and implementation of the IoT-enabled automated cloth drying system, divided into two key phases: Hardware Architecture and Software Architecture

3.1 Hardware Architecture

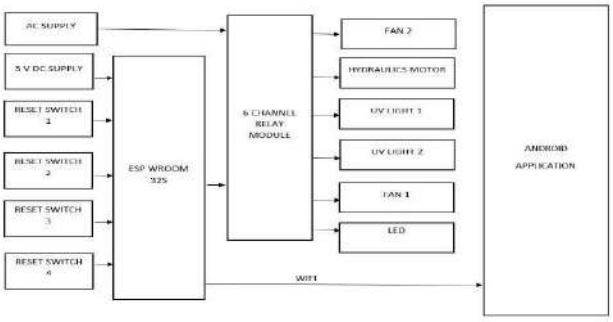


Figure 3.1 Block Diagram

The proposed system automates the drying process by incorporating heating, ventilation, and UV sterilization. At its core, the ESP32S microcontroller serves as the central control unit, processing real-time data and executing commands received from a Flutter-based mobile application. The hardware architecture is built with ESP32S microcontroller, which connects to a 4-channel relay module to manage the important components like motorized drying pole, heating rods, UV lights, exhaust fans, and an LED light. A 125W motor provides vertical adjustment of the drying poles, optimizing space utilization. The drying machine comes with two 150W heating rods and two 30W exhaust fans, working together for drying clothes efficiently. Two 3W UV lights ensure sterilization, while a 15W LED bulb provides illumination in low-light conditions. To improve energy efficiency, the system features a power consumption logger (SCT-013) that

ISBN: 978-93-343-2006-0

continuously monitors real-time energy usage and transmits the data to the cloud for analysis. The entire system operates on an AC power supply, with reset switches incorporated for troubleshooting and maintenance.

3.2 Software Architecture

The software architecture of the cloth drying system is designed to facilitate seamless interaction between hardware components and users through an intuitive mobile application. The ESP32S microcontroller serves as the central processing unit, receiving and executing user commands sent via Wi-Fi from a Flutter-based mobile app.

Embedded Firmware (ESP32S)

The ESP32S microcontroller's embedded firmware, developed using Arduino IDE, enables smooth communication with the mobile application over Wi-Fi. It interprets user commands and operates the relay module to manage key system components, including the motorized drying pole, heating rods, exhaust fans, UV lights, and LED bulb. Additionally, the firmware continuously monitors real-time power consumption, records the data, and transmits it to the cloud for analysis. This provides system efficiency, optimizes energy use, and enables remote access for users.

Mobile Application (Flutter & Dart)

Developed using Flutter and Dart, the mobile application offers a user-friendly interface for remotely managing the drying system. Users can start or stop system, modify some settings, and schedule drying cycles as per their convenience. The app provides real-time updates on system status, drying progress, and power consumption, keeping users informed about performance. The stable Wi-Fi connection with the ESP32S microcontroller enables seamless data exchange, efficient operation, and remote monitoring. This software framework improves automation, accessibility, and real-time monitoring, enhancing the system's functionality and user experience.

1. **Start –** ESP32S turns on and connects to Wi-Fi.
2. **Receive Command** – The system waits for input from the mobile application.
3. **Process Command –** Perform action based on command:
   - Turn fan on/off.
   - Turn UV light on/off.
   - Move drying poles up/down.
   - Turn LED light on/off.

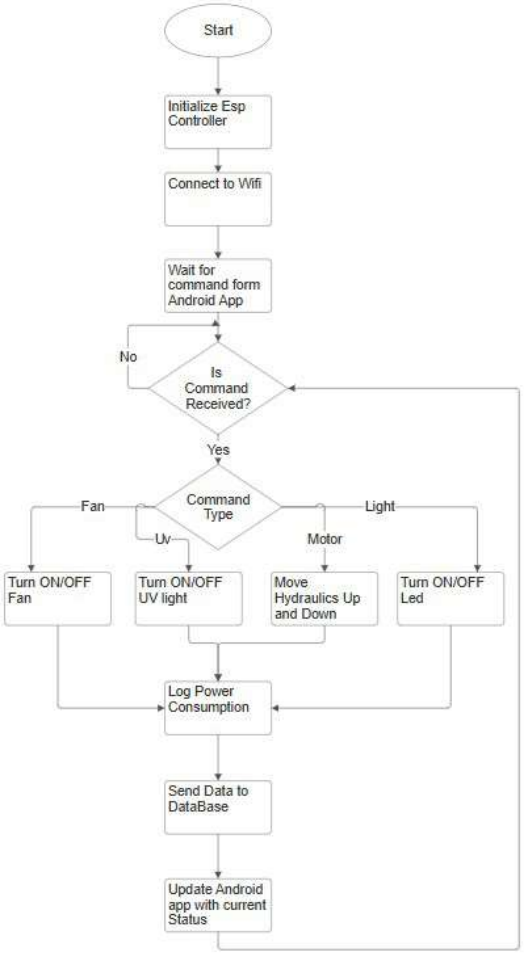


Figure 3.2 System Flow

4. **Monitor Power –** Record power usage.
5. **Send Data –** Uploads power usage data to the cloud.
6. **Update App –** Show current system status in the mobile app.

The IoT-enabled cloth drying system integrates hardware, software, and cloud-based monitoring to ensure seamless automation and efficiency. The ESP32S microcontroller functions as the central control unit, interfacing with a 4-channel relay module to manage components such as the motorized drying pole, heating rods, exhaust fans, UV lights, and LED bulb. A power consumption logger, SCT-013, is integrated to monitor real-time energy usage and transmit data to the cloud for analysis. The Flutter-based mobile application enables users to remotely control and monitor the drying process by sending commands via Wi-Fi, which the ESP32S

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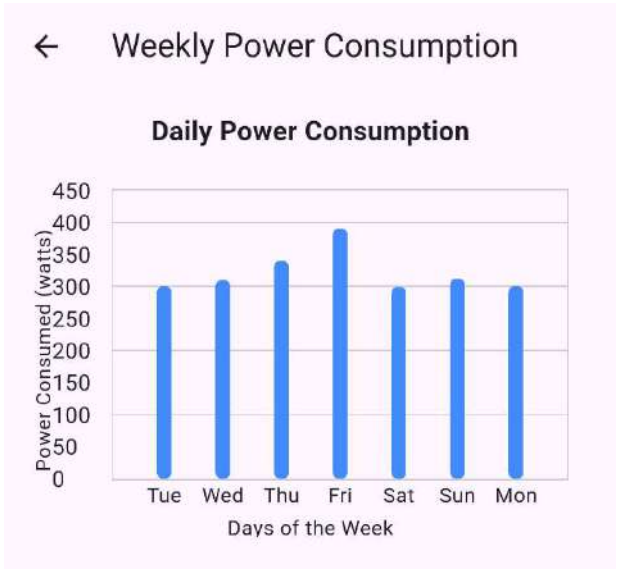
processes to activate or deactivate system components. Additionally, real-time energy consumption data is logged and stored in a cloud database, allowing users to analyze usage patterns and optimize drying efficiency. The system's Wi-Fi connectivity ensures seamless communication between the mobile app, microcontroller, and cloud storage, making it a smart, energy-efficient, and user-friendly solution for automated cloth drying.

4. Experimentation and Results



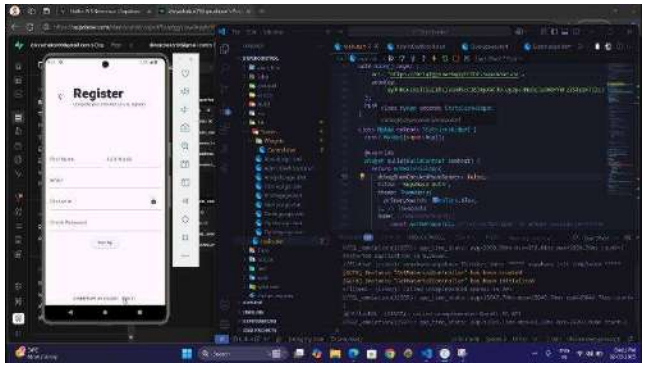
5.

The IoT-based smart cloth drying machine mobile application was built using Flutter and Supabase. The emulator displays a registration screen, while VS Code showcases the project structure and Supabase authentication configuration. The main.dart file initializes the app, and the debug console confirms successful Supabase integration. This setup ensures secure user authentication and smooth operation of the drying system.



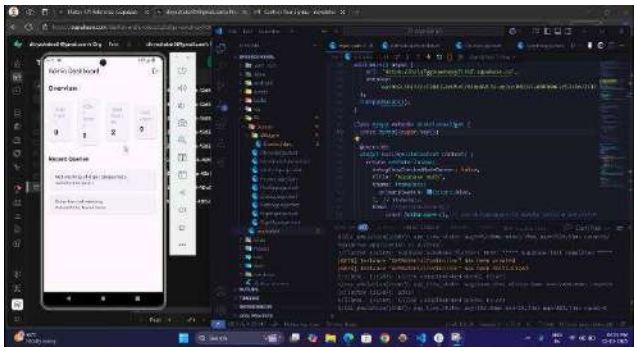
The above figure shows a Weekly Power Consumption graph for the IoT-based cloth drying machine. The bar chart represents daily power usage (in units) across different days of the week. The highest consumption is observed on Saturday and Monday, while other days show relatively consistent usage. This data helps in optimizing energy efficiency and scheduling drying cycles effectively.

User Registration



The figure showcases a Flutter-based mobile app integrated with Supabase for user authentication and backend services. The registration screen allows secure account creation, while the Dart code in VS Code initializes Supabase authentication and UI components. Debug logs confirm successful integration, with ongoing optimizations. This setup enables a cloud-connected IoT solution, managing the ESP32S-powered cloth drying system efficiently.

Admin Dashboard



The figure showcases the Admin Dashboard of the Flutter-powered cloth drying system integrated with Supabase. The dashboard provides an overview of system statistics, including total dryers, active dryers, total queries, and users. It also displays recent user queries, enabling efficient issue tracking and system monitoring.

5. Contribution

The paper denotes an IOT-based automated cloth drying machine which offers a smart energy-efficient and user friendly rather than traditional drying

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methods. The system is built using ESP32S microcontroller which is integrated with components such as heating rods, UV light, motorized poles, exhaust fans, and LED light to ensure effective drying and illumination. A flutter based mobile application helps the users to control the dryer machine remotely and monitor the machine. It also provides real time update and status of the dryer machine to the user. Also the integration of power consumption sensors that is SCT-013 allows real-time tracking of energy consumed, with data stored on cloud for analysis. The inclusions of UV sterilization ensures hygienic drying while automated control and scheduling. It also improves efficiency and reduce manual effort making the system independent of weather conditions. Overall the paper contributes to growing field of smart home technologies by enhancing daily utilities with intelligent automation and energy optimization.

6. Conclusion

The study represents the design and implementation of an IoT-enabled cloth drying machine controlled through an ESP32S microcontroller and a Flutter-based mobile application. The system is built using ESP32S microcontroller which is integrated with components such as heating rods, UV light, motorized poles, exhaust fans, and LED light to ensure effective drying and illumination. The proposed solution offers weather-independent, energy efficient and user friendly alternative to the traditional drying methods by leveraging the remote control, automation and energy tracking. The paper also contributes to the advancement of smart home appliances by promoting innovation in household automations. The overall output of the project evaluation indicates the reduction of system drying time and enhances hygiene through UV sterilization and optimizes energy consumption using smart scheduling and cloud based analytics. The ability of the application to monitor and control the dryer machine improves the user convenience and this also opens it to a home automation and laundry management.

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ISBN: 978-93-343-2006-0

IOT BASED ELECTRICITY ENERGY METER

Vivek Ghanekar
Associate Professor
dept. Electronics and Telecommunication Engineering
KJ college of engineering and management research pune
Savitribai phule pune University Pune, India

Avishkar Sawant
dept. Electronics and Telecommunication Engineering
KJ college of engineering and management research pune
Savitribai phule pune University Pune, India

Anisha Jagdale
dept. Electronics and Telecommunication Engineering
KJ college of engineering and management research pune
Savitribai phule pune University Pune, India

Saniya Jangam
dept. Electronics and Telecommunication Engineering
KJ college of engineering and management research pune
Savitribai phule pune University Pune, India

***Abstract*—IoT-Based Smart Energy Meter based on ESP32 transforms monitoring of electricity through the use of real-time data communication and IoT technology. Based on the ESP32 microcontroller, which has low power requirements and an embedded Wi-Fi and Bluetooth feature, the smart meter gathers electricity consumption data using sensors and communication modules. The information is relayed in real time to a web interface or mobile application, enabling users to keep track of their energy usage. With the ability to measure current and voltage, the system offers precise information on energy usage patterns and enables users to spot wasteful habits and cut down on wastage. This does not just reduce electricity bills but also ensures sustainable use of energy. The easy-to-use interface eases interpretation of the data, becoming accessible to users who are non-technical as well. The IoT-based smart meter enables energy consumption tracking and analysis with the required precision to facilitate smart cities and green living. It facilitates global efforts at maximizing energy use, minimizing carbon footprints, and increasing the efficiency of the resources. The incorporation of IoT provides uninterrupted connectivity and remote access, which makes it an efficient choice for contemporary homes and businesses. The smart energy meter driven by ESP32 brings cutting-edge technology, energy efficiency, and convenience, a complete tool for optimizing energy consumption in the age of smart living.**

Keywords: IoT-Based, Smart Energy Meter, ESP32, Real-time data communication, Built-in Wi-Fi & Bluetooth, Sensors

I. INTRODUCTION

Energy management plays a crucial role in reducing costs and conserving resources, making it an essential aspect of both residential and industrial settings. Traditional energy meters typically provide basic data on electricity consumption and require manual readings, which makes it difficult for users to track their energy usage effectively. Additionally, these meters do not offer real-time insights or automated features to help users manage their consumption efficiently.

An Internet of Things (IoT)-based smart energy meter, particularly one utilizing an ESP32 microcontroller, offers a modern solution to this problem. The ESP32 is a compact yet powerful device equipped with built-in Wi-Fi capabilities, which allows the smart meter to seamlessly connect to the internet. With this connectivity, users can monitor their energy consumption in real-time through their smartphones, computers, or other devices, providing them with up-to-date information regardless of their location.

This enhanced visibility into energy usage enables users to make informed decisions, set usage limits, and receive alerts when they are approaching or exceeding those limits. For instance, a homeowner can set a threshold to avoid unnecessary energy waste, while industries can optimize their energy usage for operational efficiency. By automating the process of tracking and controlling energy consumption, the IoT-based smart energy meter helps reduce waste, lower electricity bills, and contribute to overall energy conservation efforts. This system is particularly beneficial in smart homes and industrial environments, where energy efficiency is a growing priority.

II. PROBLEM STATEMENT

Managing energy consumption efficiently is a growing challenge in both residential and industrial sectors. Conventional energy meters only measure total consumption but lack advanced features such as real-time monitoring, remote access, and the ability to detectanomalies or optimize usage. This limitation prevents users from identifying energy wastage,predicting consumption trends, and making informed decisions about their energy usage.

III. RELATED WORK

The IoT smart energy meter utilizing ESP32 allows for real-time energy monitoring, prepaid refilling of units, and alerts for overuse of units. It has current and voltage sensor modules, ESP32 Wi-Fi module, and Blynk IoT application for remote control and monitoring. This system disconnects the power supply when the user runs out of units, allowing the user to be energy-efficient and pay lower electricity bills. [1]

ISBN: 978-93-343-2006-0

In the article "IoT-based Smart Meter Using Node-Red" a smart metering system using an Arduino microcontroller and Node-Red monitoring system allows the energy customer to monitor the energy usage; to share data among users; and to investigate potential theft of energy consumption. This multi-user metering provides rapidly accessible information in relation to automation, minimizes human errors, and remote access capabilities through IoT protocols for improved energy cost management, taking the consumption and costs associated with energy consumption down substantially. [2]

In the paper "Smart Energy Meter and Monitoring System using IoT," a smart energy meter is proposed through the use of IoT based on Arduino UNO and ESP8266. This meter provides instantaneous data measurements and also detects energy theft observed in the user's account. All readings provided by the meter are done automated, minimal human user intervention required, and remote data through Blynk software is provided to the user. User ability to improve energy management, reduce incorrect billing, and improve security with labour cost minimization is a significant improvement for user home or business. [3]

The research paper "Smart Energy Meter Design with Notifications and Over-Electric Energy Consumption Cut-off using ESP32 MCU Node and Blynk IoT" proposes the use of an IoT solution to monitor, notify and cut off electricity when it exceeds electrical consumption. The PZEM-004T sensor, ESP32, and Blynk are utilized to track energy consumption and notify users when set levels are being exceeded.[4]

The paper "Smart Meter Based on IoT Platform" proposes an IoT smart meter developed based on Arduino Mega and Blynk to monitor energy consumption and tampering in real-time, while data collection is performed automatically, billing accuracy is improved, and it provides the option to control the use of energy remotely. The biggest advantage is that it can monitor energy consumption in real-time while removing human error.[5]

The study "Internet of Things-based Smart Energy Meter with ESP32 Real-Time Data Monitoring" is based on an AWS and ESP32 smart energy meter that real-time monitor energy use. It monitors three-phase current, voltage, and power while the data is recorded, removing human error, and allows for observation remotely with an interface that is simple to use, and most likely could be used for industrial energy audits.[6]

The paper "Intrusive Energy Management with Advanced Smart Metering and Monitoring using IoT" is about an IoT-based Smart Energy Management System (SEMS) using advanced smart meters for real-time monitoring. It tracks energy consumption, provides two-way communication, and enhances efficiency through load scheduling, demand-side management, and precise monitoring of power consumption and losses. [7]

The paper "A Novel IoT-based Smart Energy Meter for Residential Energy Management in Smart Grid Infrastructure" proposes an IoT-based smart energy meter for real-time energy monitoring and optimization. It enables precise data collection, reduces human errors, and remote tracking of energy, increasing efficiency and ensuring smarter energy usage in homes. [8]

The paper "Design and Implementation of IoT-based Energy Management System with Data Acquisition" proposes an IoT-based system utilizing ARM controllers and GPRS for real-time monitoring. It acquires, transmits, and displays energy information on a web interface, which gives remote load control and improves energy efficiency through automated data collection and analysis. [9]

The research paper "IoT-Based Smart Energy Meter for Efficient Energy Utilization in Smart Grid" discusses a system that uses the ESP8266-12E to monitor energy in real-time, detect energy theft. The system enables two-way communications, uploads data to the cloud, reduces human error, and improves energy savings by providing the capability of remote monitoring and automatic control of energy consumption. [10]

The research paper "IoT-Based Smart Meter Using ESP32" discusses a three-phase smart meter for real-time energy monitoring and load shedding. It conducted the real-time monitoring service using an ESP32 microcontroller, current sensor and voltage sensor, and the Blynk IoT platform for many accurate data transmissions. The system can improve energy efficiency, save costs, and improve remote observation of energy within industrial and commercial settings. [11]

The research work "IoT-Based Smart Energy Meter Design and Implementation" presents a low-cost monitoring system based upon the ESP8266 Wi-Fi energy module that accurately measures energy in real-time. The research allows for the accurate monitoring of parameters such as voltage, current, and power. Data is transmitted through the system as energy is measured to web application, which increases the efficiency of energy use and reduces error while providing remote monitoring capabilities. [12]

The paper "Review on IoT-Based Smart Energy Management System" introduces a system using sensors and microcontrollers to monitor and regulate energy consumption in public spaces. It automates devices based on room occupancy and environmental conditions, optimizing energy use, reducing wastage, and facilitating remote monitoring through IoT technology for improved efficiency and cost savings. [13]

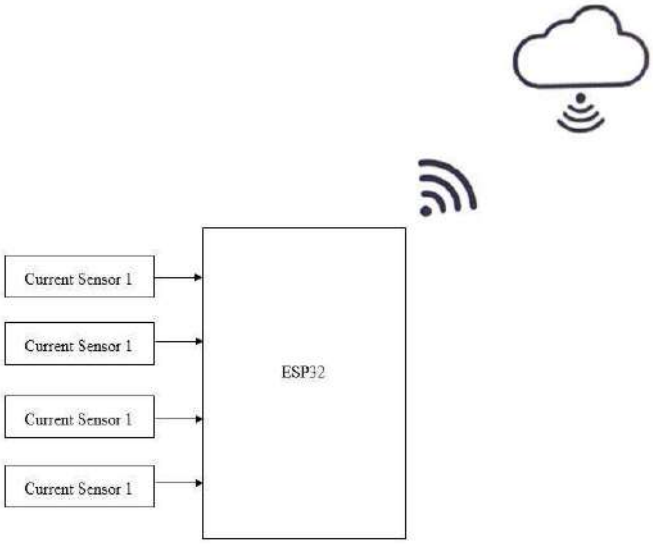
The article "Design, Deployment, and Performance Evaluation of an IoT-Based Smart Energy Management System for Demand Side Management in Smart Grid" demonstrates a system that employs smart meters and IoT middleware to

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facilitate real-time monitoring and automatic load management. It optimizes energy consumption, minimizes risks, boosts efficiency, and powers data-driven demand-side management - all from remote access. [14]

The study "IoT-Based Smart Energy Management in Residential Applications" presents a real-time energy monitoring and remote control of appliances solution based on NodeMCU. The authors present a viable solution that not only enhances data acquisition, but greatly reduces human involvement in the data acquisition process. Customers can monitor consumption and manage costs via the internet, leading to both energy efficiencies and improved bill payments accuracy. [15]

IV. METHODOLOGY



Block Diagram

1. Current Sensors: - There are, in the schematic representation, four matching current sensors called simply instrumenting as "Current Sensor 1." - The sensors read the flow of electrical current through electrical loads.

2. ESP32 Microcontroller:- The ESP32 reads and acknowledges the signal in messages, from the current sensors. - It processes the information, which can be sent wirelessly to a cloud system.

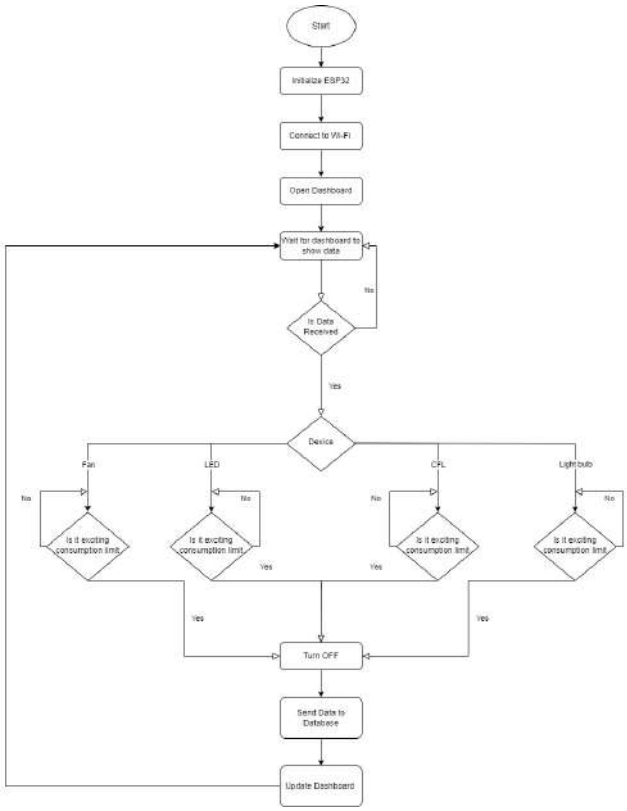
3. Wireless Communication:- The ESP32 has built-in Wi-Fi settings.- It sends the processed current information to the cloud server for remote monitoring and analytics.

4. Cloud Server:- The cloud platform stores and reads data received from the ESP32.- Data can be read remotely and viewed by users via a web subscription or mobile application.Functionality: - Current sensors read electrical current. - The ESP32 reads the sensor data either via a pin or digital input. - The ESP32 processes the information and wirelessly sends it to the cloud.- The cloud server collects data for users to read, and it also utilizes data for real-time monitoring of sensors, analytics, and visual readings.

V. FLOW CHART

Initialization Phase

1. **Start**: The system begins operation.
2. **Initialize ESP32**: The microcontroller is set up and prepared for operation.
3. **Establish Wireless Connection**: The ESP32 connects to a wireless network (likely WiFi). Initialize Dashboard: A user interface dashboard is prepared to display data.



System Flow

Data Collection and Monitoring Loop

1. **Fetch the status of Devices**: The system checks the current state of all connected devices.

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2. **Wait for dashboard to show data**: The system pauses to allow the dashboard to display information.
3. **Is Data Received?**: Checks if data was successfully obtained. If No, the system loops back to fetch device status again.

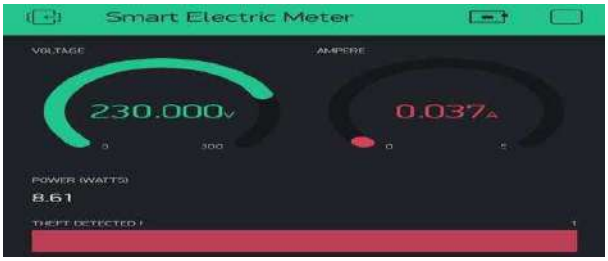
Monitoring of Power Consumption
For every gadget the system:

1. **Read Power Consumption**: Indicates the current power consumption of the gadget.
2. **Is it exceeding consumption limit?:** Compares the reading against a predefined threshold.
   - If Yes: Turn OFF Device - The system shuts down the device to prevent excessive power usage.
   - If No: The system continues monitoring.

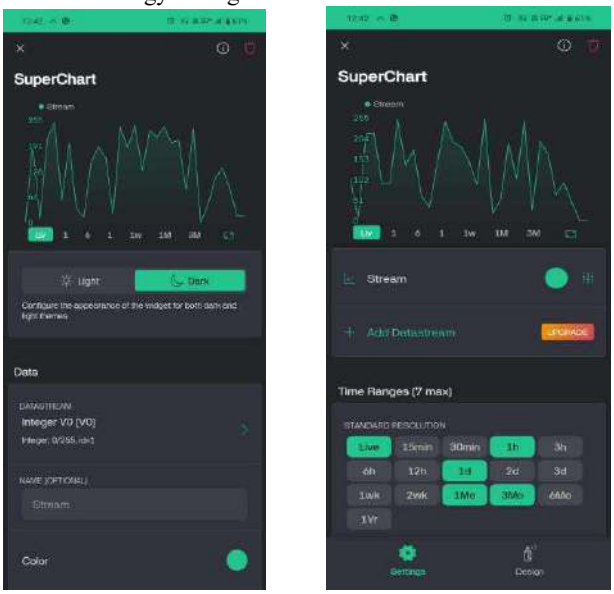
Reporting Data
Send Data to Database: The system sends the gathered data to a central database for analysis and storage after verifying all devices.

VI. SIMULATION RESULTS AND ANALYSIS

The smart energy monitoring system based on the Internet of Things (IoT) is simulated to evaluate its performance in real-time energy monitoring through a device control and user interface. The system includes four ACS712 current sensors to measure the current of each device (Fan, LED, CFL, and Light Bulb) and include a voltage sensor for measuring the voltage across the circuit. The ESP32 microcontroller contains built-in Wi-Fi, which hosts a web server, allowing the user to access the system from any device, such as PC and smartphone, by using its IP address. The system monitor devices initially, check if the energy consumption exceeds pre-established limits, and if so, take action, such as turn off the devices, or inform the user of a breach of limits. While the experiment progressed, the simulation was able to measure the current consumption for each device through the ACS712 sensors and measure the circuit voltage using the voltage sensor. These measurements were coupled to obtain Power Consumption (Power = Voltage × Current) and then measure for total energy consumed that were sent to the dashboard in real time. The dashboard exhibited a user-friendly interface displaying detailed data measures, such as current consumption, voltage, power consumption, and total energy for each respective device.



Every device had a set limit on the current it would consume, with the system programmed to turn devices off if that limit was exceeded. For instance, the Fan was set to consume up to 0.5A, which meant if it consumed more, say up to 0.6A, it would turn off and send a warning to the dashboard. The same is true for the outher devices, it would turn off. This part of the system ensured that the devices were not used inappropriately and limited the amount of consumed energy and possible damages to the system if current was exceeded. The web server accessible through the IP address let users view real-time data, receive warning notifications. The system also logged total energy consumption data in a database utilized by the sector. This function ensured users could go back and review for patterns or periods when usage happens more frequently or a device may not be consuming energy efficiently. This may lead to further energy saving.



The ACS712 current sensors gave precise current readings with a small error (±0.1A), while the voltage sensor provided accurate voltage readings and was necessary for accurate power as above. The responsiveness of the system was excellent, sending alerts and shutting down devices in a matter of seconds when a device was exceeded its allowed consumption. The web-based dashboard is user-friendly and could be accessed on any device, ensuring that users were always aware of their energy usage and their response was possible if required. The system managed devices that exceed

ISBN: 978-93-343-2006-0

their consumption limits automatically, preventing energy being wasted and supporting users to make better decisions, consequently leading to money being saved. Finally, the system can be scaled up to measure additional devices by adding further ACS712 sensors. It should be noted, though, that the ESP32 may be limited in its processing capabilities as devices are added which could be an area of improvement.

Altogether, the simulation illustrated that an IoT-based smart energy-monitoring system is effective in real-time energy monitoring, device control, and user interface functionality. The system provides real time, accurate data on energy use; automatically controls energy devices once a user-defined energy limit is reached for efficiency; provides a simplified user interface allowing for remote monitoring and control. These advantages will provide an effective solution for households and small businesses looking to optimize, reduce, and monitor their energy use, reduce costs, and be part of a sustainable energy solution.

VII. CONCLUSION

In conclusion, the use of the ESP32 represents an evolution in energy monitoring, management, and optimization smart meters. The versatility of the ESP32 and its integrated Wi-Fi allows for real-time data collection, remote monitoring, and automation, making it a practical choice for a multitude of applications. The ESP32 can be utilized for monitoring energy consumption remotely, integrating with the smart grid, managing home energy usage, automation of billing, and more, while being a great structure/resource for using energy smartly. Furthermore, the power of the ESP32 can be beneficial for detecting faults and anomalies in the energy system to enhance reliability and safety. By incorporating the ESP32 with mobile apps or cloud computing options, users gain increased control and transparency over energy consumption, to take energy-saving actions that may reduce costs and energy usage. The ESP32 also serves important functions in relation to sustainable energy practices; such as with solar energy systems or load management, to promote efficient energy distribution and waste reduction. All of these applications prove the ESP32's relevance for residential and industrial energy management and systems.

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ISBN: 978-93-343-2006-0

Wheelchair with voice and gesture control for people with physical disabilities

Poonam Gham Sarvesh Pawar Saidnya Taware Akansha nalawde
poonamgham.kjcoemr@kjei.edu.in sarveshpawar2502@gmail.com tawaresaidnya@gmail.com nalawadeakanksha245@gmail.com
Assistant Professor
Dept. of Electronics and telecommunication Engineering,
KJ College of Engineering and Management Research, Pune
Savitribai Phule Pune University, Pune

ABSTRACT-

The development of assistive technologies has significantly improved the quality of life for individuals with physical disabilities. This paper introduces an innovative Wheelchair with Voice and Gesture Control, designed to empower physically disabled individuals by providing them with enhanced mobility and independence. The wheelchair integrates advanced voice recognition and gesture-based control systems, allowing users to operate the device effortlessly through simple voice commands or hand gestures.[2][4][6]

The system utilizes a combination of microcontrollers, sensors, and machine learning algorithms to interpret user inputs accurately. Voice commands are processed through a speech recognition module, while gesture control is achieved using motion sensors or cameras to detect hand movements. The wheelchair is also equipped with obstacle detection and avoidance mechanisms to ensure user safety. [2][4]

This paper aims to address the challenges faced by individuals with limited mobility, offering a cost-effective, user-friendly, and reliable solution. By leveraging voice and gesture control technologies, the wheelchair provides a seamless and intuitive experience, enabling users to navigate their environment with greater ease and confidence. The proposed system has the potential to revolutionize assistive mobility devices, making them more accessible and adaptable to the needs of physically disabled individuals.

Keywords: Smart wheelchair, gesture control, voice control, object detection etc.

I. INTRODUCTION-

In recent years, advancements in assistive technology have made it possible for people with physical disabilities to regain a significant degree of independence and mobility. One such breakthrough is the development of the wheelchair with voice and gesture control. This innovative device merges cutting-edge technology with accessibility, offering an intuitive and highly customizable means of navigation for individuals with limited mobility.

Traditional wheelchairs require manual operation or joystick-controlled systems, which may be difficult or impossible for some users to manage. The wheelchair with voice and gesture control eliminates these challenges by incorporating smart sensors and voice-recognition software, allowing users to control the wheelchair's movement and features with simple vocal commands or hand gestures.[2][4]

By combining these two control methods, the wheelchair adapts to the specific needs and preferences of the user. Voice control offers hands-free operation, making it ideal for individuals who may have limited or no use of their hands. Gesture control, on the other hand, provides a natural way to interact with the device through movement or signals, improving ease of use and comfort.[4][6]

This type of wheelchair not only enhances physical mobility but also promotes emotional well-being by empowering users to navigate their environments independently and confidently. It represents a significant step forward in creating more inclusive, accessible solutions for people with disabilities, ensuring they can participate fully in daily activities and social interactions.[1][2][4][5]

II. RELATED WORK-

1. J. Dhamodharan et.Al discusses “Automated voice and gesture control of wheelchair for physically challenged people using IOT”. The author presents a smart wheelchair system designed to assist physically challenged individuals by enabling control through voice commands and hand gestures, integrated with IoT technology. The system uses sensors, a microcontroller, and communication modules to interpret the user’s inputs and move the wheelchair accordingly.[2]

2. Dr. Rohith S et.Al discusses “Voice controlled wheel chair for persons with disability”. The author presents the design and implementation of a voice-controlled wheelchair to support mobility for people with physical impairments, particularly those who cannot use their hands for traditional joystick control. The system uses a voice recognition module (like HM2007 or similar) integrated with a microcontroller (such as Arduino or 8051) for giving commands. These commands are then translated into electrical signals that control DC motors connected to the wheels.[4]

3. K. Sangeetha et.Al discusses “Voice controlled wheelchair for physically disabled people”. The author presents system using a voice recognition module integrated with a microcontroller to interpret spoken commands and translate them into directional movement. The authors propose this system as a low-tech yet effective mobility aid, particularly suitable for people suffering from paralysis, muscular disorders, or limb loss. They also suggest that such technology can be expanded further with automation, obstacle detection, or wireless control for broader application in healthcare settings.[5]

III. PROBLEM STATEMENT-

The individuals with some type of physical disabilities using a manual wheelchair even face difficulties in handling wheelchair and also requires someone all the time to help them so, there is a pressing need for an intuitive and accessible control system for wheelchairs that integrates voice commands and gesture recognition, enabling users to operate their wheelchairs seamlessly and independently, regardless of their physical limitations. By developing a wheelchair with voice and gesture control, this technology can provide a more personalized, adaptive, and empowering solution for people with physical disabilities, enhancing their mobility, autonomy, and quality of life.

IV. PROPOSED SYSTEM-

The diagram presents a block-level representation of a system designed to detect and potentially deter vehicle theft. Here's a breakdown of each component and its role:

1. Battery (12V): Provides the power source for the entire system.
2. ADXL345 Accelerometer: This is a sensor that detects motion and tilt. In this context, it would be used to sense if the vehicle is being moved or tampered with.
3. Arduino UNO: This is the microcontroller, essentially the "brain" of the system. It receives data from the sensors, processes it, and controls the other components.
4. Ultrasonic Sensor (HC-SR04): Measures distance using sound waves. This can be used to detect if someone is approaching the vehicle or attempting to enter it.
5. GSM Module: This enables the system to communicate wirelessly over cellular networks. It can send alerts (SMS, calls) to the owner in case of a theft attempt.
6. HC-05 Bluetooth: Allows for short-range wireless communication, potentially for configuring the system or transmitting data to a nearby device.
7. Android App: Likely used for interfacing with the system, receiving alerts, and possibly controlling certain aspects of the system.
8. Panic Button: Allows the user to manually trigger an alert in case of an emergency or suspected theft.
9. Buzzer: Produces an audible alarm to deter thieves and alert people nearby.
10. Motor Driver (L293D): This component controls the motors (M1 and M2). These motors could be used for various purposes, such as locking/unlocking mechanisms, steering control (if the system aims to disable the vehicle), or even a small robotic arm for added security.

How the System Would Work-

- Detection: The ADXL345 accelerometer constantly monitors the vehicle's movement. If it detects unusual motion (e.g., the vehicle being towed or started without authorization), it sends a signal to the Arduino.
- Distance Monitoring: The ultrasonic sensor checks for objects or people approaching the vehicle. If it detects someone too close, it also sends a signal to the Arduino.
- Processing: The Arduino analyzes the data from the sensors. If it determines that a theft attempt is likely, it triggers the following actions:
- Alarm: It activates the buzzer to sound an alarm.
- Alert: It sends an alert (SMS, call) to the owner's phone via the GSM module.

- Possible Actions: It might activate the motors through the motor driver to lock the doors, disable the ignition, or perform other security measures.
- User Interaction: The user can interact with the system through the Android app, receiving alerts and potentially controlling certain functions.
- Panic Button: The user can press the panic button to manually trigger an alert in case of an emergency.

Expected Results-

- Theft Deterrence: The audible alarm and potential immobilization features could deter thieves.
- Real-time Alerts: The owner would receive immediate notifications of any suspicious activity.
- Increased Security: The system provides an additional layer of security beyond standard car alarms.
- User Control: The Android app would allow the owner to monitor and control the system remotely.

Important Considerations-

- Power Consumption: The system needs to be designed to minimize power consumption to avoid draining the car's battery.
- Reliability: The system must be reliable and function correctly in various conditions.
- False Alarms: The system should be calibrated to minimize false alarms.

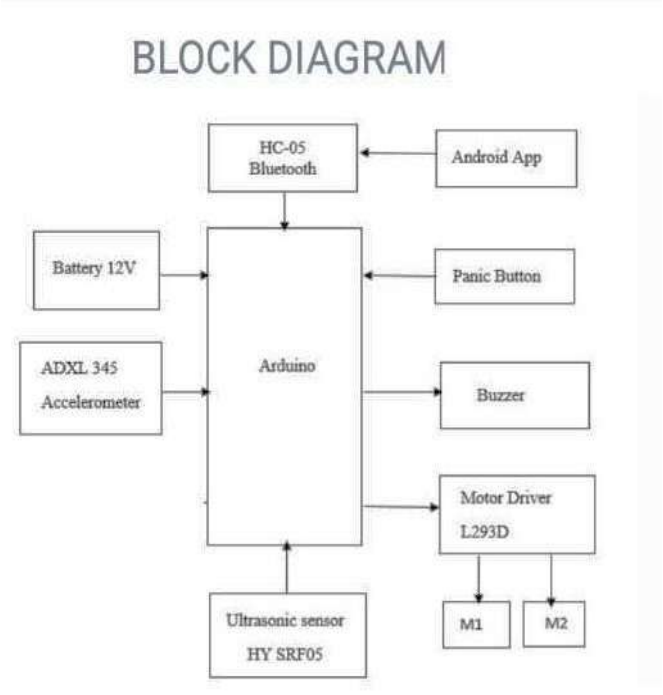


Fig1.1:Proposed system (transmitter section)

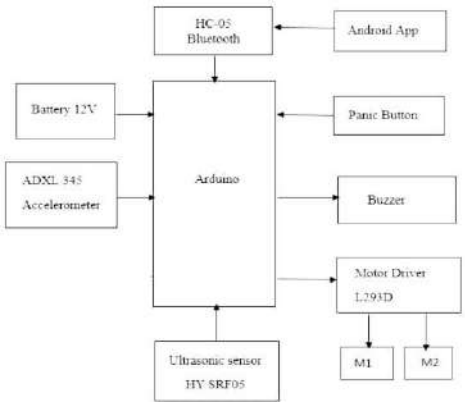


Fig1.2: Proposed system (Receiver section)

V. RESULT AND DISCUSSION-

- **Central Component: Arduino UNO**

The Arduino UNO serves as the microcontroller at the heart of the system. It acts as the central processing unit, receiving inputs from various sensors and controlling the output devices.

- **Input Components:**

1. ADXL345 Accelerometer: This sensor detects changes in acceleration, which can indicate unauthorized movement or tampering with the vehicle.

2. Ultrasonic Sensor (HC-SR04): This sensor measures distance using ultrasonic waves. It can detect the presence of objects near the vehicle, potentially indicating someone approaching or attempting to break in.

3. Panic Button: This allows the user to manually trigger an alert in case of a suspected theft.

4. Battery (12V): Provides the necessary power for the system.

- **Output Components:**

1. Buzzer: Emits an audible alarm to deter thieves and alert people nearby.

2. Motor Drivers (L293D): These control the motors (M1 and M2). The motors could be used for various purposes, such as locking/unlocking mechanisms, immobilizing the vehicle, or triggering a mechanical alarm.

3. Android App: This suggests that the system can communicate with a user's Android device, likely to send alerts, provide status updates, or allow remote control.

- **Communication Component:**

1. HC-05 Bluetooth: Enables wireless communication with the Android app, allowing for remote monitoring and control.

2. GSM Module: While not shown in the block diagram, it is listed in the components required. This is a very important part of the system. This allows the system to communicate over cellular networks. This would be used to send text message alerts, or to communicate location data to the user or authorities.

- **Discussion and Interpretation:**

1. Functionality:

The system aims to detect and deter vehicle theft by using sensors to monitor the vehicle's movement and surroundings. Upon detecting suspicious activity, the system triggers an alarm (buzzer) and potentially activates mechanical deterrents (motors). The system also provides remote alerts and control through an Android app, leveraging Bluetooth and GSM communication.

2. Strengths:

The combination of accelerometer and ultrasonic sensors provides robust detection capabilities. The inclusion of a panic button allows for manual activation of the alarm.

The Android app and GSM module offer remote monitoring and control, increasing the system's effectiveness.

- **Potential Improvements:**

1. GPS Module: Integrating a GPS module would allow for real-time tracking of the vehicle's location, aiding in recovery.

2. Camera Integration: Adding a camera could provide visual evidence of theft attempts.

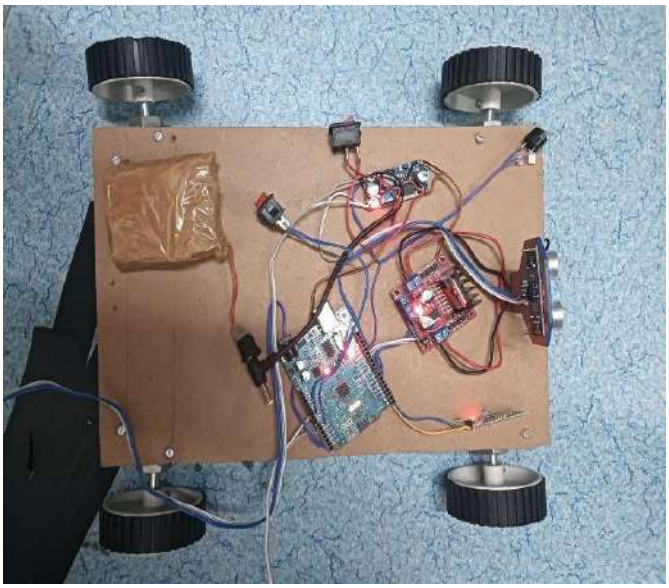
3. More Advanced Alarm system: The motors could be used to trigger a louder siren.

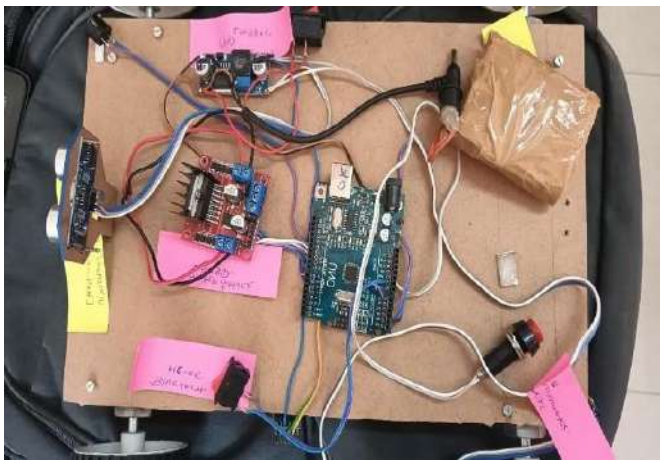
4. Power Management: The system should have features to prevent excessive battery drain.

- **Applications:**

1. This system could be used in cars, motorcycles, or any other vehicles that are prone to theft.

2. It can provide an added layer of security and peace of mind for vehicle owners.





VI. CONCLUSION-

The proposed system “Wheelchair with voice and gesture control for people with physical disabilities” is build and tested in the laboratory and found satisfactory result, this system is operated in two modes that is voice command mode and gesture command mode and uses Arduino uno as central unit, also providing safety by using ultrasonic sensor for object detection and alarm system.

Thus, the use of such smart wheelchair provides physical disabled people with assurance of a safe and reliable system on which they can trust ultimately making them travel, move from one place to other without anyone’s help or support.

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AUTOMATION CANTEEN FOOD ORDERING SYSTEM

Aloy Anuja Mary *Department ofElectronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute ofscience and Technology,* Chennai, India draloyanujamary@veltech.edu.in

S.Jaya krishna *Department ofElectronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute ofscience and Technology,* Chennai, India Vtu20746@veltech.edu.in

Raman Suvarna Paul Reddy *Department of Electronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute ofscience and Technology,* Chennai, India ramanpaulchintu@gmail.com

Gunja Jithendra *Department ofElectronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute ofscience and Technology,* Chennai, India Vtu21960@ve1tech.edu.in

Abstract— *Customers can easily take advantage of the canteen food ordering system. All the problems of conventional queue systems are solved by this system. Most people use the system to buy food more often for takeaway than to enjoy it at the restaurant. As a result, both speed and consistency in standards are improved when collecting orders from customers. They benefit from a better way to talk to each other through the system. Logging uses automated systems as its main tool. Placing an order on Canteen Connect involves just clicking on the menu you want from the online user interface. The use of an online food menu lets you oversee orders and manage customer information as you offer better food delivery. The system helps users decide what they want from the menu. The system allows users to pick which foods they want to order. Once their order arrives, the user can choose how to make payment between online transfer and delivery. All user accounts are individually protected because they only work with one user at a time. To use the system, all users must get a personal ID and a password. The way the system is set up ensures there is more security in process. A system for automating orders from canteens such as schools, colleges and offices is available on the web to make today's food ordering more efficient. With the online platform, customers find it easy to browse what's available, order their meals and pay, so their wait times are reduced and buying is more convenient. A user is able to use the website to review the available foods, request their own choices and follow their order's progress at any time. With the admin panel, canteen staff can regulate what's on the menu and address student orders*

while **monitoring daily financial activities. The platform** sends

times and improved service quality. Customers and inventory managers obtain vital information through system-generated reports which include inventory tracking and customer behavior data. The platform's development

requires HTML and CSS **together** with **JavaScript** code **that** enables connection to Node.js **PHP or** Firebase systems to **improve function and** scalability **potential.**

Keywords—Automated Food Ordering, Web-Based Systems, Canteen ManogemenS Real-Time Order Tracking)

INTRODUCTION

Food and beverage companies, together with many more industries, now require automation to offer better online services and increase productivity. Traditional canteens face many issues because their operating systems lead to long queues, a lack of communication and late service during the most crowded periods. Because of these operational issues, unhappy customers can harm the system's efficiency. The Automation Canteen Food Ordering System greatly improves this situation with its online tools. Customers of the canteen use the system to explore dishes, select their order and make the payment through their phone to skip waiting in line. Members of the platform enjoy easy-to-use order tracking and a straightforward user interface. Staff at canteens rely on a backend system in the platform to handle menus and orders, with report services being the only exception so far from using widespread technology which boosts precision at work and satisfies everyone. Institutional and corporate canteens are experiencing major changes today. Automation can improve both customer care and

how administrative processes run. Large numbers of people at schools and in corporate spaces gain from using canteens that operate alongside bigger facilities such as hospitals and manufacturing companies. Having a kitchen in a canteen means there is queueing, paperwork for orders, speaking to staff about your meal and cash as a payment method. All ongoing procedures cause delays and give rise to human mistakes and administrative flaws that make performance challenging. Our project presents an Automation Canteen Food Ordering System that users can use to enhance canteen operations with a food management solution over the internet. Users get access to a list of features to modify what they want to buy, digitally order it, pay online and receive notifications when their meals are ready.

Problem Statement

End-users and canteen staff face multiple issues with the standard food ordering process at the canteen. The canteen counter experiences long lines that develop when students and employees gather during their lunch break hours. Time becomes wasted and stress develops along with inconvenience. Manual errors that include verbal ordering mistakes and incorrect delivery problems and price computations generate frequent dissatisfaction among users. Workers who are students frequently face restricted intervals for their restroom breaks along with meal times. Food preparation time losses become wasteful when users spend an extended period waiting for their meals. The process of ordering becomes problematic when users cannot determine what to expect about order completion times or out-of-stock product availability. Most standard payment systems depend on cash payments that become inconvenient after allocating change. A faulty system for tracking orders and inventory will lead to resources being managed inefficiently thus causing overstocking or food waste at canteens.

LITERATURE SURVEY

Any technological project depends heavily on literature surveys for understanding its scope by assessing current research systems and solutions. Microprocessor technologies as well as other methodologies operate in automated food ordering systems to minimize worker involvement and optimize workflow efficiency. The evolution of automated food ordering systems benefits from multiple existing implementations as well as technological proposals which demonstrate a requirement for further innovation..

Review of Existing Systems

Traditional Manual Canteen SystemsThe current manual food ordering process at canteens begins with customers lining up in queues and then using verbal communication to convey their orders and paying with cash. Traditional canteen orders follow two procedures: direct verbal launch from customers to kitchen personnel or customers composing paper slips. Traditional ordering procedures create multiple operational problems through time delays and errors made during processing and information misinterpretations as well as requiring additional labor among staff members.

Limitations: No proper queue management No record-keeping or order history High risk of miscommunication

Time-consuming during rush hours

Touch Screen-Based Kiosk Systems

interaction thereby increasing operational efficien cies during food ordering.

Patel et al. (2016) developed an automated restaurant food ordering system using touch screen technology to achieve higher order accuracy and operational speed according to their study.

Limitations: High initial setup cost

The system delivers restricted access since it

serves only one or two kiosks to a large number of people

Mobile-Based Food Ordering Applications

The mobile applications Zomato, Swiggy, Uber Eats and Domino's Pizza enable their users to order food from any location using their advanced mobile interface. The technological infrastructure enables time-dynamic monitoring together with digital transaction capabiliti es and assessment functionalities. Commercial applications prove how automation enhances food business activities by delivering better customer experiences and improving order handling systems. Limitations for institutional canteens: Expenses connected to developing and sustaining the application interface

Such applications include extra features that do not benefit closed-campus environments

Such systems do not integrate with the changing menu

selection patterns of institutional feeding facilities...

Web-Based Canteen Systems

The development of web-based canteen systems as proprietary systems was one of the efforts made by academic institutions together with startups. Students and employees using these platforms need to register first but can then access the menu through log-in to place onlin e orders.

The platform produces statistical reports and controls food stock as one of its functionalities. M. Sharma and R. Gupta (2018) conducted research that evaluated a college canteen management system which used PHP and MySQL to manage users' orders with menus.

Advantages: Low-cost implementation

Accessible on any device with a browser

METHODOLOGY

Users can utilize the internet-based application for e-menu card selection via online registration and order food after reading the menu options. The application allows users to choose their desired food items for selection. The results following food selection, the E-menu card will show up on the restaurant administrator's screen. The waiter's workload is decreased and, in a sense, eliminated when this application is used. The advantage of this is that customers can use this application to place online orders for food directly from the chef in the event that there is a rush at the restaurant and waiters are not available. To log in, the user will receive a username and password.

Admin Module

Dashboard: This component allows administrators to rapidly access condensed information including comprehensive order statistics with details on unconfirmed and confirmed orders, alongside metrics regarding food preparation processes, pickup activities, delivery quantities, order cancellations, and user data. Reg Users: Administrators can oversee registered users (view/update) through this section.

Orders: Through this section admin can both view food orders and adjust their current status depending on the current orders.

Search Order: From this section admin can conduct

particular order inquiries by using order numbers.

Reports: The section enables administrators to check order information along with sales statistics and order quantity by date selection. Through this section Admin has the capacity to modify his profile while simultaneously changing passwords and recovering them.

User Module

On this page, people can check the current menu items available from restaurants

In My Accounts, users have the ability to update their password, look at their profile and sign out.

Users can access their order history after signing in to the system.

Cart: It allows users to pick their favorite order items.

People using the platform can download invoices and cancel their orders anytime they decide to stop an order.

A basic explanation of homepage

Anyone visiting this webpage without registering can check out the list of restaurant foods. Guest users can search for food names and also register for restaurants on the platform. If a user is registered, they can use the system, but anyone can view their delivery updates without being logged in.

Brief Information about homepage

Unregistered visitors to this webpage can examine restaurant food menu listings. Restaurants enable guest users to conduct food name searches along with offering restaurant signup options. Registering users gain access to the system while anyone can check their delivery status independent of authentication.

Implementation

Frontend Development

HTMLS: Gives structure to the web pages.

CSS3: Makes the application look good and responsive.

JavaScript: Adds the interactivity (form validation, cart updates, dynamic content rendering).

Backend (Future Scope / Optional)

Firebase / PHP /Node.js: For user authentication, processing orders, and storing data in real time.

Database: Firebase Realtime Database or MySQL for data management.

Authentication System

User accounts are authenticated through email/password. Admin has an independent login page for secured access.

Two-Factor Authentication (optional, in development) to enhance security.

Software Requirements:

(Operating System: Mac / Linux / Windows (PHP is technology;

(HTML, JavaScript, CSS is web technologies.

IDE: notepad++

(WAMP / XAMPP / LAMP / MAMP (any one) web server;)

SYSTEM TESTING

Project Implementation & Testing

System development starts when creating the proposed system through coding after finalizing the design phase. The development phase initiates with database table structure creation to establish appropriate data types supporting backend development while enabling system connectivity and data transfer functions. Client program development for computers commences simultaneously, followed by web services for mobile device-server connections, with mobile client application finalization concluding the development phase. System reliability and accuracy assessment will occur during the testing phase through multiple test case implementations. Test cases will generate system testing reports, facilitating further evaluation of system deficiencies and necessary enhancements. staff of the particular restaurant will receive training before system deployment that includes operability instructions in addition to process guidance for different events along with system operation protocols.

Implementation Challenges & Problem

Multiple obstacles need handling because end users must evaluate the production system through different operational scenarios during the implementation period. During this stage end users will confront several specific challenges.

User without background

Users must possess fundamental competency in computer system operation and Android mobile phone usage to interact with the system. Training users may not present significant challenges as such basic information is readily accessible via the internet.

Test Plan

Once the system is up and running, we'll jump into the testing phase. At this stage, we'll set up the system on the right devices to check how well it performs. After everything's set up, folks in different roles, like managers and staff, will start putting the system through its paces. The main goal here is to check how stable the system is and to give developers a chance to spot any errors or bugs that didn't show up during the development phase. Any issues we find while testing will be fixed before the system goes live. Bear in mind that the developers usually do some initial testing themselves, which can lead to a bit of bias since they already know how the system works. The system's reliability will be verified through four testing methodologies: unit testing, integration testing, system testing, and acceptance testing.

Unit Testing

First off, let's talk about unit testing. It's really the starting point when it comes to testing the system we've built. Regarding unit testing, it serves as the initial phase in the system evaluation process. This approach examines individual modules separately before their incorporation into the complete system. Unit testing enables developers to efficiently identify errors and bugs by focusing on discrete system. They'll enter both valid and invalid inputs to test and see if the system performs as expected.

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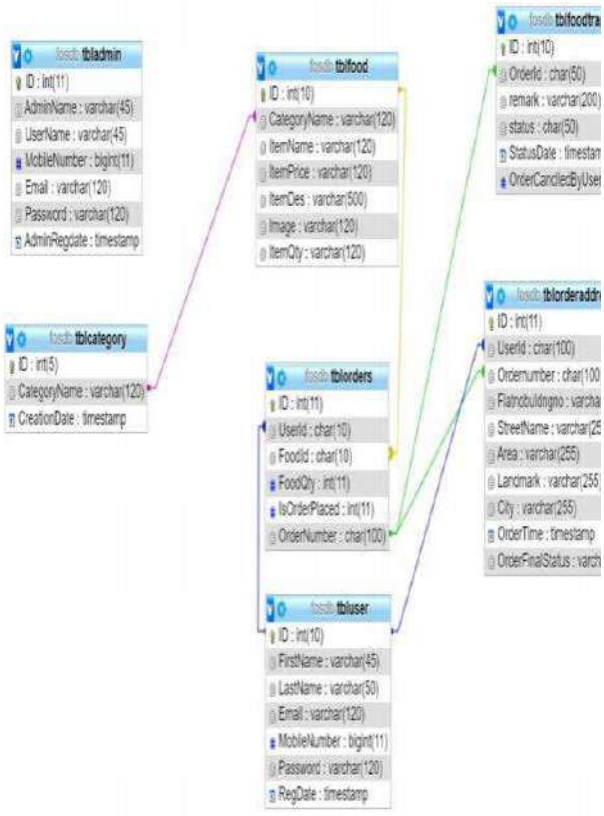


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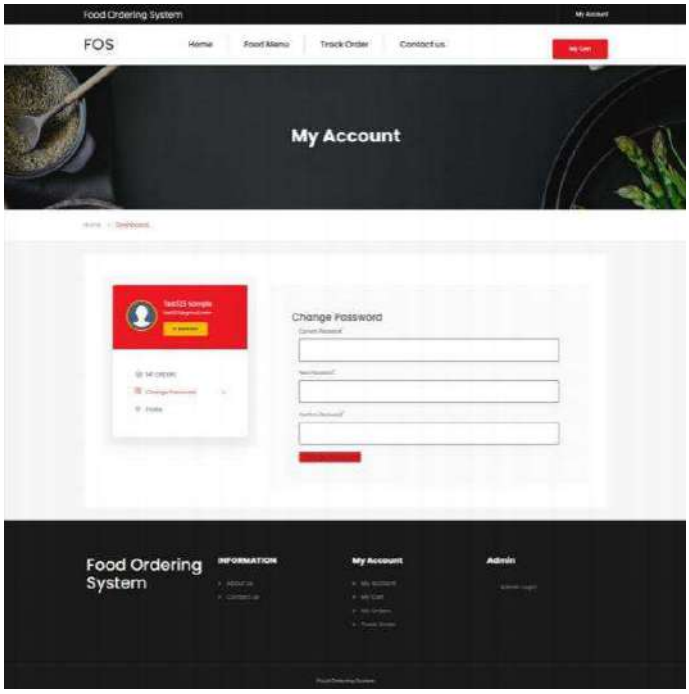


Fig : My acount

- **Design**

Designing is the starting porn) in the progress stage any methodologies and guiding principle To really nail down a device, a system, or a process so that makes it possible to actually bui1‹f it, we need to go through some steps. Once we've figured out what the software needs do, the design phase comes next. This includes three key tasks: designing, coding, implemenfing, and testing—everything we need

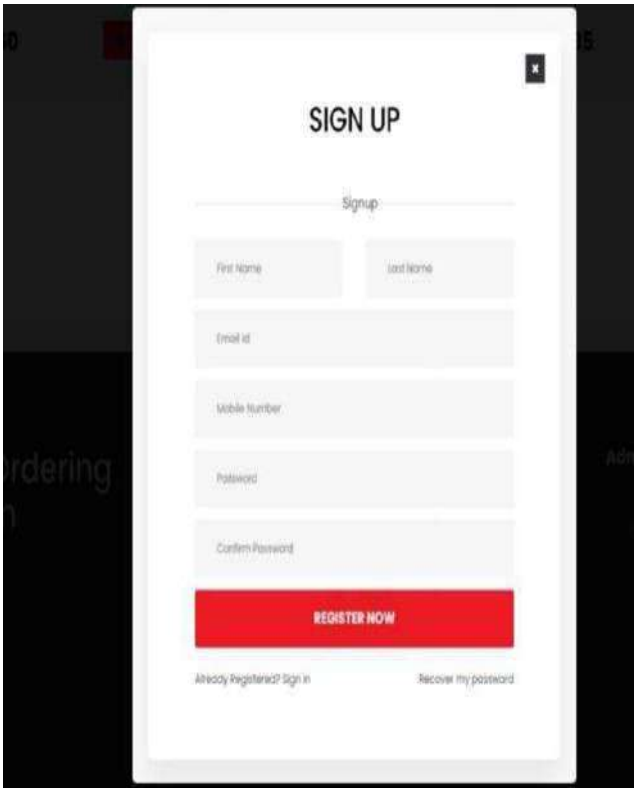
and vahdate the software.

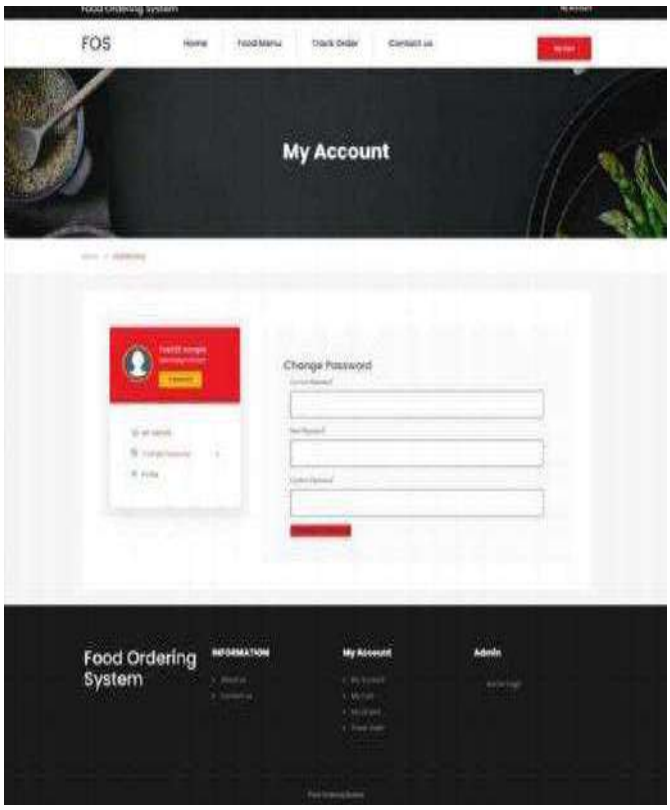
During this design phase, we focus a lot on making the right decisions. It's these choices that will dictate how successful the software is and how easy it will be to maintain in the long run. The choices we make really affect how reliable and easy to maintain the system. Essentially, design is our way of turning what the customer wants into actual, usable software or a system.

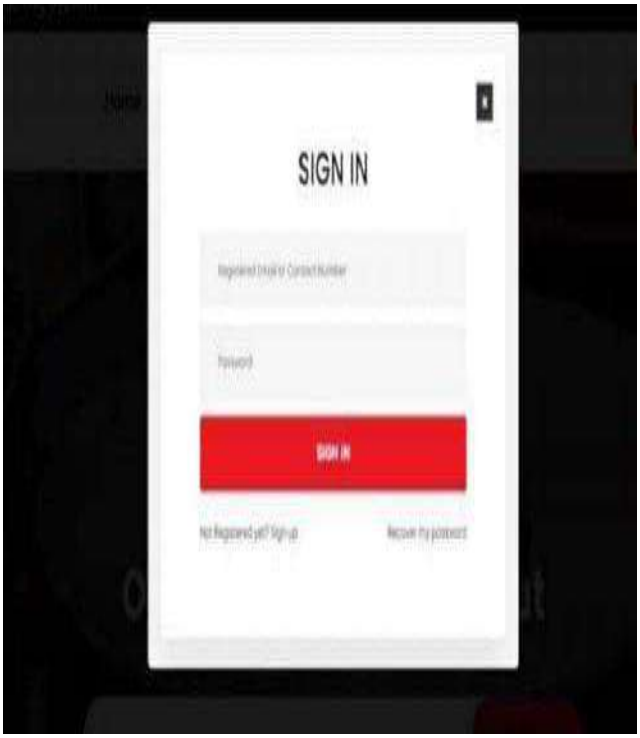
This is where we begin to weave quality into our development process., Software design is really about turning those requirements into a visual map. We usually break this down into two stages. In the inidal design stage, we're mainly focusing on transforming requirements into data.

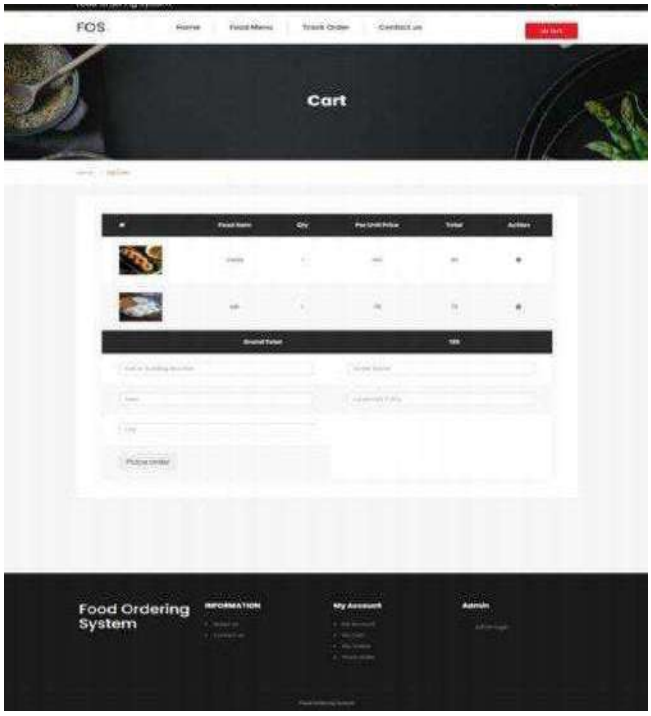
RESULTS AND ANALYSIS

After a decade, technological advancement and innovation have facilitated more efficient and straightforward task management for individuals. Numerous industries implemented management systems to foster business growth previously, consequently establishing a trend that has prompted the F&B sector to adopt management systems for their operations. This project's completion will enable the system to diminish and substitute human labor tasks, decrease transaction time requirements, and generate reports that enhance management through optimal system utilization. This new setup could tptally boost the restaurant's productivity, which would definitely have a positive on its profitability. Plus, it can help cut down on operating costs when it comes to staffing because the system handles a lot of the business processes on its own. So, it's safe to say that this system can really help the restaurant grow over period time.









ISBN: 978-93-343-2006-0

. CONCLUSION

5.1 Conclusion

Automation Canteen Food Ordering System has been created to automate and simplify the conventional process of food ordering at canteens, especially in institutional settings like colleges, offices, and hostels. The system is designed to minimize manual dependence, human error, and improve the overall eating experience using technology.

By using web development technologies such as HTML, CSS, and JavaScript for the front-end and optionally adding Firebase or server-side logic for authentication and data management, the system has a high degree of functionality and usability. The modular design and architecture enable scalability and future expansion, including real-time order tracking, payment gateway integration, and mobile app support.

During the development phase, the system was designed based on the Waterfall Software Development Life Cycle (SDLC) to provide a systematic and documented approach. Each step from requirement gathering and design to implementation and testing was taken with utmost care, and a solid and dependable application was produced.

A few of the most important results and advantages of the system are:

User Convenience: Customers are able to browse menus, order, and get updates with less effort.

Effective Management: Food items can be managed with ease by admins, orders can be tracked, and sales can be analyzed.

Precision & Quickness: Order errors are minimized, and service is accelerated by automation.

Security: User information is secured using correct authentication methods.

Expandability: The system can be scaled up to handle multiple canteens, provide analytics, and handle digital payments.

Despite its current effectiveness, there are still areas for future improvement. Features like OTP-based login, live kitchen status, delivery time estimation, and integration with messaging platforms for real-time notifications can further elevate the user experience.

In conclusion, the project effectively resolves the shared problems that come with typical canteen operations and offers a digital solution that is practicable, easy to use, and innovative. It shows the potential of web-based automation in enhancing day-to-day services and opens the door for wider usage of smart canteen systems in the future.

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PrepPal: Combating Study Isolation through Smart Peer Matchmaking

Assistant Prof.Lakshmiprabha
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail: laxmi-prabha.balaji@dypiemr.com

R.Sreenidhi
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail: sreenidhi.r.22@gmail.com

Nikita Naik
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail: niki123naik@gmail.com

Shruti Nayak
Electronic and Telecommunication Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi Pune - 44, India
E-mail:nayak.shruti@gmail.com

Abstract :

PrepPal was created to motivate individuals to study together and help them achieve their academic or professional goals. It started as a peer study app idea and has been successfully developed, designed, and launched. It includes options like survey correlations based on Cosine Similarity, live video and chat-integrated study spaces, a timer for timing and task scheduling, and a tool for organizing assignments. People on the platform are able to cooperate with one another using Next.js, Tailwind CSS, Django, and MongoDB Atlas. Real-time features allow individuals to connect and assist each other through highly interactive and exciting activities. Users' identities are confirmed by connecting their accounts on LinkedIn and GitHub. Trialing the application with a small number of users resulted in noticeable changes in their consistency and abilities to work together as a team. PrepPal is revolutionizing how individuals learn by harnessing the power of AI to enable enhanced collaboration, improved organization, and engaging motivation.

Keywords:

Collaborative Learning, Peer Study Platform, Matchmaking Algorithm, Cosine Similarity, Pomodoro Technique, Task Management, Real-Time Communication, EdTech Integration.

1. INTRODUCTION

In today's digital-first academic environment, students and exam aspirants often face the challenge of studying in isolation, lacking peer support and structured collaboration. Traditional learning models, while effective in classroom settings, fall short in addressing the motivational and organizational needs of self-directed learners. This gap has become increasingly evident with the rise of online education and competitive exam preparation, where independent study is common but often lonely and unstructured. Addressing issues faced by learners, PrepPal has been set up as a platform where students can learn together, create personalized study plans and interact instantly. While many EdTech tools just give lessons, PrepPal is designed to support students and help them work better. It links learners with similar study interests and goals using algorithms and lets them use a Pomodoro timer, task organizer and interactive live rooms with video and chat capabilities. Social connectivity added to structured learning in PrepPal both helps users become more productive and leads to more motivation and a feeling of responsibility. Modern tools were used by the developers to develop and deploy the platform which has proven that it can revolutionize how students approach both studying alone and teaming up for exams.

2. PROBLEM STATEMENT

Students and exam aspirants can often struggle with isolation, lose motivation and lack a clear plan when studying by themselves. Popular educational platforms are primarily created for sharing information, not for fostering teamwork, regular updates and active involvement from peers. Individuals trying to study with others usually lack proper academic spaces and often choose general apps that do not support productive learning. Adopting many unrelated subjects in one lesson interrupts concentration and the learning process. There is a strong demand for an integrated platform where learners can work together, interact and study while achieving their goals. PrepPal offers an exclusive and protected space for students to interact, work together and encourage each other as they study.

3. OBJECTIVES

PrepPal's main aim is to help people learn on their own by working together and overcoming the problems of isolation often faced by students, exam takers and lifelong learners. The goal is to ensure that learners have a secure, orderly and

enjoyable space for learning consistently.

The key objectives are:

1. To help students meet other students who share their academic interests and learning aspirations with a smart algorithm.
2. To maintain focus on your studying by using a timer, tracking the times you study and organizing your tasks.
3. To offer the ability to study together online via video and text chatting.
4. To provide security and proof of user identity through the verification process on LinkedIn and GitHub profiles.

Setting up a flexible system that allows for personalized study materials and adds more resources from technology in the future.

4.LITERATURE REVIEW

This literature review is adapted from the previously published research paper on PrepPal titled *"PrepPal: Your Go-To Website for Study Mates and Exam Preparation"* [1]. It highlights key studies related to collaborative learning platforms and identifies the gaps addressed by PrepPal.

Chen and Yang-Hsueh [2] explored blended MOOC study groups and found that localized peer collaboration improves engagement, though limited by sample size and pandemic constraints. UCL Library Services [3] analyzed student use of Virtual Learning Spaces (VLS) during lockdowns, noting that while they promote motivation and collaboration, issues like home distractions and access limitations persist.

Fan Qing and Lin Li [4] presented the benefits of web-based collaborative learning in fostering critical thinking and communication but lacked in-depth empirical analysis. Ansari and Kha [5] focused on social media's role in learning, emphasizing the importance of instructor involvement and student participation, although the study primarily captured student perceptions.

While these studies explore important components of collaborative learning, most address individual features in isolation. In contrast, PrepPal offers an integrated solution combining AI-based peer matching, real-time study rooms, task scheduling, and profile verification to deliver a secure, engaging, and scalable collaborative learning experience for students and exam aspirants.

5. SYSTEM ARCHITECTURE AND DESIGN

5.1 SYSTEM ARCHITECTURE

The PrepPal platform is designed using a modern and scalable architecture that ensures high performance, strong security, and a seamless user experience. The system follows a modular client-server model, supports real-time communication, and is fully deployed on the cloud.The frontend of PrepPal is built using Next.js, a React-based framework that enables server-side rendering, resulting in faster page loads and improved SEO. For styling, Tailwind CSS is used, offering a utility-first approach that allows for rapid UI development and a consistent, responsive user interface across all devices.The backend is developed using the Django framework in Python. It handles all core functionalities including user registration and authentication, matchmaking logic, session management, and API endpoints. Django's built-in ORM (Object Relational Mapper) ensures efficient interaction with the database, maintaining data integrity and supporting secure operations.

PrepPal uses MongoDB Atlas as its cloud-hosted database solution. It provides flexible schema design, high availability, and scalability. The database stores user profiles, academic interests, match history, task records, and Pomodoro streaks.For real-time communication, PrepPal integrates WebRTC for video calling and Socket.IO for real-time chat functionality. These technologies allow users to join or create study rooms where they can collaborate live through video and messaging, enabling an engaging and interactive learning environment.

User authentication and verification are handled securely through JWT (JSON Web Tokens) for session management. Additionally, users can link their LinkedIn and GitHub accounts for social verification, ensuring profile authenticity and increasing trust within the community.The platform is hosted on Vercel, a modern cloud deployment service that offers serverless architecture, automatic scaling, and continuous integration and deployment (CI/CD). Vercel's global edge network ensures fast content delivery and high uptime, allowing PrepPal to handle traffic efficiently as its user base grows.This carefully selected technology stack provides PrepPal with the necessary infrastructure to support a secure, interactive, and scalable collaborative learning platform.

5.2 MATCHMAKING ALGORITHM: DESIGN AND IMPLEMENTATION

One of the core innovations and the unique selling point of PrepPal is its smart matchmaking algorithm, designed to connect students with compatible study partners based on multiple academic and personal attributes.

5.2.1 ATTRIBUTE WEIGHTING AND PROFILE CONSTRUCTION

To prioritize meaningful matches, user profiles are converted into weighted text data based on three core attributes:

- **Exam Focus** – highest priority (repeated 3 times)
- **Field of Study** – medium priority (repeated 2 times)
- **Status (Student/Professional)** – lower priority (repeated 1 time)
- **Personal Description** – used only for refining close matches

5.2.2 VECTORIZATION WITH TF-IDF AND COSINE SIMILARITY

These weighted profiles are then converted into numerical vectors using TF-IDF (Term Frequency-Inverse Document Frequency). The similarity between users is calculated using Cosine Similarity, which measures the angle between their vector representations.

Cosine similarity is ideal because it:

- Ignores text length differences
- Works well with TF-IDF-based text data
- Allows weighting of different profile fields

5.2.3 Refining Matches Using Personal Descriptions

When similarity scores between users are very close, personal descriptions are compared using BERT-based Sentence Embeddings to refine the final ranking. This helps identify deeper semantic alignment between users.

5.2.4 ALTERNATIVES CONSIDERED

Other similarity techniques like Jaccard Similarity and K-Means Clustering were evaluated but rejected due to poor performance on weighted and text-rich data. Sentence-BERT offers better semantic matching but at higher computational cost. Therefore, TF-IDF + Cosine Similarity was chosen for its balance between efficiency and accuracy.

5.2.5 SCALING TO 1M+ USERS

For large-scale deployments, the following optimizations are proposed:

- Use FAISS (Facebook AI Similarity Search) for efficient approximate nearest-neighbor search
- Precompute similarity scores for frequent or active users
- Apply Approximate Nearest Neighbor (ANN) techniques to reduce matching time

5.2.6 BIAS MITIGATION

To ensure fairness and inclusivity:

- No sensitive attributes (gender, ethnicity, location) are collected
- Diversity is promoted by suggesting near-matches if perfect ones aren't available
- Attribute weights can be dynamically tuned to avoid bias toward overrepresented groups

5.2.7 FUTURE ENHANCEMENTS

Future versions of PrepPal will:

- Migrate from TF-IDF to Sentence-BERT embeddings for better context understanding
- Integrate FAISS for real-time matching at scale
- Include user feedback loops to continuously refine match accuracy.

5.2.8 FLOWCHART OF WORKING OF MATCHMAKING ALGORITHM

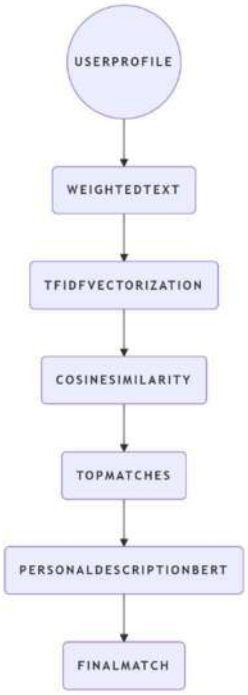


Fig: Procedure of Matchmaking Algorithm

6.METHODOLOGY

The development and operation of PrepPal are based on five key stages: user onboarding, matchmaking, productivity tool integration, real-time collaboration, and deployment. The onboarding process begins with users creating a profile by entering basic details such as age, target exams (GRE, CAT, etc.), academic interests, and study preferences. This information forms the basis of personalized matchmaking. The system also allows optional integration of LinkedIn and GitHub accounts for profile verification, which increases credibility and user trust within the platform. The matchmaking algorithm is a core component of PrepPal's functionality. It utilizes Cosine Similarity to compare the multidimensional user vectors generated from profile data. This method calculates the angle between user preference vectors to assess compatibility. Compared to other methods like Pearson Correlation or K-Means Clustering, Cosine Similarity provides more precise, user-specific matches suited for one-on-one academic collaboration.

PrepPal integrates various productivity tools to enhance user engagement and consistency. The task manager helps users set and prioritize study goals, assign deadlines, and track completion. The Pomodoro timer, customizable by the user, facilitates time-blocked study sessions followed by short breaks to prevent fatigue. The timer is connected to a streak tracking feature that

motivates users to maintain regular study habits. One of the standout features of PrepPal is its real-time study room functionality. Users can create or join public and private rooms where they can collaborate with matched peers via video calls and chat. These rooms are equipped with shared resources, interactive messaging, and file-sharing options, fostering a collaborative environment. WebRTC powers the video interaction, while Socket.IO ensures real-time text-based communication.

Finally, the entire platform is securely deployed and hosted on Vercel, which supports fast load times, automatic deployments, and global distribution. Continuous integration ensures that any updates or improvements are deployed instantly without downtime. Through this architecture and methodology, PrepPal successfully bridges the gap between isolated self-study and collaborative learning, offering a scalable, interactive, and intelligent platform for exam preparation and lifelong learning.

7. Implementation

The implementation of PrepPal involved translating the platform's conceptual design into a fully functional web application. Development began with frontend prototyping using Figma and Canva, which helped map out user flows and wireframes for pages such as sign-up, dashboard, matchmaking, and study rooms. These prototypes ensured an intuitive and consistent user experience across the platform. **The frontend** was developed using Next.js for its server-side rendering capabilities and performance optimization, while Tailwind CSS was used to design responsive and clean user interfaces. Key pages implemented include user onboarding, profile setup, matchmaking suggestions, Pomodoro session tracker, task manager, and the real-time study room interface. **On the backend**, Django was used to handle server-side operations such as user authentication, data storage, matchmaking logic, and API endpoints. The Cosine Similarity-based matchmaking algorithm was implemented in Python, comparing user vectors based on their preferences and goals to generate personalized study companion recommendations. **Data was stored** securely in MongoDB Atlas, which provided a flexible schema for managing user profiles, match history, tasks, and study activity. To facilitate real-time interaction, WebRTC was integrated for video calling, and Socket.IO enabled instant messaging between users in study rooms. **The development environment** was managed using Visual Studio Code (VS Code), and version control was handled with GitHub for collaborative development. After rigorous testing, the platform was deployed on Vercel, enabling automatic builds, continuous integration, and global access with high reliability.Through this structured implementation, PrepPal evolved into a seamless, fully functional collaborative learning platform that supports smart peer matching, real-time interaction, and focused study.

8. USER TESTING AND EVALUATION

To evaluate the usability, effectiveness, and real-world performance of PrepPal, a structured user testing phase was conducted within Dr. D. Y. Patil Institute of Management and Research, Pune. The testing involved 30 students from different departments who were preparing for competitive exams such as GRE, GATE, and CAT. Users were onboarded onto the platform and guided through the entire workflow, including profile creation, matchmaking, use of productivity tools, and real-time study rooms. The testing was conducted over a period of two weeks, during which user behavior was observed and feedback was collected through surveys and interactive discussions.

Key evaluation points included:

1. **User Experience**: Most students found the interface user-friendly and easy to understand.
2. **Matchmaking**: 80% of users were satisfied with their suggested study partners. However, a few users reported slightly mismatched suggestions due to similar but non-identical interests.
3. **Real-Time Collaboration**: The video call feature worked effectively in most cases, but a few users experienced minor lags and disconnections, particularly on unstable internet connections.
4. **Productivity Tools**: The task manager and Pomodoro timer helped students manage their time better and maintain focus.
5. **Verification & Safety**: Social profile verification via LinkedIn and GitHub added a strong layer of trust, making users feel more comfortable collaborating with new peers.

The issues related to video calling and matchmaking accuracy were identified and addressed by optimizing the matching logic and improving WebRTC stability. Additionally, student suggestions such as a dark mode and notification reminders were documented for future feature releases.

In conclusion, the testing conducted within our college validated PrepPal's core features and its potential to support collaborative learning. The positive feedback and high engagement levels among students confirm its effectiveness in addressing the challenges of self-directed exam preparation.

9. SYSTEMATIC EVALUATION OF STUDY PLATFORMS

Table 2: Systematic overview

Platform	Tech Used	Pros	Cons
Zoom / MS Teams	Video Conferencing	Real-time access, easy to use	No matchmaking, not study-specific
Edmodo / Google Classroom	Content Sharing	Classroom-friendly, organized tasks	No peer matching

Discord	Chat & Voice Channels	Flexible, community-based	Lacks structure, not academic
PrepPal	AI Matching + Tools	Smart pairing, Pomodoro, live rooms	Limited content, needs internet

10. RESULTS AND DISCUSSION

PrepPal was successfully tested at Dr. D. Y. Patil Institute of Management and Research with 30 students preparing for competitive exams. The platform's matchmaking algorithm achieved approximately 80% user satisfaction, effectively connecting learners with shared academic goals. Some mismatches indicated a need to refine profile granularity and further adapt the matching logic.

The chart below illustrates how various components contribute to the final match score, including TF-IDF similarity, year similarity, exam bonus, and status bonus:

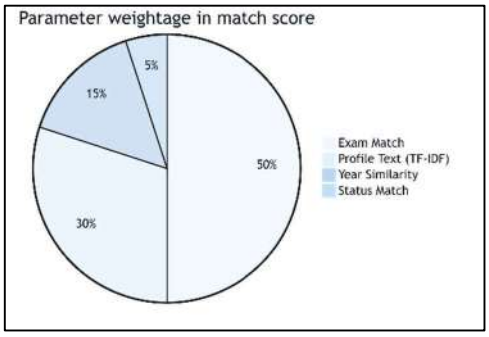
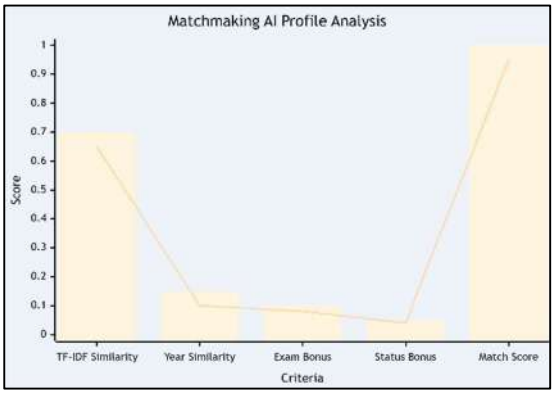


Figure 1: Matchmaking AI Profile Analysis

As seen, TF-IDF profile similarity and exam alignment contribute significantly to the final match score, while year and status play supportive roles.

To determine these scores, PrepPal assigns different weightages to each matching parameter, as shown in the pie chart below:



Parameter Weightage in Match Score

Exam relevance contributes the most (50%), followed by profile similarity (30%), year (15%), and status (5%). These values were fine-tuned during the testing phase for optimal matchmaking accuracy.

In addition to smart matching, productivity tools such as the Pomodoro timer, task manager, and streak tracker were widely appreciated. Users reported improved focus and study consistency, with streak tracking particularly helping reinforce daily habits.

The real-time study rooms, featuring video calls and chat, fostered collaboration and received positive feedback. Some connectivity issues were noted but resolved by optimizing WebRTC performance. Furthermore, LinkedIn and GitHub verification provided a layer of trust and security, making users more comfortable interacting with new peers.

Overall, PrepPal effectively addressed the isolation commonly associated with self-study by combining intelligent peer-matching with interactive tools, delivering a collaborative and structured learning experience.

11.SECURITY AND VERIFICATION MEASURES

Security and user authenticity are central to PrepPal's design, ensuring a trusted and safe environment for collaborative learning. To prevent misuse and build user trust, PrepPal integrates a profile verification system through LinkedIn and GitHub, allowing users to authenticate their academic or professional identities. This verification helps filter out fake profiles and ensures that study companions are genuine learners.All user credentials are securely stored using encrypted methods, and authentication is handled through JWT (JSON Web Tokens) to maintain session integrity and prevent unauthorized access. Sensitive data, such as passwords and personal details, are protected using hashing and secure communication protocols (HTTPS) to guard against data breaches and man-in-the-middle attacks.

Additionally, real-time communication through WebRTC and Socket.IO is secured to prevent eavesdropping during video calls and chat interactions. The backend, developed in Django, includes built-in security features such as CSRF protection, input validation, and rate limiting to safeguard against common web vulnerabilities.By combining identity verification, encrypted data handling, and secure real-time communication, PrepPal provides a safe, trustworthy platform for learners to connect and collaborate.

12.LIMITATIONS

While PrepPal successfully addresses key challenges in collaborative self-study, a few limitations remain. The platform has been tested with a limited user base, which may not fully represent the diversity of learner needs and behaviors across larger populations. The current matchmaking relies primarily on static profile data; it does not yet adapt dynamically based on user behavior over time. Additionally, while the platform offers essential features like video calls, task management, and Pomodoro tracking, it lacks built-in content such as subject-specific materials or quizzes, which users must source externally. The

dependency on stable internet connectivity can also hinder access for users in low-bandwidth regions.

13.FUTURE SCOPE

PrepPal aims to evolve into a comprehensive smart learning ecosystem. Future developments include integrating AI-driven personalized recommendations for study partners and resources, allowing dynamic matchmaking based on real-time activity and learning patterns. The platform plans to introduce gamification features such as badges, leaderboards, and challenges to increase engagement. To expand learning support, PrepPal will collaborate with EdTech providers to offer curated content, expert-led sessions, and verified study materials. Additionally, immersive technologies such as AR/VR may be explored to create virtual study environments, and mobile app development is underway to extend accessibility and usability.

ACKNOWLEDGEMENT

We extend our sincere gratitude to Dr. D. Y. Patil Institute of Engineering, Management and Research for providing the essential resources and support for this research. We sincerely thank our mentor for their invaluable guidance and our peers for their support and insightful feedback.

CONCLUSION

PrepPal successfully addresses the key challenges faced by students and exam aspirants during self-directed learning, such as isolation, lack of motivation, and difficulty in finding suitable study partners. By integrating smart matchmaking, real-time collaboration tools, and productivity-enhancing features into a single platform, PrepPal transforms individual preparation into a more structured, interactive, and engaging experience.

The platform's implementation using technologies like Next.js, Django, MongoDB Atlas, WebRTC, and Socket.IO ensures robust performance, scalability, and a smooth user experience. User testing within Dr. D. Y. Patil Institute of Management and Research confirmed the platform's usability and effectiveness, with positive feedback on features like the Pomodoro timer, task manager, and matchmaking system.

Minor issues with matchmaking accuracy and video calls were identified and resolved, and user suggestions have informed the roadmap for future development. Overall, PrepPal demonstrates strong potential as a scalable EdTech solution that promotes collaborative learning and consistent study habits, making it a valuable tool for students preparing for competitive exams and beyond.

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Automatic number plate recognition system using optical character recognition for vehicle identification

[1]Prof. Aher Suvarna R.
suvarnaaher2510@gmail.com
Department of Electronics &Computer Engineering, SND College of Engineering, Yeola, India

[2]Prof. Narode Sweety S.
sweetynarode1992@gmail.com
Department of Information Technolagy Engineering, SND College of Engineering, Yeola, India

Abstract- One remarkable application of optical character recognition (OCR) is automatic number plate recognition, or ANPR. ANPR is an image processing breakthrough that uses sophisticated images to differentiate a car from its license plate. In light of optical character recognition (OCR), we have presented an observation for vehicle number distinguishing evidence in this work. OCR is used to read a printed character number plate that has been optically created; layout coordination is required. This computation is tested using a variety of comprehensive brightening car images. The final step in the recognition of a vehicle's number plate is OCR. The characters on the license plate are converted into writings as a gesture of gratitude. The layout coordination computation is then used to perceive the characters.

Keywords: Template matching, optical character recognition (OCR), and automatic number plate recognition (ANPR).

I. INTRODUCTION

One kind of programmed vehicle recognized proof is number plate acknowledgment.The unique and easily identifiable proof of a car is its number plate. It's a visual aid that uses creativity to set apart automobiles by their unique license plates.Maintaining compliance with legal requirements and traffic regulations is contingent upon consistent recognition of license plates.It can be used in many different contexts, such as toll roads, halting zones, high-security areas, tourism areas, and more. The purpose of number plate recognition is to identify the plate and then identify the vehicle number plate from a moving vehicle as a result. The process of recognizing a vehicle's number plate is called number plate extraction. After the identified number plate is ready to quiet the commotion, the results are sent to the division section, which divides the characters from the deleted number plate into separate portions. The separated characters are put through an OCR calculation after standardization. The optical character data will finally Encoded content will be created from the optical character data. The characters are seen through the use of template coordination. The final yield needs to be made using a string of characters. This served as motivation for the development of an excellent camera that required little work and had a dedicated equipment unit for the extraction and identification of vehicle number plates using optical character recognition.

The process of recognizing a vehicle's number plate is called number plate extraction. The recognized number plate is set up to remove the disturbance, and the results are then sent to the division department to separate the individual characters from the deleted number plate. The separated characters are put through an OCR calculation after standardization. Ultimately, encoded content will be created from the optical character data. The characters are seen through the use of template coordination. The final yield needs to be made using a string of characters. This served as

motivation for the development of an excellent camera that requires little work and a dedicated equipment unit for the extraction and identification of vehicle number plates using optical character recognition.

II. LITERATURE REVIEW

A widely used invention, optical character recognition (OCR) converts handwritten message characters on filtered images of printed material into machine-encoded content data, such ASCII. The execution is directly dependent on the nature of information records, even though it can be read as printed characters or written by hand. The OCR functioned in a disjointed manner.

The target audience for K. K. Kim et al. is just Korean plates. It has designed and implemented a Support Vector Machine architecture, reporting exceptional normal character recognition.

Most optical character recognizer given in a 2D-plane can maintain a high achievement rate just inside a limited scope of visual edge and shooting separation, according to research by M.A. Ko et al. and T. Naito et al.

Dish et al. suggested a two-includes Differentiating similar characters based on adjacent supporting elements and constructing a framework that combines quantitative and fundamental recognition methods. The four sub-classifiers first independently identify the character, and the acknowledgment outcomes are then combined using the Bayes approach. Moreover, the auxiliary stage is used for additional selection if the observed characters fit in with the arrangements of ambiguous characters.

In order to recognize the license plate in the obtained photo captured by the camera, Y. Huang et al. present. The number plate range, the method for binarizing the image, and the layout coordination for recognition are all found using the angle administrator. The root-mean-squared error (RMSE) is a tool used to calculate the proximity of a model and two images. This method provides a substantial incentive for to reduce the ALPR framework's overall computation. Auto number plate recognition and discovery can be accomplished with a robust and continuous technique presented by S. Hamidreza Kasaei et al. [8]. To locate the license plate and format coordinating for character recognition, morphological administrator is used. Although this approach leaves a lot of room for assessment, the accuracy of recognition is quite high. The straight relationship between the captured images and the database images is basically measured by the second technique, the format coordinating strategy. This method is entirely dependent on the type of captured image.

In 1976, the UK's Police Scientific Development Branch pioneered automatic number plate recognition. The review procedure was implemented by looking at studies conducted over the previous five years (2010-2015) to gather data on distinguishing proof rate alongside zero wrong recognizable proof rate. The caught picture is contrasted and all the database pictures of alphanumeric characters and after that the most encouraging character is picked. Along these lines the acknowledgment procedure is finished. This technique is very quicker than the element coordinating methodology however we need to trade off with the precision of acknowledgment. The OCR techniques in this are touchy to misalignment and to various sizes. Along these lines, the fundamental contrast between Template coordinating and Machine Learning methodology is that Template coordinating is a Shape-Matching methodology however machine learning

methodology is a Feature-Matching methodology. Along these lines, the time required to prepare any framework for highlight coordinating methodology is very long. In this venture we accepted a controlled situation, the format coordinating methodology is use

TABLE 1. % accuracy year/month of detected count

Duration	% Accuracy
May 2010	98
June 2011	94
July 2011	95
December 2011	89.74
April 2012	93
October 2012	93

The intended system will examine each character on the range plate individually. An procedure involving morphology could accomplish this. It has a feature that allows you to section every character used in the quantity plate. The process of extracting a vehicle's range plate begins whenever one is found. After pre-processing the detected range plate to remove any noise, the findings are sent to the section half, which separates each character from the retrieved range plate one at a time. The OCR formula received the split characters normalized associate degree. The optical character information will ultimately be converted into encoded text. The characters understood template matching for exploitation. The final result ought to fit within the character string format.

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III. OVERVIEW OF THE SYSTEM

The automatic number plate identification system that is being shown aims to be lightweight in order to operate in real time under all environmental conditions. There are three steps in the automatic number plate recognition system's operation. Finding and taking a picture of a vehicle is the first stage; finding and extracting the number plate from an image is the second. In the third phase, individual characters are obtained using the picture segmentation technique and optical character recognition (OCR), which uses a database containing all of the alphanumeric characters to identify each individual character.

IV. Automated number plate recognition system phases

The phases that an automatic number plate recognition system follows are as follows:

1. **Obtain image:** In order for the system to be able to process the image as needed for number recognition.

2. Number Plate Segmentation: An extracted image is used for segmentation. The extracted image is partitioned into several pieces for additional processing by segmentation.

3. Number Identification: To properly identify numbers, noise in the image must be eliminated.

Number identification is the last stage of automatic number plate recognition (ANPR).

IR sensors, a camera, a motor with a motor driver, a PC running ANPR software, an LCD display, indicators, a GSM module, a MAX 232, and a microcontroller (ARM 7) make up the hardware model.

1. IR SENSORS: To detect a car's presence

2. CAMERA: To take a picture

3. MOTOR WITH MOTOR DRIVER CIRCUIT : To manage the barrier on the entrance.

4. PC WITH ANPR SOFTWARE: The computer used to run the algorithm.

5. LCD DISPLAY: To show the license plate that has been identified.

6. INDICATORS (RYG): To show the cars' "Access Granted" and "Access Denied" purposes.

7. GSM MODULE: To communicate with the designated mobile number.

8. MAX 232: For the purpose of interface.

9. MICROCONTROLLER (ARM7): The Automatic Number Plate Recognition System's Hardware Setup Block Diagram is displayed. When a car moves into and stays in the sensor's field of view, the infrared sensor detects it and sends a signal to the PC via the microcontroller ARM7 so that the PC can take a picture of the car.

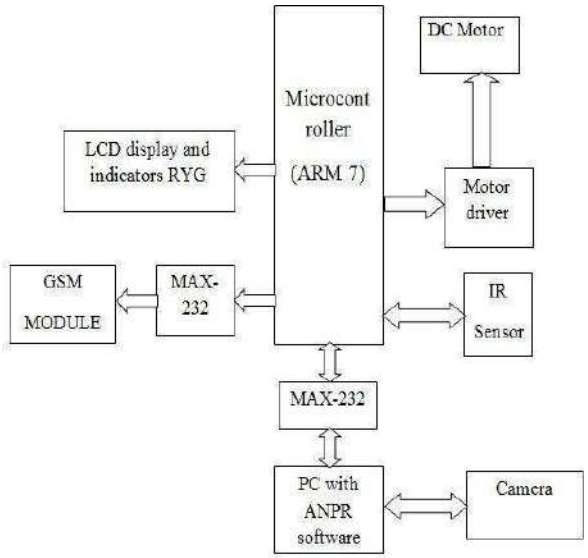


Fig 1. Hardware Block Diagram

A picture of a car is taken by the camera that is attached to the PC via a USB connector. The picture is sent to a PC, where the ANPR algorithm processes it to produce the vehicle number. Next, in order to verify this number's legitimacy, it is compared to the approved number.

V. RESULTS OF SIMULATIONS

The reenactment implications of the developed ANPR framework are illustrated in this section. The camera is initially interfaced with the PC using Matlab. A USB port is used to link the camera. Various photos of cars with different colors and body types are taken and stored on computers. During handling, the various effects of the daylights are also taken into account. As seen, the images are in RGB format and have a resolution of 800 × 600 pixels. The next step was the yellow hunt computation after capturing the image. The images following the completion of the yellow inquiry computation. The white area alludes to the yellow or a shade closer to it.



Fig 2. Images taken using USB camera

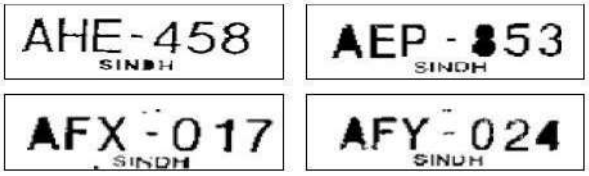


Fig 3. Binary image

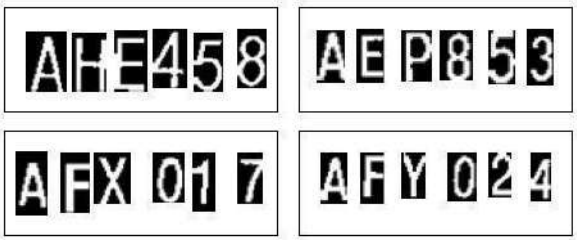


Fig 4 .Character separation using column segmentation

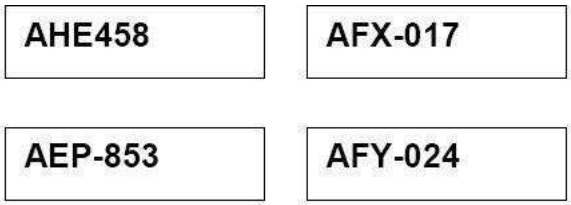


Fig 5. Recognize character using OCR

The PC determines the vehicle approval and starts the ANPR computation. ANPR computation is tested on a large number of images with an 800 x 600 pixel resolution. The results show how well the developed ANPR calculation identifies Sindbad standard vehicle number plates under various lighting situations and exhibits a greater identification and acknowledgment rate. It has the ability to recognize and interpret license plates at various distances. The distance affects how wide the license plate appears in an image. After identifying the vehicle number plate, the OCR computation is used to perceive each individual character. Relationship approach is used by the OCR to recognize characters, and the possibility that the recognition can be detected.

CONCLUSION

After taking into account everything said above, we can say that this framework exhibits the Automatic vehicle distinguishing proof framework using the vehicle number plate. The layout of image handling systems is used by the framework to differentiate the car from the database stored on the PC. The framework is implemented in Matlab and tested using real images. The simulation shows that the system can detect and identify a car using its license plate at a distance of up to a very short distance, and it can do so well in a variety of assisting scenarios.

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Prof. Aher Suvarna R. (Assistant Professor of Electronics & Computer Department) SND College of Engineering & RC Yeola.



Prof. Narode Sweety S. (Assistant Professor of Information Technology Department) SND College of Engineering & RC Yeola.

Autism Detection Using HAAR Cascade machine learning algorithm

Prof. Lakshmiprabha,
Associate Professor, Department of Electronic and telecommunication Engineering,
D. Y. Patil Internation University, Pune, India

Shivam Patil, Sumit Kakad, Sanket Patil
Students, Department of Electronic and telecommunication Engineering,
Dr. D. Y. Patil Institute of Management and Research, Pune, India,

ISBN: 978-93-343-2006-0

Abstract: Autism Spectrum Disorder It refers to a big spectrum of conditions that influence social interactions, communication skills, and repetitive behaviors. Traditionally, ASD diagnosis relies on behavioural observations, but there is increasing interest in leveraging technology for earlier detection. This project explores using the HAAR Cascade algorithm, typically employed for object detection like facial recognition, to identify different ASD types. We concentrated on four categories: Asperger Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), and Classic Autism are all conditions that fall under the umbrella of developmental disorders. Our approach involved training separate HAAR Cascade models for each type using meticulously labelled images. Positive samples highlighted features associated with each condition, while negative samples included unrelated facial characteristics. The system analyzes new images to classify the type of ASD or indicate no detection if relevant features are absent. Although HAAR Cascade is generally used for simpler tasks, this project aimed to assess its capability in this complex application. The success of our system heavily depended on the quality of the training data and the precision of feature identification by each model. This project is an initial exploration into using HAAR Cascade for ASD detection, suggesting that more advanced techniques, such as deep learning, may be necessary for improved accuracy. Our findings could inform future research, potentially leading to more effective combined methods.

Keywords: Autism Spectrum Disorder (ASD), ASD Detection, HAAR Cascade, Object Detection, Asperger Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), Classic Autism, Facial Features, Image Analysis, Classification, Training Data, Positive Examples, Negative Examples, Variability in Facial Features, Deep Learning, Future Research, Combined Methods, Diagnostic Accuracy.

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a multifaceted neurodevelopmental affliction characterized by difficulties in interaction and behavioral patterns. As per the information from the Centers for Disease Control and Prevention (CDC) Shows that around 1 in 44 children in the United States are identified with autism, which aligns closely with global prevalence trends. Due to the spectrum's diverse nature, individuals display distinctive traits, making early identification and intervention challenging. However, early diagnosis is vital, as it allows for timely support that can greatly enhance developmental progress. including behavioral therapies, educational support, and family counseling. However, diagnosing autism is challenging due to the subjective nature of behavioral assessments and the need for trained professionals to interpret complex cues. Consequently, there is a growing demand for objective, technology-driven methods for early detection and diagnosis. This project proposes a computer vision-based approach for detecting autism

by analyzing facial expressions in real-time using Python's OpenCV library and Haar Cascade classifiers. The system processes live video input from a camera, analyzes facial features, and classifies four different types of autism based on key expression patterns. By employing image preprocessing techniques and a trained classifier, the system aims to provide accurate and reliable detection, contributing to early diagnosis. This project highlights the importance of using noninvasive, facial recognition techniques to identify potential indicators of autism, offering an accessible tool for healthcare professionals and caregivers. The research advances the use of machine learning and computer vision in autism detection, paving the way for further developments in assistive technologies.

II. LITERATURE REVIEW

Characteristics of Autism Spectrum Disorder (ASD):

- Ongoing challenges with communication and interaction that occur across different contexts.
- The presence of repetitive behaviors or a pronounced resistance to alterations in daily routines.
- Symptoms generally become apparent during early childhood, often manifesting within the very first years of life.

Header: Brain Growth, Structure, and Connectivity in Autism Spectrum Disorder (ASD) Authors: Bartholomeusz HH, Courchesne E, Karns CM Source: *Neuropediatrics* (October 2002, Volume 33, Issue 5, pp. 239–241)

Info: Research utilizing head circumference measurements in infants and young children diagnosed with autism has shed light on abnormal patterns of early brain development. Head circumference, a reliable indicator of brain size in early postnatal stages, has been pivotal in identifying both accelerated and reduced growth tendencies in Autism Spectrum Disorder (ASD). Numerous studies have reported unusually large head circumferences in children with ASD, particularly around the time when symptoms first become noticeable. These findings underscore significant deviations in brain growth trajectories that are associated with ASD.

Header: Nutrition and the Development of Autism Spectrum Disorder (ASD) Authors: Thommen, E., Suarez, M., Guidetti, M., Guidoux, A., Rogé, B., & Reilly, J. S. Source: *Understanding Emotions in Children with Autism: Crossed Perspectives According to Tasks*, *Enfance*, 2010; Volume 3, pp. 319–337.

Info: Both parents and doctors working with children diagnosed with autism spectrum disorder (ASD) have observed a potential connection between dietary habits and the intensity or frequency of symptoms. Several theories have been proposed to explain this relationship, including the involvement of food additives or specific dietary components in the development of ASD. Recent findings from animal research have revealed that propionic acid (PA), a dietary short-chain fatty acid commonly used as a food additive, can trigger neuroinflammatory responses and

behavioral changes in rats that closely resemble symptoms associated with ASD.

III. OBJECTIVE

- Develop a HAAR Cascade-based Detection System: Create a system using HAAR Cascade classifiers to detect ASD-related facial features and distinguish between specific ASD types, this includes Asperger Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), and Classic Autism.

- Train and Validate Classifiers: Train individual HAAR Cascade models for each ASD subtype using labeled positive and negative image samples, ensuring reliable feature identification for each condition.

- Evaluate Feasibility of HAAR Cascade for Complex Detection: Assess the effectiveness of HAAR Cascade, traditionally used for simpler tasks, in identifying nuanced facial features related to ASD, and determine its potential in this more complex application.

- Contribute Foundational Research for Future Approaches: Establish baseline findings on HAAR Cascade's applicability in ASD detection to inform and inspire future studies, potentially combining this approach with deep learning for improved accuracy.

- Enhance Early Diagnostic Accessibility: Explore the potential of an image-based system to support accessible early diagnosis, especially in under-resourced areas, ultimately aiding in timely intervention for individuals with ASD.

IV. BACKGROUND

Autism Spectrum Disorder (ASD) is a A multifaceted neurodevelopmental disorder characterized by challenges in connecting with others, navigating social interactions, and engaging in repetitive behavioral patterns. As a spectrum disorder, its severity and expression differ significantly among individuals. Timely diagnosis is crucial to enable interventions that can greatly enhance developmental progress and quality of life for those affected. Nonetheless, conventional diagnostic techniques predominantly depend on behavioral evaluations, which are inherently subjective and can vary based on the expertise and perspective of the evaluator.

One promising approach to improving diagnosis is the use of machine learning and computer vision techniques, particularly those focused on facial expression analysis. Studies have shown that individuals having Autism Spectrum Disorder (ASD) often exhibit distinct facial expression patterns and emotional responses compared to neurotypical individuals. These differences, though subtle, can be detected by automated systems designed to analyze facial features and expressions, providing an objective and non-invasive diagnostic tool.

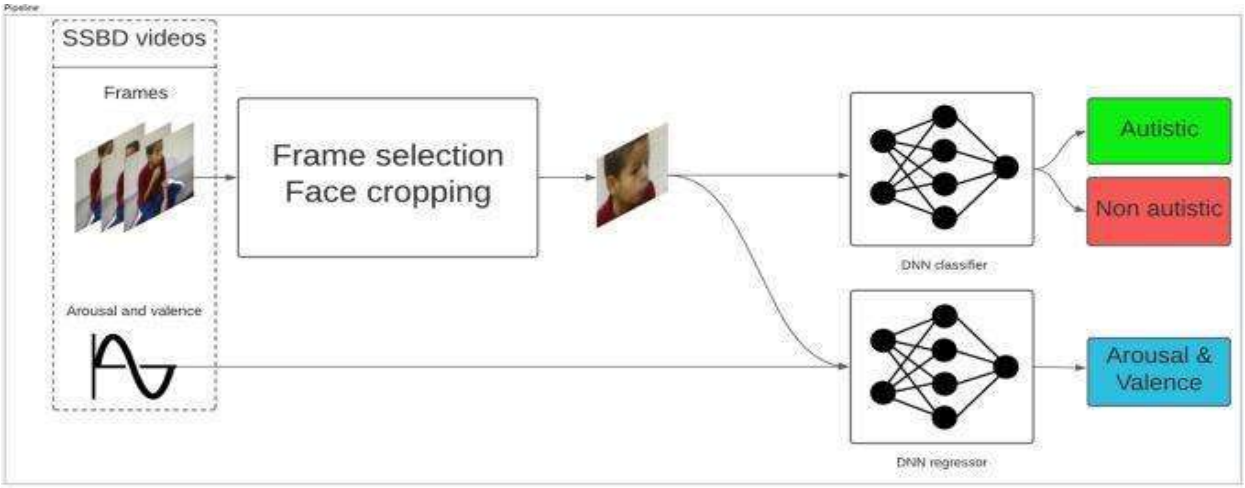


Fig - 1

Fig description – Here we can see the frame selection algo in pictorial form also here we crop the face of child for further process.

(i) HAAR Cascade Classifier for Object Detection

The HAAR Cascade Classifier is a learning-based method used for object spotting in images and video streams. Originally developed for face detection, HAAR Cascade uses simple rectangular features to identify objects based on the presence of particular patterns in the image. It works by scanning an image at multiple scales and detecting faces by analyzing the image at various resolutions. The classifier is trained using a dataset of positive (faces) and negative (non-faces) examples, learning to distinguish between these two by detecting the patterns that differentiate them.

In the context of ASD detection, the HAAR Cascade Classifier can be extended beyond simple face detection to identify specific facial features and expressions that may indicate ASD. By training the classifier with a labelled dataset of facial images from individuals with different types of autism, the system can learn to recognize facial expression patterns corresponding to Asperger Syndrome, Childhood Disintegrative Disorder, PDD-NOS, and Classic Autism.

(ii) OpenCV and HAAR Cascade for Autism Detection

In addition to facial expression analysis, other important technologies used in this project include the OpenCV library, which provides a comprehensive set of tools for

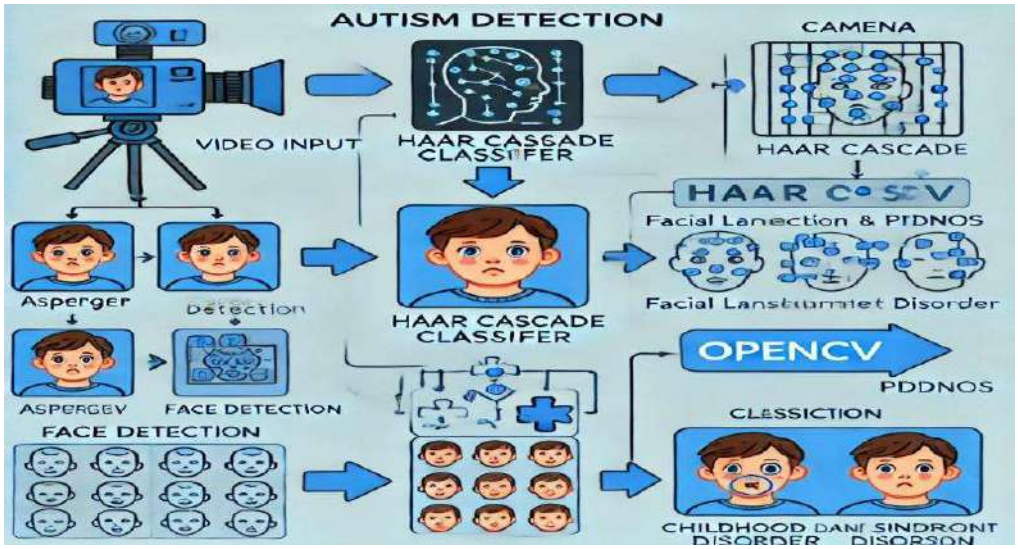


Fig - 3

Fig description - This fig explains the steps involved in identifying autism spectrum disorders through facial recognition and classification algorithms.

real-time computer vision tasks, such as image processing, feature extraction, and object detection. OpenCV helps process video input, detect faces in real-time, and analyze facial expressions by tracking facial landmarks. By combining HAAR Cascade with these technologies, A system can be designed to identify and categorize autism-related expressions with greater speed, consistency, and potentially higher accuracy compared to conventional methods.

This theoretical background highlights the foundation for applying computer vision techniques like HAAR Cascade Classifiers to ASD detection, providing the necessary framework for this project's development and offering a pathway for further advancements in early diagnosis and intervention.

(iii) Facial Morphology with HAAR Cascade

This project aims to create a system utilizing Python's OpenCV library and the HAAR Cascade Classifier to examine facial expressions and categorize four specific forms of autism: Asperger Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), and Classic Autism. By training the classifier with a dataset of facial images labelled according to these types, the system aims to detect and classify facial expressions in real-time video inputs, offering a valuable, non-invasive diagnostic tool for healthcare professionals.

V. PROBLEM DEFINITION

The project "Autism Detection Using HAAR Cascade Machine Learning Algorithm" aims to address the challenge of identifying autism spectrum disorder (ASD) characteristics through facial feature analysis. Autism Spectrum Disorder encompasses a variety of developmental conditions that impact social interaction, communication, and behavioral patterns, and its early detection remains a critical need. Traditional diagnosis often depends on behavioral assessments conducted by specialists, which can be time-consuming and may delay early intervention. This project explores the feasibility of using the HAAR Cascade machine learning algorithm to detect specific facial features associated with four ASD subtypes: Asperger Syndrome, Childhood Disintegrative Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), and Classic Autism are developmental conditions that fall under Autism Spectrum Disorder (ASD). This project aims to adapt and train the HAAR Cascade classifier, a tool typically used for object detection in images, to identify facial patterns and features associated with these specific ASD subtypes. The core goal is to create a prototype system capable of analyzing facial images and, using HAAR Cascade-based models, either classify them under an ASD subtype or indicate the absence of ASD-related characteristics. However, due to the complexity of ASD and the subtle differences in facial features, this initiative serves as a foundational exploration into ASD detection through technology. It provides a basis for future advancements, such as incorporating deep learning models, to enhance detection accuracy and reliability.

VI. METHODOLOGY AND DESIGN

The proposed methodology involves several key steps. First, a dataset of facial images representing individuals with various types of autism will be collected. This dataset This will form the basis for training the HAAR Cascade classifier. Various image preprocessing techniques will be employed to improve the quality of the input data. ensuring that the classifier can accurately detect and analyze facial features.

Once the model is trained, the system will utilize real-time video input from a camera to capture facial expressions. The trained classifier will process each frame to identify and classify the detected expressions, providing insights into the potential indicators of autism.

Planning

The planning phase was critical in defining the project's core objectives and setting a clear direction for the development process. Key goals included the need for real-time data updates, a highly responsive user interface, and secure authentication mechanisms. The goal behind this project is to develop a system that uses the HAAR Cascade algorithm to detect autism-related traits in individuals based on facial expressions or behavioural patterns. The system will analyze images or video streams in real time, providing insights or alerts for caregivers or medical professionals.

To meet these goals, it was crucial to select appropriate technologies and tools. The decision to use Next.js for the front end and Convex for the back end reflected a focus on real-time performance and scalability. Additionally, robust authentication was identified as a key requirement, leading to the selection of OAuth2 to enable secure logins through third-party providers such as Google.

Design

In the design phase, the platform was modeled with a modular architecture. This design allowed for the independent development and deployment of core components, such as the frontend, backend, authentication, and database systems. The modular approach not only enhanced flexibility but also ensured that each component could be developed and tested individually, reducing the risk of integration issues later in the development cycle.

The machine learning module, integrated with OpenCV, will employ the HAAR Cascade classifier to detect facial attributes and features indicative of autism. This classifier will undergo training using a meticulously curated collection of facial images, ensuring its capability to recognize autism-related traits promptly and with high efficiency. The system will preprocess the data (e.g., converting images to grayscale and detecting facial regions) to optimize detection speed and accuracy. The database (ikely MongoDB) will store user profiles, session data, and detailed reports, offering an easily accessible way to manage and retrieve data.

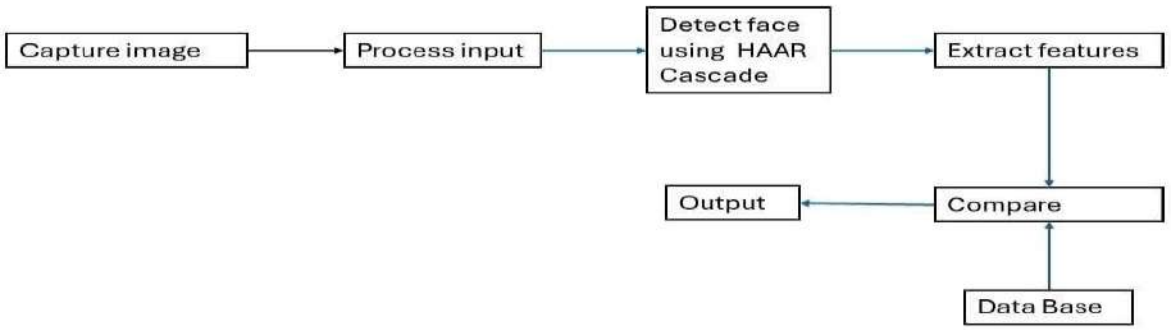


Fig - 3

Fig description – Block diagram to show process in simple manner.

FUTURE SCOPE

The future scope of the project "Autism Detection Using HAAR Cascade" could include several promising advancements and extensions to enhance its utility, accuracy, and scalability. Here are some key areas for future exploration:

1. Incorporating Deep Learning Models: Although HAAR Cascade offers reliability in fundamental feature detection, advanced deep learning frameworks, such as Convolutional Neural Networks (CNNs) and specialized models like ResNet, are better equipped to identify intricate and subtle patterns with greater precision. Combining HAAR Cascade with deep learning could improve the system's ability to differentiate ASD-related facial features from typical features.

2. Development of a Hybrid Model: Creating a hybrid system that combines HAAR Cascade for initial facial region detection with deep learning for in-depth analysis could enhance detection accuracy. This combination could refine feature extraction and improve classification across different ASD subtypes.

3. Expanding Dataset Diversity and Size: Gathering a larger, more diverse dataset with a variety of facial expressions, ages, and ethnic backgrounds could help the system generalize better and perform more accurately across different populations. Including more labeled examples for each ASD subtype would also improve model training.

4. Feature Expansion Beyond Facial Analysis: While this project focuses on facial features, incorporating other ASD

indicators—such as gaze patterns, facial expressions, or head movements—could enhance early detection capabilities. Future models might analyze video data to capture behavioral indicators that complement static image analysis.

5. Mobile and Cloud Deployment for Remote Screening: Developing a mobile app or cloud-based platform could make ASD detection more accessible, allowing caregivers or educators to conduct preliminary screenings. A remote application could support rural and underserved areas with limited access to healthcare services.

6. Multi-stage Diagnostic Pipeline: Creating a multi-stage diagnostic tool could allow the system to flag potential cases and guide them for further in-depth assessment by specialists. This staged approach could be beneficial in clinical settings, where early-stage screening can lead to a more detailed follow-up evaluation.

7. Integration with Clinical and Educational Tools: Partnering with healthcare providers and educational institutions to incorporate this tool into existing diagnostic workflows could support a more holistic diagnostic approach, combining facial analysis with traditional behavioral assessments.

8. Investigating Alternative Learning Methods: Future studies might consider utilizing other learning approaches, like Support Vector Machines (SVMs) or decision trees, to enhance or fine-tune the classification process. Testing these methodologies could aid in identifying the most effective model tailored to specific ASD subtypes.

9. Ethical and Privacy Considerations: As the project scales, addressing ethical considerations, such as data privacy, informed consent, and appropriate usage, becomes critical. Implementing strict privacy standards and transparency about data handling can build trust with users and ensure responsible technology deployment.

10. Continuous Learning System: Implementing a system that learns continuously from new data, using semi-supervised or unsupervised learning techniques, could allow the model to improve over time. This adaptive learning could make the system more robust and responsive to subtle changes in ASD-related research.

Implementing these future strategies has the potential to develop a robust, user-friendly, and precise ASD screening system. Such a tool could play a critical role in facilitating early diagnosis and providing essential support for individuals on the autism spectrum.

ACKNOWLEDGEMENT

We extend our sincere gratitude to D Y Patil International University for providing the essential resources and support for this research. We sincerely thank our mentor for their invaluable guidance and our peers for their support and insightful feedback.

CONCLUSION

In conclusion, the "Autism Detection Using HAAR Cascade" project represents a significant first step in exploring the potential for technology-assisted early screening of autism spectrum disorder (ASD). By adapting the HAAR Cascade algorithm—commonly used in simpler object detection tasks—this project set out to determine if facial features associated with specific ASD subtypes could be identified. Through separate models trained for Asperger Syndrome, Childhood Disintegrative Disorder, PDD-NOS, and Classic Autism, the project aimed to classify ASD-related characteristics and distinguish them from non-ASD traits.

Despite the inherent challenges, such as the subtlety of ASD-related facial features and the limitations of HAAR Cascade in complex feature differentiation, this project demonstrated the feasibility of an image-based approach to ASD screening. The results underline the importance of high-quality training data and suggest that more advanced machine learning models, such as deep learning, may be needed to enhance accuracy and reliability.

This project opens the door for further research and improvement, including the use

of hybrid models, expanded datasets, and the integration of complementary behavioral indicators. With continued development and ethical consideration, such technology holds promise for aiding early ASD detection, making preliminary screening more accessible, and potentially supporting earlier intervention. Ultimately, this work provides a foundation upon which more sophisticated, effective diagnostic tools for ASD can be built in the future.

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CNN-Enhanced Multi-Sensor Fusion for Autonomous Robotic Navigation in Hazardous Environments.

Prakash Malvadkar [1] Sunita Deshmukh [2] Pooja Pawar [3]
Department of Electronics Engineering (VLSI D&T)
KJCOEMR Pune

Abstract: - Robotic vehicles are emerging as transformative tools for addressing hazardous environmental challenges through autonomous navigation. Accurate front wheel angle prediction and position adjustment based on visual data are critical in this field. This paper presents a multi-sensor fusion framework combining CNN-based image processing with ultrasonic sensors and vehicle parameters to enhance steering precision and decision reliability. The CNN processes images for robust, context-aware decisions. Clustering tasks take 1.5 times longer than navigation but ensure smooth sequential operation. An in-house robotic model, controlled by a Raspberry Pi with ultrasonic sensors and a camera, implements the system. TensorFlow and MATLAB enable precise angle predictions and effective decisions. The robotic vehicle transitions efficiently between tasks, optimizing time and energy. Experimental results highlight significant improvements in execution, decision-making, and efficiency, making this framework suitable for real-time applications.

Keywords: *convolutional neural networks (CNN), Tensor Flow, Decision Making*

I. Introduction:

Autonomous vehicles hold immense potential to transform transportation by enhancing safety, as they significantly reduce accidents caused by human error. They improve traffic efficiency by optimizing routes and minimizing congestion, leading to shorter travel times. These vehicles also increase accessibility, offering mobility solutions for the elderly, disabled, or those unable to drive. Additionally, their energy-efficient designs and smooth driving patterns contribute to reduced fuel consumption and lower emissions, supporting environmental sustainability[1]. The history of driverless cars dates back to the mid-20th century, with early concepts appearing in the 1950s as part of futuristic visions of automated highways. In the 1980s, advancements in robotics and

computing led to significant progress, notably with Carnegie Mellon University's Navlab project and Mercedes-Benz's early autonomous prototypes. The 2000s saw breakthroughs with DARPA's Grand Challenges, which spurred innovation in self-driving technology. By the 2010s, companies like Google, Tesla, and Waymo accelerated development, bringing autonomous vehicles closer to commercial reality. To develop the automated driverless electric vehicle multi sensor fusion is playing pivotal role. This paper aims to present a multi-sensor fusion framework combining CNN-based image processing with ultrasonic sensors and vehicle parameters to enhance steering precision and decision reliability. The following section is describing the literature survey.

Ren Yue et al. conducted research on vehicle collision avoidance and vehicle motion estimation. They used a Kalman filter algorithm to estimate the relative speed and distance state of the vehicle. Additionally, they utilized Prescan software to analyse the risk of collision avoidance control. The simulation results show that the proposed estimation algorithm can provide an accurate motion relationship between the host vehicle and the front vehicle or obstacle[2].Ben-Li et al worked with Semi-Automatic Video Labeling Tool for Multi-Object Detector and Tracker. They exhibited multi object detector and tracker using open source tool of VATIC. A multi-object detector and tracker is first used to annotate the video. Possible errors in the labeling of the objects are identified and then presented to human annotators to produce correct annotations[3].Ming Tsai et al Designed the Autonomous Surface Vehicle enabled with AI-based Sensing Capability. They study demonstrates the design and applications of an ASV with an AI-based sensor. The functions of the proposed ASV include autonomous sailing, remote communications, smart 3D mapping, and real-time image detection and identification[4]. Jean-Pierre et el studied the highlights of problems and complexity of sensor applications in the autonomous vehicles. They elaborates the layered sensor network to remove the complexity of the sensing the data[5]. Francisco et al demonstrated system that fuses radar blob and camera data. The obstacle detection process and classification is divided into three stages, the first consist in reading radar signals and capturing the camera data, the second stage is the data fusion, and the third step is the classify the obstacles, aiming to differentiate the obstacles types identified by the radar and confirmed by the computer vision[6]. Seongwook et al worked based on the SVM technique classification for classifying vehicles in the live system. For the classification they proposed 77-GHz automotive frequency modulated continuous wave radar system[7].

Based on the literature survey a multi-sensor fusion framework combining CNN-based image processing with ultrasonic sensors and vehicle parameters to enhance steering precision and decision reliability. The CNN processes images for robust, context-aware decisions. Clustering tasks take 1.5 times longer than navigation but ensure smooth sequential operation. An in-house robotic model, controlled by a Raspberry Pi with ultrasonic sensors and a camera, implements the system. TensorFlow and MATLAB enable precise angle predictions and effective decisions. The robotic vehicle transitions efficiently between tasks, optimizing time and energy. Experimental results highlight significant improvements in execution, decision-making, and efficiency, making this framework suitable for real-time applications.

II. Proposed Methodology:

The proposed methodology is the final fusion signal getting from the input data from the different sensors. Available algorithm for whole scenario is complicated in terms of cost time and design. From this paper the movement of sequential task completing robot is done in different sections.1st section is scanning of surrounding environment is done with ultrasonic sensor. With the help of surrounding particles in the environment cluster is designed. Auto tuning of front wheel angle and distance map is 1) decided with the help of cluster formed. Designed 2) the whole methodology is working on sequential fusion with multistage fusion. The machine learning algorithm is used to save past cluster data where action has to be taken and used for next clustering operation. The schematic operation of proposed methodology is given in fig no 1.

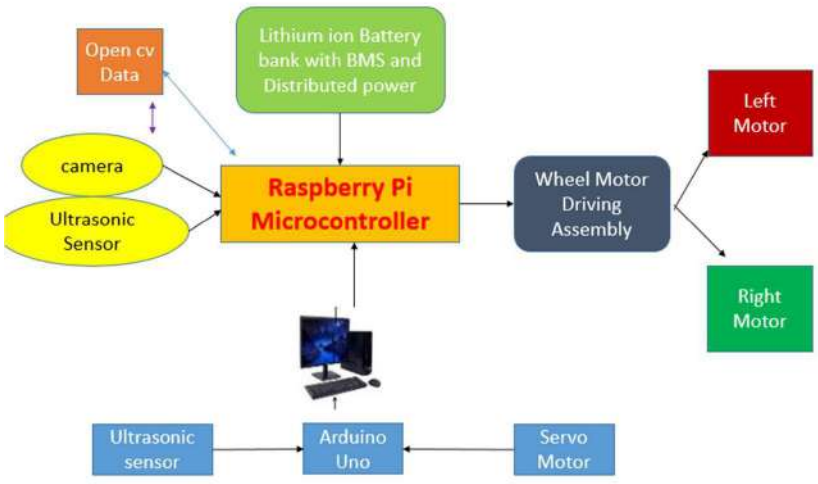


Fig 1: Block diagram of proposed method

III. Working Mechanism:

The proposed methodology outlines an integrated system for autonomous robotic navigation and decision-making, combining hardware components and advanced software algorithms. The system is structured around two primary modules: Sensor Data Acquisition and Image-Based Decision-Making. In the first module, an **Arduino microcontroller** controls ultrasonic sensors mounted on a servo motor, which sweep across a 180° arc to measure distances to obstacles in the robot's environment. These distance measurements, along with the corresponding angles, are processed in real-time by the Arduino and sent to the **Raspberry Pi** for further analysis. The Raspberry Pi uses this data to generate a **distance map** that helps determine the optimal front wheel angle, ensuring smooth navigation and obstacle avoidance. In the second module, the Raspberry Pi is equipped with a camera that captures real-time images of the environment. These images are processed using a pre-trained **Alex Net Convolutional Neural Network (CNN)**, which classifies objects in the environment based on learned patterns. The CNN's classification results are used to make real-time decisions, such as triggering an obstacle avoidance maneuver or activating specific actuators for task execution.

The communication between the Arduino and Raspberry Pi is managed through **serial interfacing**, where the Raspberry Pi synchronizes the sensor data with the image classifications. Python scripts on the Raspberry Pi handle this data exchange, ensuring seamless integration between the sensor inputs and the visual data processed by the CNN. By combining the distance map from the ultrasonic sensors with the image classification results from the camera, the system enables the robot to make intelligent, real-time decisions about its environment. Furthermore, the system is designed to evolve with time through the integration of machine learning, which will store past cluster data and use it to optimize decision-making in future operations. This capability will allow the robot to learn from previous tasks and environmental conditions, reducing processing time and improving overall efficiency.

3.1 Radar System

The radar system for an autonomous robot uses an ultrasonic sensor on a servo motor to detect objects, measure their distance and angle, and visualize them in a radar-like display. It

calculates obstacle distance by measuring the time delay between emitted and received sound pulses.

$$d = t.\frac{v}{2}$$

where d is the distance in centimetres, t is the measured time delay in microseconds, and v is the speed of sound in air, approximately 0.0343 cm/μs.

The servo motor sweeps the ultrasonic sensor across a 180-degree arc, capturing distance measurements to map obstacles. The Arduino sends angle and distance data to a PC, where Processing visualizes the radar pattern by converting polar to Cartesian coordinates.

$$x = d.\cos(\theta) \ , \quad y = d.\sin(\theta)$$

To fit the distance measurements within the radar display, a scaling factor (S is applied to the coordinates, yielding.

$$x' = s.x \qquad y' = s.y$$

The radar system features concentric arcs for distance ranges and a rotating red line that scans and marks obstacles as red points in real time. A 15-millisecond delay between servo movements ensures smooth and accurate operation.

3.2 Mapping Surroundings Using Cluster Data and Machine Learning with UV Sensors.

The proposed methodology establishes communication between an Arduino microcontroller and a Raspberry Pi via serial interfacing for efficient sensor fusion and real-time decision-making. The Arduino manages the ultrasonic sensor and servo motor, collecting spatial data by sweeping the sensor across a 180-degree arc. This data, including obstacle distances and angles, is transmitted to the Raspberry Pi, which processes it alongside camera-based image inputs. Python scripts ensure seamless synchronization between sensor data and image classifications, enabling effective decisions. The Arduino excels in precise sensor control and rapid data collection, while the Raspberry Pi executes advanced computations, such as CNN models, for intelligent navigation. By introducing clustering, the system optimizes decision-making by dividing the environment into manageable sections, reducing complexity and cost. The robot

operates in two slots: scanning with ultrasonic sensors and measuring object distances based on time of flight, ensuring adaptive performance in dynamic environments.

$$d = t.\frac{v}{2}$$

- d: Distance measured by the iiird sensor
- t: Time of flight of the ultrasonic signal
- v: Speed of sound in air (343 m/s)

A distance map is generated using sensor data to determine the optimal front wheel angle (α) for precise robotic movement. The angle is calculated by analyzing the angular position (θi) and distance (dj) data, represented as **α = f(θi, dj)**. The environment is divided into clusters, with each cluster representing a specific area or task. The robot processes clusters sequentially, completing tasks one at a time, starting with the first and refining its movement for the next. This approach enhances efficiency by focusing on one task at a time and reducing processing overhead.

3.3 Movement of the Robot Towards Clusters

The robot uses ultrasonic sensors to detect surface conditions by collecting distance data to identify objects, gaps, and flat regions. This data is mapped into clusters using AI algorithms, defining boundaries and classifying regions for movement. In a polar coordinate system, each distance reading did d_i is associated with an angle θi, forming coordinates P(x,y)P(x, y)P(x,y) for each cluster. The robot calculates the centroid of a cluster, with coordinates C_x and C_y, derived from cluster points (x_i,y_i) to align its trajectory effectively. The front wheel angle Φ is adjusted to guide the robot toward the centroid, optimizing its path. The distance 'D' to the next cluster is calculated using the Pythagorean theorem, and the time to travel is derived based on the robot's linear velocity. The number of wheel revolutions needed is determined by relating the wheel radius to the linear displacement, ensuring precise movement and alignment with cluster centroids.

$$\alpha = f(\theta_i, d_j)$$

$$C_{n+1} = g(C_n, \alpha, d)$$

$$P(x, y) = \sum_{i=1}^{n} (d_i \cos(\theta_i), (d_i \cos(\theta_i)$$

$$C_x = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$C_y = \frac{1}{n}\sum_{i=1}^{n} y_i$$

3.4 Distance to Time Relation

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

$$t = \frac{d}{v}$$

$$n = \frac{D}{2\pi r}$$

Convolutional Layers:

$$F_i(x, y) = \sigma(\sum_{i=-k}^{k}\sum_{j=-k}^{k} K_{i,j} I_{i-1}(x + i, y + i) + b)$$

$$(C_x, C_y) = (\frac{1}{n}\sum_{i=1}^{n} x_i, \frac{1}{n}\sum_{i=1}^{n} y_i)$$

Fully Connected Layers:

$$Z = W.P + b$$

$$y = softmax(z)$$

IV. Experimental Setups

Experimental Setup

The experimental setup involves integrating an Arduino Uno, Raspberry Pi 3 Model B, ultrasonic sensor (HC-SR04), servo motor (SG90 9g), and Raspberry Pi Camera Module V2 to implement an AI-driven obstacle detection and decision-making system. The Arduino Uno captures distance and angular data from the ultrasonic sensor and transmits it via USB serial communication to the Raspberry Pi. Using the MATLAB Support Package, the Raspberry Pi processes real-time camera input with the Alex Net CNN model for object detection and decision-making. MATLAB scripts ensure data synchronization, while Python manages device communication. Testing was conducted in a controlled environment featuring both stationary and moving obstacles under varied lighting conditions to evaluate the accuracy of ultrasonic measurements and the reliability of object

detection. The setup showcases effective integration of sensor data with AI-powered decision-making for real-time applications.

Radar System for Cluster Formation

A radar system was implemented to detect environmental conditions and organize detected data into clusters for the proposed autonomous robot. The experimental setup, illustrated in Figure 4, includes a servo-mounted ultrasonic sensor capable of rotating in a 180-degree arc. The ultrasonic sensor emits sound pulses, and the time for their return is used to calculate the distance to obstacles. This data is transmitted to a connected computer and visualized in a radar-like interface. The radar display features concentric arcs for different distance thresholds and a sweeping red line representing the servo's motion. Detected obstacles appear as red points, indicating their distance and angle relative to the sensor. Radar simulation was performed using Processing 4.3 software on a Windows system with an Intel i7 processor.

End-to-End Front Wheel Angle and Displacement Calculations

A novel method for calculating front wheel angles and displacement was developed for autonomous robot navigation. Sample images were fed into the Alex Net pre-trained CNN model for object detection and decision-making. The radar system and associated mathematical models calculated essential navigation parameters. A clustering approach was applied to process radar data, dividing the environment into dynamic clusters. The robot’s movement was determined based on these clusters, allowing for accurate adjustments in front wheel angles and displacement calculations. Radar data processing, cluster design, and software integration were executed on a Windows system with an Intel i7 processor. Once the clusters were formed, the robot navigated from the starting point to the destination, dynamically adjusting its path based on the designed clusters. Figure 5 illustrates the interfacing of the Raspberry Pi controller and sensors within the system.



V. Results and Discussion.

The radar system for an autonomous robot is designed to detect and map objects in the surrounding environment using an ultrasonic sensor mounted on a servo motor. This system provides critical input for robotic navigation by measuring the distance and angle of obstacles and visualizing them in a radar-like display

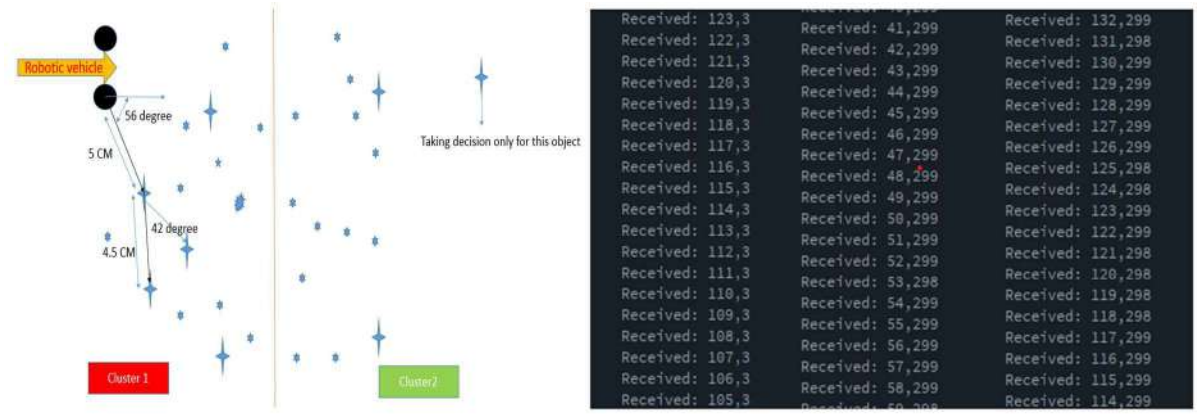


Figure 6: Front Wheel Adjustment with selected Object

The robotic system features a secondary and critical function that ensures precise front wheel angle adjustments to align with the designated target and calculate the required displacement for the robot's travel. This is achieved through the interaction of two ultrasonic sensors interfaced with a Raspberry Pi module and a microcontroller. Python-based integration software is employed to determine front wheel angles and displacement dynamically. Separate algorithms are developed to handle danger flow and navigation.

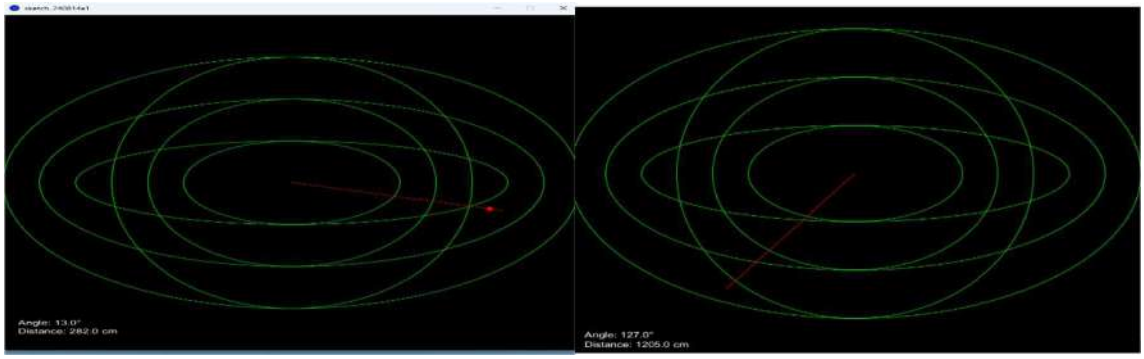


Figure 7: Processing 4.3 windows x 64 software simulation results of the radar system

6.1. Visual Representation

The robot's trajectory is determined by mapping clusters, represented as regions with distinct boundaries, similar to the diagrams provided [23]. Each cluster signifies a step in the robot's path planning, allowing it to detect obstacles, align its wheels, and calculate the distance and time required to move efficiently.

In the visualization, polar coordinates (angle, distance) are converted into Cartesian coordinates (x, y) using mathematical formulas. The radar visualization helps the robot in detecting obstacles and planning navigation, particularly in environments where visual input from the camera might be obstructed. The integration of the radar system with the camera feed and CNN-based decision-making enhances the robot's ability to navigate in complex and hazardous environments

Particle No.	Angle (Degrees)	Distance (cm)	Cluster ID	Action
1	0	50	Cluster 1	Adjust wheel angle slightly
2	5	48	Cluster 1	Move towards detected particle
3	10	52	Cluster 1	Continue navigation
4	15	49	Cluster 1	Adjust wheel angle slightly
5	20	51	Cluster 1	Maintain movement
6	25	50	Cluster 1	Continue navigation
7	30	47	Cluster 1	Adjust wheel angle slightly
8	35	48	Cluster 1	Move towards detected particle
9	40	50	Cluster 1	Adjust wheel angle
10	45	49	Cluster 1	Navigate towards detected area
11	50	51	Cluster 1	Maintain movement
12	55	48	Cluster 1	Slightly rotate wheel
13	60	47	Cluster 1	Move to the next particle
14	65	49	Cluster 1	Continue navigation
15	70	50	Cluster 1	Adjust displacement
16	75	48	Cluster 1	Move towards detected particle
17	80	46	Cluster 1	Rotate wheel slightly
18	85	47	Cluster 1	Navigate towards detected area
19	90	49	Cluster 1	Adjust wheel angle
20	95	50	Cluster 1	Maintain movement
21	100	52	Cluster 1	Move towards next particle
22	105	48	Cluster 1	Slightly adjust wheel direction
23	110	49	Cluster 1	Continue navigation
24	115	50	Cluster 1	Maintain movement
25	120	47	Cluster 1	Adjust displacement and proceed

Table 1: Angle and distance for making clusters.

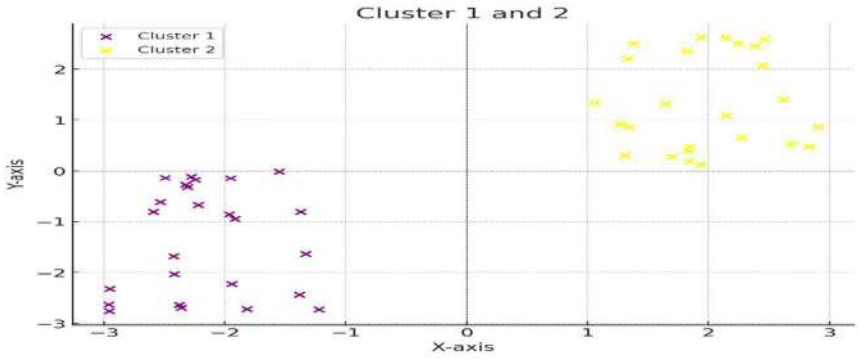


Figure 8: Visual Representation of clusters

The cluster diagram demonstrates two distinct groups, Cluster 1 and Cluster 2, plotted in a 2D space. Cluster 1 is represented with purple markers and primarily occupies the lower left quadrant, while Cluster 2, marked in yellow, is located in the upper right quadrant. The clustering process visualizes the separation of data points based on features such as proximity or similarity, which is critical for decision-making in robotics. This segmentation helps the robot analyse environmental patterns efficiently for tasks like obstacle detection and navigation.
Three diagrams showcasing the clusters have been created. Each visualizes different combinations of cluster interactions. Here's a detailed explanation for the context

6.2. Traveling map of robot

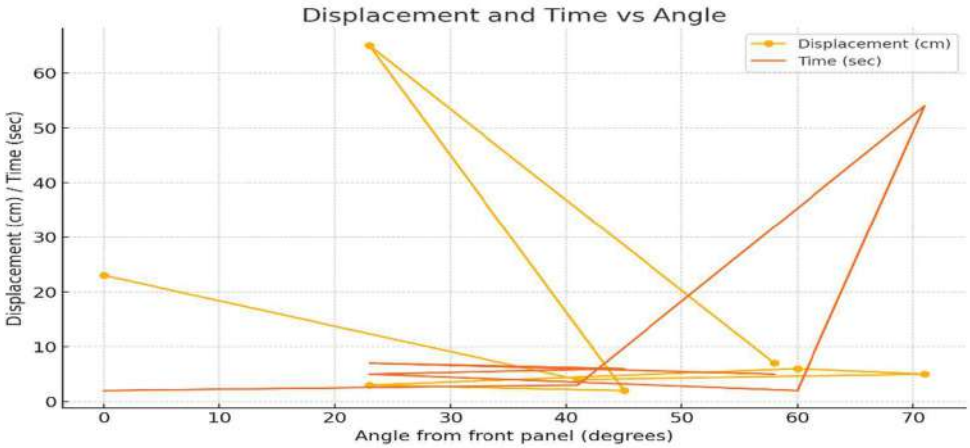


Figure 9: Moving track of radar for radar data for decision making
The proposed system integrates advanced sensor technology and AI-driven algorithms, combining CNN-based image detection, ultrasonic sensors, and radar clustering to achieve autonomous navigation and obstacle avoidance. A Raspberry Pi module interfaces with ultrasonic sensors and a microcontroller to gather environmental data, dynamically adjusting front wheel angles and calculating displacement pulses for precise navigation. Radar-based clustering guides the robot's path, while deep learning techniques enhance object detection and decision-making. Experimental readings, including wheel angle adjustments, displacement time, and distance travelled, demonstrate the system's efficiency in navigating complex environments, representing a significant advancement in robotic vehicle design for hazardous applications.

6.3. Real-Time Image Collection and Decision-Making Using Pre trained Alex Net CNN

The experimental setup integrates a Raspberry Pi microcontroller with a camera module to capture real-time images, which are processed using OpenCV and classified with AlexNet CNN models implemented in MATLAB. Operating in a dynamic field environment, the robotic vehicle utilizes radar signals for front wheel angle and displacement adjustments, while a multi-stage sensor fusion approach incrementally processes data to minimize computational complexity and cost. Real-time

images are compared with pre-stored datasets, enabling precise decision-making as the robot navigates and detects its target position. This method demonstrates superior performance in

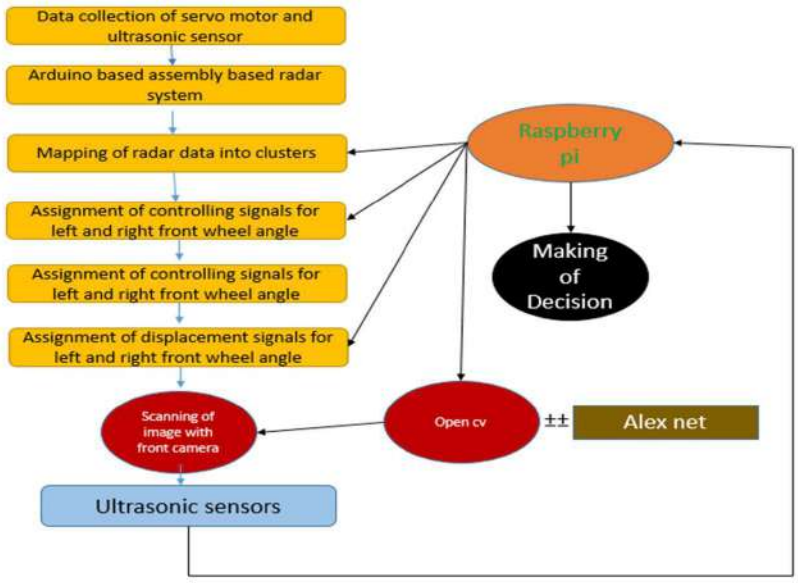


Figure 10: working flow diagram

hazardous environments, achieving accurate navigation, efficient obstacle detection, and reduced power consumption compared to traditional systems. By leveraging AI-driven algorithms, radar-based navigation, and multi-stage data processing, the system showcases significant advancements in robotic vehicle design, offering improved adaptability, reliability, and safety in dynamic and hazardous conditions.

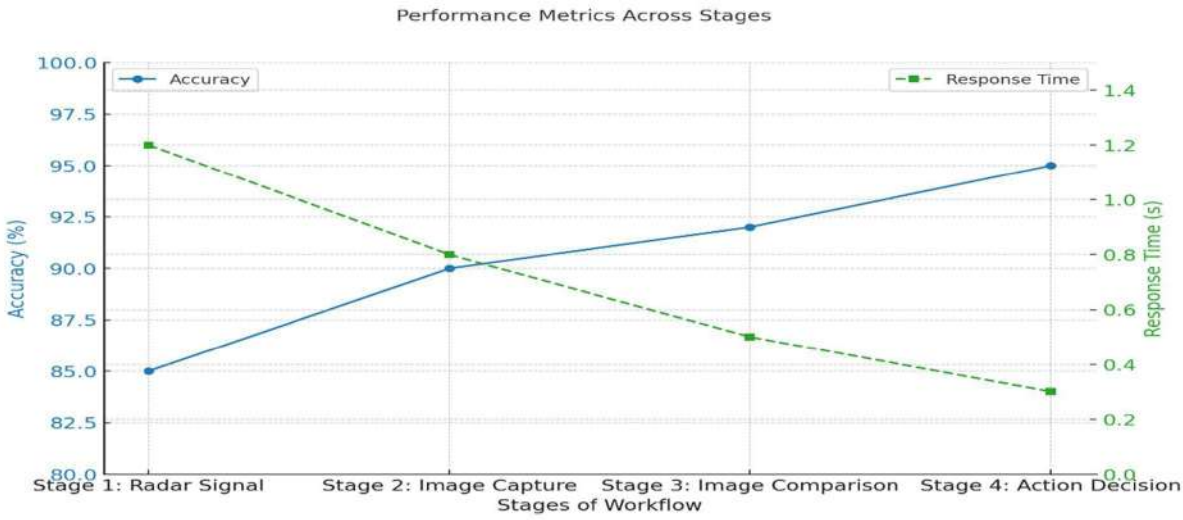


Figure 11: Decision making with accuracy provided by Alex net CNN

Real-Time Image Collection and Decision-Making Using Alex Net CNN

Performance Matrix	Traditional methods	AI-Based System(Proposed)
Navigation Accuracy(%)	68-75	93
Obstacle Detection Efficiency(%)	65-70	95
Decision Making Speed(ms)	800-1200	300
Power Consumption (Watt-hours)	130-150	90
Real-Time Adaptability(/10)	5-6	9

Table 2: Summary of performance matrix comparison

6.4. Data set for this method

The proposed AI-based method, leveraging OpenCV for real-time image processing and AlexNet CNN for classification, demonstrates superior performance compared to traditional approaches like Dijkstra's algorithm, especially in dynamic and hazardous environments. The system efficiently processes camera-captured images by applying Gaussian blurring, normalization, and edge detection, synchronizing the processed image data with ultrasonic sensor readings for precise navigation. Unlike Dijkstra's algorithm, which relies on pre-mapped and structured environments with high computational overhead, the AI-based method adapts in real-time to unknown terrains with cluster-based obstacle detection, ensuring low latency and cost-effectiveness through optimized hardware integration. This method is ideal for hazardous areas and dynamic terrains, offering enhanced flexibility, real-time adaptability, and reduced operational costs compared to traditional systems designed for static road maps or indoor navigation.

Comparison of This Method with Another Method

Comparison Table:2

Feature	Proposed AI-Based Method	Dijkstra's Algorithm
Environment	Dynamic and hazardous	Structured and pre-mapped
Real-Time Adaptation	Yes	Limited
Obstacle Handling	Real-time cluster-based object detection	Requires pre-defined obstacle data

Feature	Proposed AI-Based Method	Dijkstra's Algorithm
Computational Overhead	Low (optimized for real-time applications)	High (graph computations)
Flexibility	Works in unknown/unstructured environments	Limited to structured paths
Cost-Effectiveness	High (low-cost hardware + AI integration)	Moderate to high
Applications	Hazardous areas, dynamic terrains	Indoor navigation, static road maps

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Design and Evaluation of Passive Balancing Techniques for Series-Connected Li-Ion Cell

Prof.Pooja R Shastri[1]

Prof. Balwantsingh Bisht[2]
Assistant Professor in Electrical Engineering Department
K J COEMR Pune
poojashastri.kjcoemr@kjei.edu.in

Prof. Mugdha Deshpande [3]

Abstract

Lithium-ion battery packs, widely used in electric vehicles and energy storage systems, require effective battery management systems (BMS) to ensure safety, longevity, and performance. A key function of the BMS is cell balancing, which equalizes the voltage or state of charge (SoC) of individual cells. Passive cell balancing, a commonly used method, discharges excess energy from higher-voltage cells through resistors, aligning cell voltages without transferring charge among cells. This paper presents a comprehensive study of passive cell balancing, discussing its operation, advantages, limitations, and implementation considerations. Experimental and modeling insights are used to evaluate its efficiency and suitability for various applications. The results underscore the trade-offs between simplicity, energy loss, and balancing speed in passive balancing systems.

Keywords: Battery management systems; Passive cell 1.

1. Introduction

As lithium-ion batteries become central to energy storage in electric vehicles (EVs), renewable energy systems, and consumer electronics, maintaining optimal battery performance and safety has become increasingly important. Battery packs are composed of multiple cells connected in series and parallel configurations. Due to manufacturing inconsistencies, aging, and varying operating conditions, individual cells often diverge in capacity and state of charge (SoC) over time [1], [4]. These disparities can lead to several problems: overcharging of stronger cells, undercharging of weaker ones reduced usable capacity, and accelerated degradation. Cell balancing mitigates these issues by equalizing cell voltages, ensuring the pack operates safely within its limits [2]. Among balancing techniques, passive balancing is favored for its simplicity, cost-effectiveness, and minimal hardware complexity. Unlike active balancing, which redistributes energy among cells, passive methods dissipate surplus energy as heat via resistors. This paper investigates passive balancing architectures, highlighting their implementation, performance trade-offs, and applicability in constrained systems such as small EVs and backup power units [3], [5].

2. Passive Cell Balancing Methods

Passive cell balancing operates by dissipating excess energy from higher-voltage cells as heat, using relatively simple electrical components. This section presents three major types of passive balancing techniques and outlines their control methods, typical use cases, and advantages.

2.1 Resistive Bypass Balancing

Resistive bypass balancing is the most widely adopted passive balancing method due to its simplicity and ease of implementation [3], [4]. In this approach, when a cell voltage exceeds a predefined threshold (typically close to the maximum charge voltage, e.g., 4.2 V for Li-ion), a MOSFET switch activates a parallel resistor to discharge the cell. The discharge continues until the cell voltage falls within an acceptable range relative to others in the pack. Control of the discharge process can be executed in two primary ways: On/Off Control: The MOSFET turns on fully once the threshold is exceeded. Pulse Width Modulation (PWM): Allows finer control over discharge rate and thermal output, using a switching frequency such as 1 kHz or 10 kHz [6]. Continuous Balancing: The resistive path remains active as long as the voltage difference persists. Switched Balancing: The resistor is only periodically engaged, reducing average power dissipation and thermal stress. This method is commonly employed in small-to-medium battery packs, such as those in hybrid EVs, drones, and consumer electronics [3]

2.2 Shunt Regulator Balancing

Shunt regulator balancing utilizes dedicated analog components—such as the TL431 voltage reference IC—to clamp the cell voltage once it reaches a certain limit. These regulators effectively act as voltage-controlled current sinks that divert charge away from the cell when overvoltage is detected [1]. The control is entirely analog, relying on the internal reference and feedback loop of the shunt regulator to maintain voltage stability. This method is advantageous in low-cost, low-complexity systems, such as industrial backup supplies or handheld devices, where minimal digital control is available [5]

3. Methodology

The methodology of this study involves both theoretical analysis and simulation-based validation of passive cell balancing strategies. The following steps were carried out:

3.1 Balancing Circuit Design

The basic passive balancing circuit consists of: resistive load (balancing resistor), MOSFET switch controlled by the BMS, Voltage sensing circuitry for each cell. The BMS continuously monitors the cell voltages. When a cell exceeds a preset threshold (typically near full charge, e.g., 4.2V for Li-ion), the switch closes, and current is shunted through the resistor, thereby discharging the cell until its voltage aligns with others in the series string [3], [6].

3.2 Simulation Model

A MATLAB/Simulink model was developed to simulate a 4-cell Li-ion pack with an initial SoC imbalance of 5%. Passive balancing logic was implemented to activate balancing resistors when any cell exceeded 4.15V. Simulations were run under constant current charging conditions, and key metrics such as time to balance, energy loss, and cell temperature were observed [5].

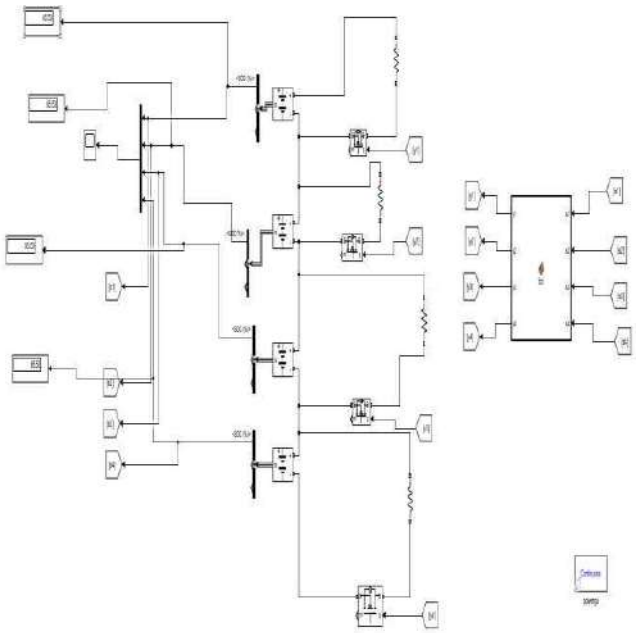


Fig. 1 Matlab Simulink Model

3.3 Performance Metrics

The system was evaluated using the following criteria: Balancing Time: Time taken to reduce voltage mismatch below 10 Mv. Energy Efficiency: Ratio of energy dissipated to total charge capacity Thermal Analysis: Heat generated and temperature rise across balancing resistors. These metrics provide insight into the practicality of passive balancing in real-world systems and help assess its applicability to specific battery pack configurations and use cases [4]

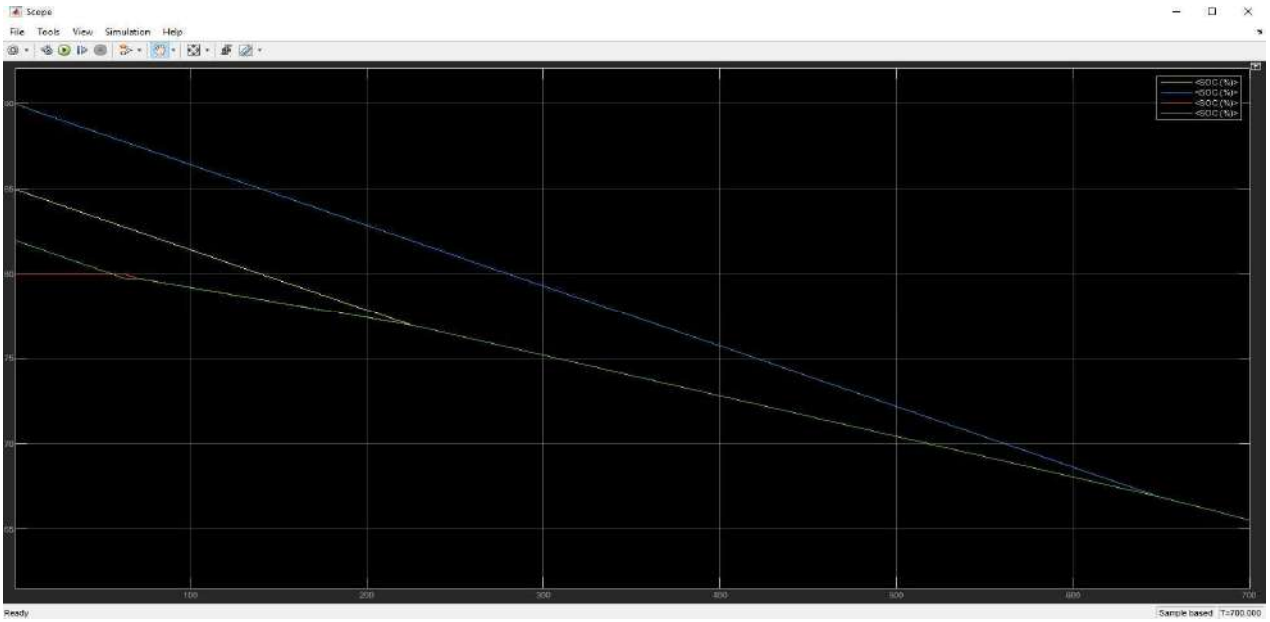


Fig.2 Matlab Result

4. Conclusion

The simulation of passive cell balancing for a series-connected 6-cell Li-ion battery pack demonstrates effective voltage equalization over time using resistor-based discharge circuits controlled by the BMS. The results indicate that all cells achieve near-perfect balance after approximately 650 seconds, converging to a state of charge (SoC) level of 65.53%. Intermediate balancing events highlight the dynamic nature of the process: at 80 seconds, Cell 3 balances with Cell 4 at an SoC of about 79%, and 230 seconds, Cells 1 and 4 balance when the SoC drops to approximately 75%. Subsequently, Cells 2 and 4 equalize at the final SoC of 65.53%, demonstrating the gradual convergence of individual cells. These findings validate the passive balancing method's capability to mitigate voltage and SoC disparities, enhancing the overall pack uniformity and safety. Although passive balancing inherently dissipates energy as heat, its simplicity, cost-effectiveness, and reliable operation make it a practical solution for small to medium-sized battery packs where balancing speed and energy efficiency trade-offs are acceptable. For applications requiring faster balancing or higher energy efficiency, active balancing techniques may be considered; however, passive balancing remains a robust baseline approach, especially where system complexity and cost constraints are paramount

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Multi Capacitor-Based Active Cell Balancing Techniques for Lithium-Ion Batteries

Prof Devendra J Goyar[1]

Assistant Professor in Electrical Engineering Department

KJCOEMR, Pune

devendra4939@gmail.com

Prof. Pallavi D Dalvi[2]

Assistant Professor, Electrical Engineering Dept.

KJCOEMR Pune

Pallaviphadatre.kjcoemr@kjei.edu.in

Prof.Pooja R Shastri [3]

Assistant Professor, Electrical Engineering Dept.

KJCOEMR Pune

poojashastri.kjcoemr@kjei.edu.in

Abstract:
Lithium-ion batteries are widely used for their efficiency, but maintaining balance in series-connected cells is crucial for optimal performance and lifespan. We propose a capacitor-based active cell balancing method, implemented in MATLAB, to address SOC imbalances across four series-connected cells. This method enhances energy utilization by efficiently redistributing charge using capacitors. A Battery Management System (BMS) monitors performance and ensures safety, improving overall battery efficiency and longevity in electric vehicle applications.

Keywords: Battery management systems; cell imbalance; electric vehicles; cell balancing; state of charge; active balancing.

1. Introduction

Battery-powered electric vehicles (EVs) rely on lithium-ion (Li-ion) batteries for efficient performance. However, variations in cell characteristics like capacity, resistance, and State of Charge (SOC) can cause imbalances, affecting performance and lifespan. Active cell balancing, which redistributes energy between cells, is more efficient than passive methods, with capacitor-based balancing being especially effective for multi-cell systems. The Battery Management System (BMS) ensures safety and monitors battery health. This paper introduces the design of a capacitor-based active cell balancing system using MOSFETs as switches. The system incorporates 8 switches and 3 capacitors (100 farads each) to facilitate efficient charge transfer and improve the overall performance of the battery pack.

2. Battery Cell Imbalance and Its Impact

Battery cell imbalance refers to the unequal distribution of charge, capacity, or voltage among individual cells in a battery pack, even if the cells were originally identical. It can arise due to variations in cell characteristics, environmental factors, or usage patterns.

Causes of Battery Cell Imbalance:

1. **Manufacturing Variations**: Small differences in capacity or internal resistance can occur even between cells from the same batch.
2. **Operating Conditions**: Temperature fluctuations, uneven charging/discharging, and varying degradation rates among cells contribute to imbalance.
3. **Aging**: Over time, cells degrade at different rates, further increasing imbalance.

Impact of Battery Cell Imbalance:

1. **Reduced Efficiency:** Weaker cells with lower SOC deplete faster, causing the pack to show as discharged sooner, even if other cells still have charge.
2. **Decreased Battery Capacity:** The battery's total capacity is limited by the weakest cell, so imbalance reduces the overall capacity.
3. **Shortened Battery Life:** Overcharging or over-discharging due to imbalance accelerates cell wear and reduces overall lifespan.
4. **Increased Heat Generation:** Imbalance causes certain cells to work harder, generating excess heat, which can lead to thermal issues.

5. Safety Risks: Significant imbalance may lead to overvoltage or undervoltage conditions, increasing the risk of cell failure, fire, or explosion**.**

Addressing Cell Imbalance:

A Battery Management System (BMS) is crucial for addressing cell imbalance by integrating active balancing, such as capacitor-based techniques, to redistribute charge. The BMS monitors key parameters like current, voltage, SOC, and temperature, while protecting against over-discharge, overvoltage, and extreme temperatures. This ensures optimal performance, maximizes capacity, and extends battery life.**II. Fundamentals of Cell Balancing**

Cell balancing can be categorized into two types:

- **Passive Balancing:** Excess energy from higher-charged cells is dissipated as heat using resistors. While this method is simple, it results in energy losses and increased thermal management requirements.
- **Active Balancing:Active Balancing** involves transferring excess energy from higher-charged cells to lower-charged ones within a battery pack. This is typically done using components like **inductors**, **capacitors**, or **transformers**. [1][5].

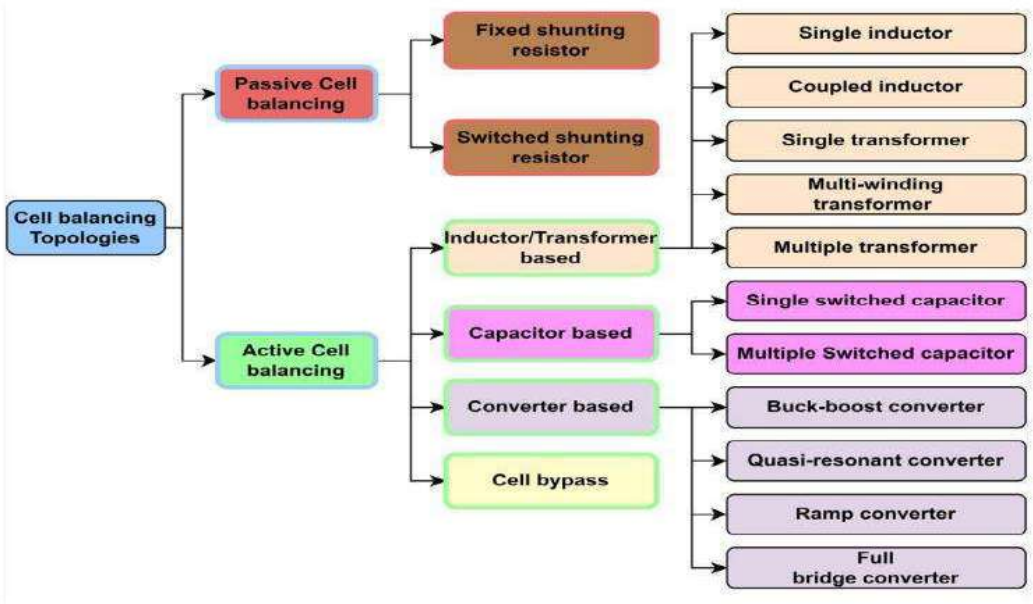


Figure 1. Chart of the Basic cell-balancing topology

III. Active Cell Balancing

- A Battery Management System (BMS) addresses cell imbalance by using active balancing, like capacitor-based techniques, to redistribute charge. It monitors current, voltage, SOC, and temperature, while protecting against over-discharge, overvoltage, and extreme temperatures, ensuring optimal performance and longer battery life.

- **Cell to Cell:** Energy is transferred between neighbouring cells, commonly seen in small batteries for balancing charge levels locally.
- **Cell to Battery:** High-energy cells provide energy to the battery pack, ensuring the voltage is balanced across all cells.
- **Battery to Cell:** Energy is drawn from the whole battery pack and supplied to the weakest or least charged cells, often seen in systems with matched chargers.
- **Bidirectional**: Energy flows both ways—either from the pack to cells or vice versa, offering flexible balancing.

- cell to the battery or the other way around—based on the balancing needs, offering flexibility for dynamic charge redistribution.

Each approach has its ideal use case: cell-to-cell balancing is suited for small packs, cell-to-battery balancing is the most efficient for large packs, battery-to-cell balancing works well with chargers that have individual outputs for each cell, and bidirectional balancing is best for flexible energy redistribution across cells.

IV. Capacitor-Based Active Cell Balancing

Capacitor-based balancing operates by using capacitors to temporarily store and transfer charge between cells. The process typically involves

:

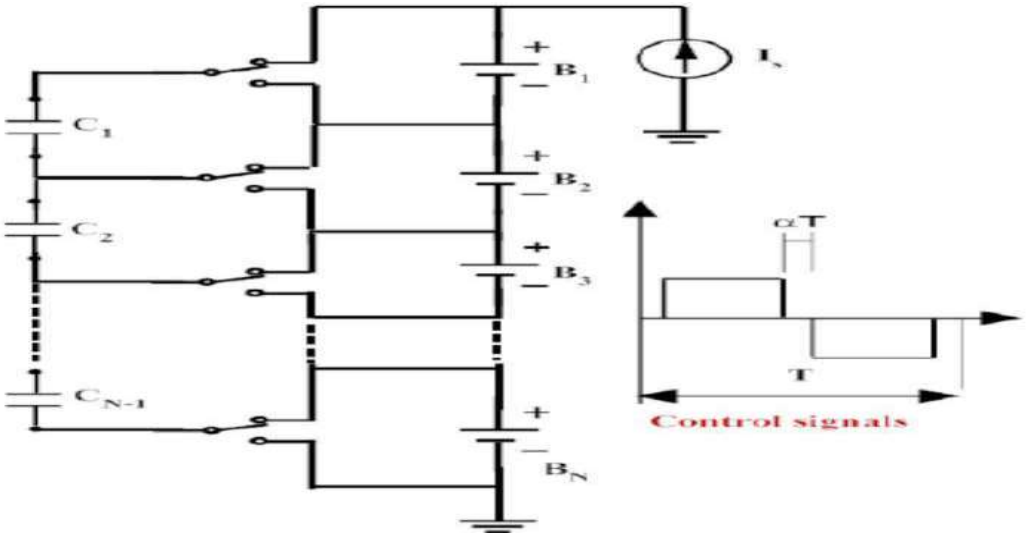


Fig. 2 Basic structure of Capacitor based active cell Balancing

Capacitor-based active balancing methods redistribute charge to equalize voltage levels and enhance battery performance. The traditional switched-capacitor method uses capacitors and PWM control but can be slow, especially in series configurations. To improve speed, more efficient designs like double-tiered, chain, and mesh structures have been developed, enabling faster charge transfer. Modular designs also balance smaller cell groups, reducing overall balancing time. These advancements enhance the efficiency, speed, and lifespan of battery packs in applications such as electric vehicles and energy storage systems.[1][2].

1. Single capacitor balancing techniques are capable of directly addressing the discrepancies between cells with the highest and lowest state of charge (SOC); however, they require more sophisticated control algorithms to function optimally.
2. **Charge Extraction:** A capacitor is connected to the highest charged cell, absorbing the excess charge.
3. **Charge Redistribution:** The stored charge is then transferred to a lower charged cell by connecting the capacitor across the lower charged cell.
4. **Switching Mechanism:** Ideal switches (such as MOSFETs) are used to control the capacitor's connection to the cells. This sequential switching ensures effective energy transfer between cells without excessive losses.
5. **Balancing Controller:**The balancing controller continuously monitors the SOC or voltage of each cell in the pack. When it detects a significant difference between cells, it activates the appropriate switches to start balancing. The balancing process continues until all cells have approximately the same voltage.[1]

IV. Benefits of Capacitor-Based Active Cell Balancing

1. **Energy Efficiency:** Unlike passive methods, capacitor-based balancing recycles excess energy between cells

rather than wasting it as heat, improving the overall energy efficiency of the system.

2. **Thermal Management:** Less heat is generated during balancing, reducing the need for complex cooling systems.
3. **Extended Battery Life:** By maintaining more uniform SOC across cells, capacitor-based balancing can significantly prolong the lifespan of the battery pack.
4. **Scalability:** The system is easily scalable for large battery packs, making it suitable for applications such as electric vehicles and grid storage.

V. Key Components:

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- **Capacitors:** High-capacity capacitors are used to store and transfer charge between cells. Capacitors with low equivalent series resistance (ESR) are preferred for faster charge transfer and lower energy loss.
- **Switches:** Ideal switches, typically MOSFETs, are used to control the connection of capacitors to the cells. The design of the switching circuit plays a crucial role in determining the overall efficiency of the system.
- **Control Circuitry:** A central control unit monitors the SOC of each cell and controls the switches to ensure effective balancing. Advanced algorithms can be employed to optimize the balancing process

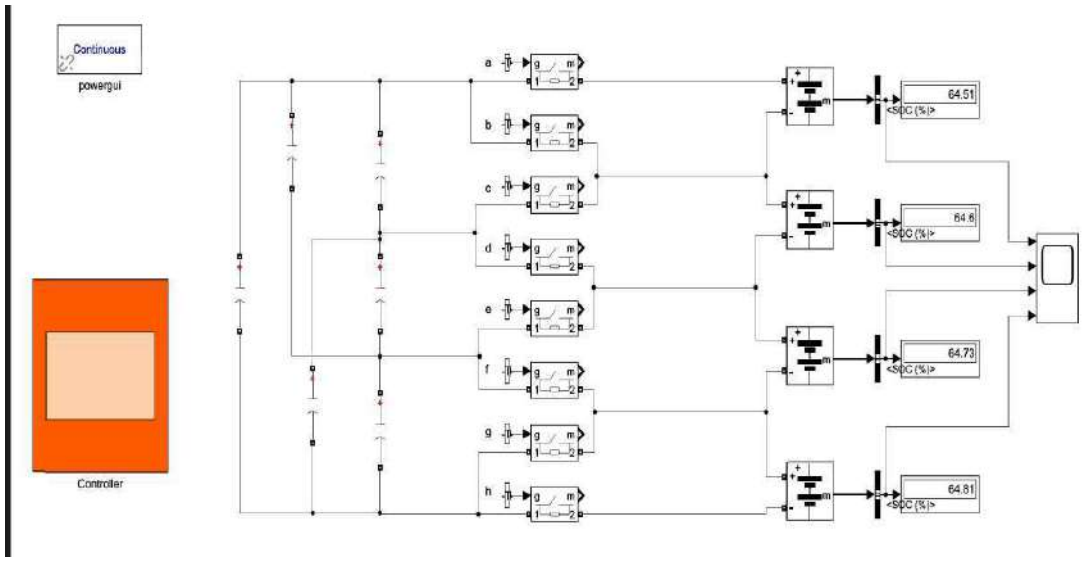


Fig. 3 Simulink Model

Fig. No. 3 Shows the active cell balancing for four serially connected cells with three capacitors. I was observed the time required for cell balancing at different level of SOC. The larger capacitance value will be provided large charge for cell balancing. It also depends on the Capacitance value. Ideal switch we have utilised in this scheme for providing the transfer of SOC from higher cell to lower cell for balancing time from capacitor. For that purpose required complex control algorithm for multiple switched capacitor method of active cell balancing. As per the simulation at 12 minutes all cells are balance as per Table no. 1.

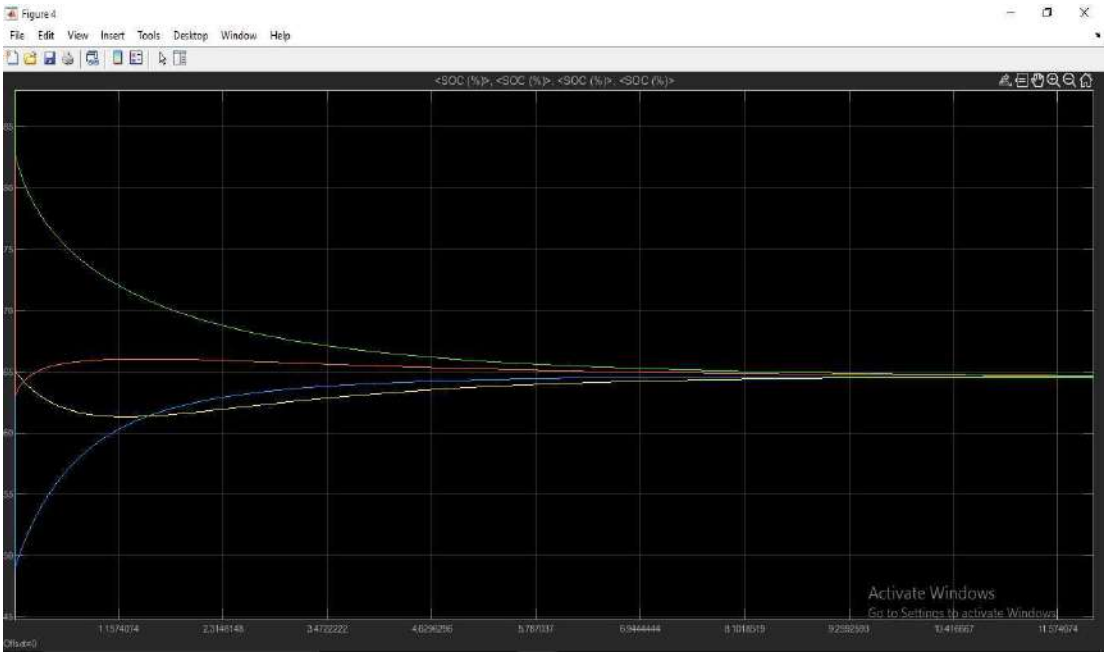


Fig. 4 Result of Simulation

VI. Conclusion:

According to simulating result of SoC1, SoC2, SoC3 and Soc4 at the 11.574 sec the following table shows the percentage difference between highest SoC to remaining with other SoC.

% Error between highest Soc and other SoC level of Batteries		% Error
SOC 1	64.51	0.462 %
SOC2	64.5	0.478%
SOC3	64.73	0.0008%

Table No.1

VII. Future Work

Due to the inherent variations in individual cells during charge and discharge cycles, it is difficult to accurately predict the State of Charge (SOC) across the entire battery pack. When the SOC of one cell is higher, it may lead to overcharging, while a cell with a lower SOC may be undercharged. This imbalance can cause discrepancies in the temperature of the cells, as cells with higher SOC may generate more heat, while those with lower SOC may not charge as efficiently. As a result, predicting the overall battery life and performance becomes more complex. Therefore, achieving an accurate life assessment of the battery requires careful monitoring and prediction of the behaviour of all individual cells within the pack. For the purpose for it in future we will apply AI-Ml or IoT application for the exact prediction about degradation of battery performance on the point of safety.

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Distributed MPP Tracking for PV Systems Using Total-Cross-Tied String-Integrated Converters Under Diverse Partial Shading Conditions

Prof.Mugdha Deshpande Prof. Mohitkumar Shakya Prof. Devendra J. Goyar
Assistant Professor in Electrical Engineering Department
K J COEMR Pune
mugdhakulkarni.kjcoemr@kjei.edu.in

Abstract:

In photovoltaic (PV) systems, partial shading conditions (PSCs) significantly reduce energy harvest due to the mismatch between the power output of different modules. To address this challenge, we propose a distributed Maximum Power Point Tracking (MPPT) strategy utilizing a Total-Cross-Tied (TCT) configuration of string-integrated converters. This innovative approach enables efficient extraction of maximum power from each module and string, even under diverse and dynamic PSCs. The TCT configuration interconnects PV strings in such a way that the effects of shading on individual modules are mitigated, and the overall energy production is optimized. By using string-integrated converters and distributed MPPT controllers, each module independently tracks its optimal power point, reducing losses and improving overall system efficiency compared to traditional centralized MPPT systems. The proposed system is tested under varying PSCs through simulations and experimental setups. The results demonstrate that the TCT configuration significantly enhances power output, reduces mismatch losses, and provides more robust performance under non-uniform shading compared to conventional approaches. This work contributes to the development of more efficient and resilient PV systems capable of operating under real-world shading conditions, ultimately leading to higher energy yields and improved economic viability for solar energy systems.

Key Words: T-C-T configuration converter P & O algorithm Photovoltaic module

1. Introduction:

Partial shading is a major challenge in photovoltaic (PV) systems, causing power mismatch between modules and reducing overall energy output [1], [6], [7]. Traditional centralized Maximum Power Point Tracking (MPPT) methods are often ineffective under non-uniform irradiance [3], [8]. To address this, we propose a Total-Cross-Tied (TCT) configuration integrated with String-Integrated Converters (SICs), where each short string of PV modules is equipped with its own dc-dc boost converter and P&O-based MPPT controller [4], [9]. This setup allows each string to independently track its maximum power point, significantly reducing mismatch losses [3], [6]. The system is tested on a 4x4 PV array under various irradiance levels (300–1000 W/m²) and different shading patterns (row, column, diagonal, and narrow shading). Compared to traditional central inverter and series SIC configurations, the proposed design shows improved energy extraction, better efficiency, and greater resilience to shading [5], [7].

Key benefits include:

- Decentralized MPPT for improved tracking under shading [4], [8]
- Single-stage voltage conversion and reduced voltage stress [5]
- Lower cost than Module-Integrated Converter (MIC) systems—up to 5× more economical [5]
- Enhanced performance and reliability in real-world conditions [6], [9]

A. PV Short-String Characteristics

The PV short-string has a series connection of five PV modules. For implementing the proposed PV D-MPPT architecture, 16 PV short-strings are considered [1].

2. Design of S-I-C (Single-Input Converter)

Figure 1 illustrates the circuit of a **non-isolated DC–DC boost converter**, referred to as **S-I-C**. This converter is designed for

efficient **Maximum Power Point Tracking (MPPT)**

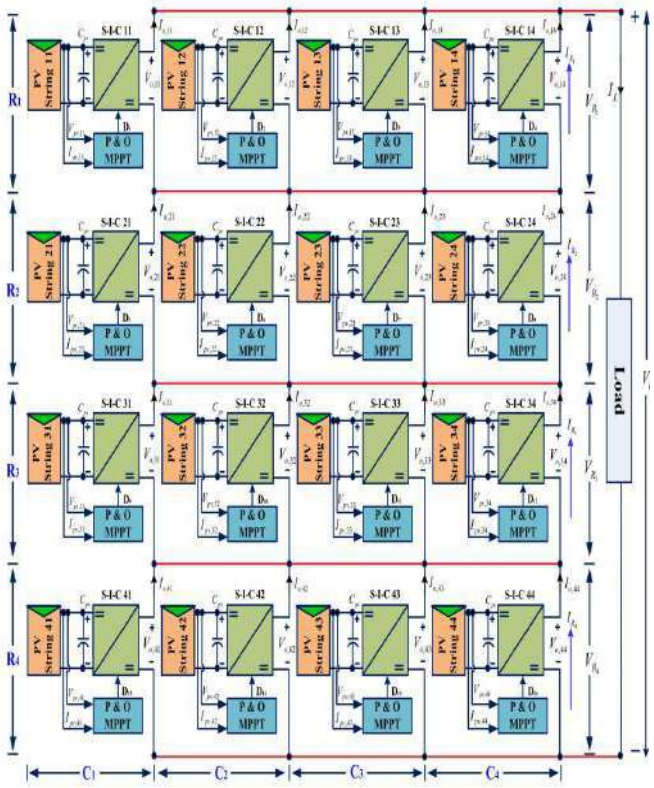


Fig. 1 Proposed T-C-T configuration of S-I-Cs

1) The proposed system not only optimizes power tracking but also enhances the output voltage of each PV short-string. At the Maximum Power Point (MPP), the output voltage Vpv and current Ipv of the short-string are used as input parameters to the String-Integrated Converter (S-I-C) [5]. The S-I-C is a compact, high-efficiency boost DC–DC converter designed to operate under varying irradiance and partial shading conditions. The capacitance value of the input capacitor (Cpv) can be determined using the following

2) **Cpv = ΔIL/(8 × ΔVpv × Fsw)**

where ΔIL is the inductor current ripple, ΔVpv is the PV short string output voltage ripple and Fsw is the switching frequency of the main switch (SWb), respectively.

2) **Selection of Inductor**:

The **inductor** in the S-I-C circuit maintains a **continuous current** from the PV short-string's output, helping to **smooth the current ripple**. Its **current rating** must exceed the **short-circuit current** of the PV short-string to ensure safe and reliable operation [4], [5]. The required **inductance (Lb)** can be calculated based on the desired ripple current and switching parameters.

L_b = Vpv × D / (2 × ΔIL × Fsw) **(2)**

where Vpv is the output voltage of the PV short-string and D is the duty ratio of the main switch (S_{wb}), respectively. The relation between the input voltage (Vpv) and output voltage ($V_{b)}$ of S-I-C is expressed by (3). Similarly, the relation between the input current (Ipv) and output current (I_b) of the S-I-C is expressed

V_b = Vpv / (1-D)

I_b = Ipv (1 – D).

3) Selection of Output Capacitor:

The output capacitor is used to smoothen the output voltage of the S-I-C. The capacitance (C_b) of the output capacitor can be calculated by

(C_b) = Vo × D / (2 × ΔVo × Rb × Fsw) **(3)**

Here, **Vo** is the output voltage, **ΔVo** is the allowable output voltage ripple, and **Rb** is the load resistance of the S-I-C module.

ISBN: 978-93-343-2006-0

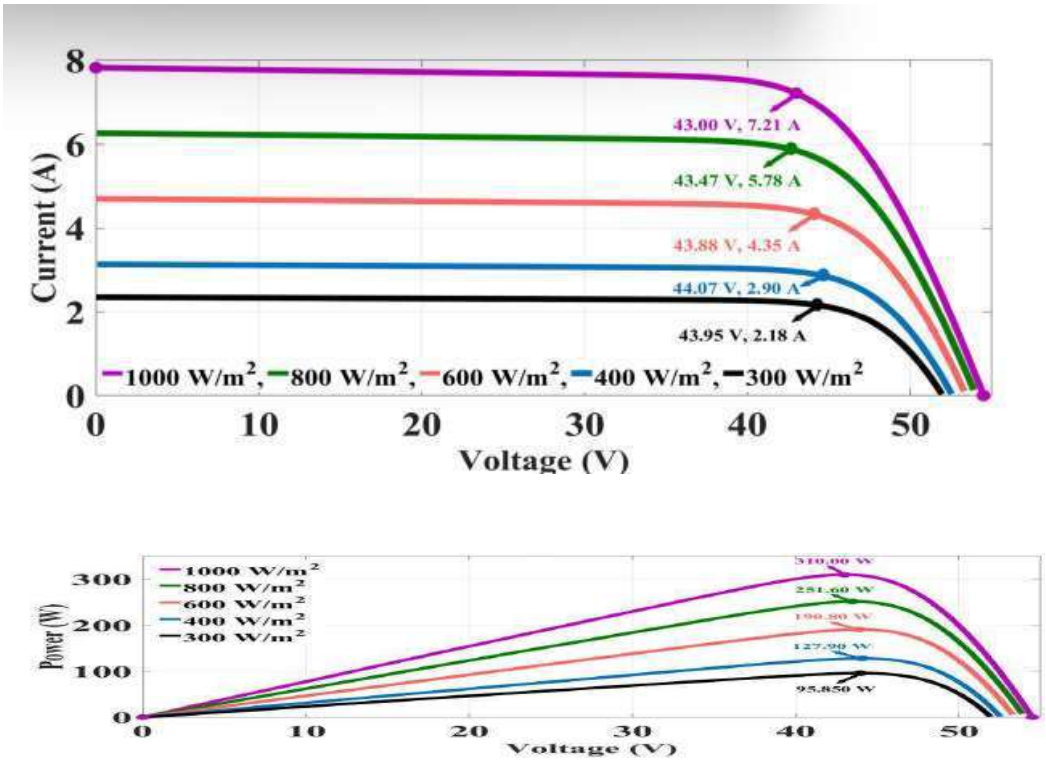


Fig_2 (a) I – V characteristics. (b) P – V characteristics

4) **Implementation of P & O MPPT Techniques**

The Perturb and Observe (P&O) algorithm is one of the most widely used Maximum Power Point Tracking (MPPT) techniques due to its simplicity and ease of implementation [4], [8]. The P&O method employs voltage and current sensors to detect the output characteristics of the solar PV array, as shown in Fig. 3 – P&O Algorithm. In this technique, the controller periodically perturbs (modifies) the duty cycle DDD of the DC-DC converter and observes the change in power. If the output power increases following the perturbation, the system continues in the same direction. Conversely, if the output power decreases, the direction of the perturbation is reversed. This comparison between the current measured power and the previous one determines whether to increase or decrease the duty cycle [4]. If the input voltage is higher than the previous value and the power decreases, the duty cycle is reduced to move closer to the Maximum Power Point (MPP). Conversely, if the input voltage is lower and the power increases, the duty cycle is increased [9]. However, if the perturbation value DDD is too large, the

algorithm will cause continuous oscillations around the MPP, never settling on the exact maximum. This is a well-known limitation of P&O [8], which can be minimized by optimizing the step size or using hybrid algorithms [9]. Despite its drawbacks, P&O simplifies the MPPT operation without the need to alter the physical characteristics of the PV modules. It is particularly suited for systems where computational resources are limited. **A 10 kHz saw tooth waveform is compared with the P&O control signal to generate a PWM, which controls the S-I-C duty cycle for maximum power extraction. The P&O MPPT flowchart and its MATLAB/Simulink implementation are discussed next.**

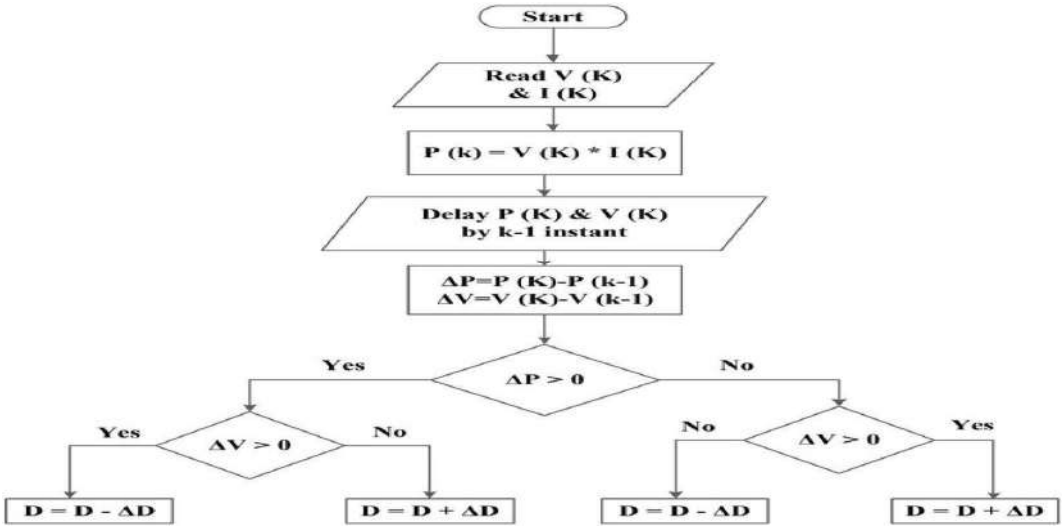


Fig_3 P & O Algorithm

In the **P&O MPPT method**, a small **voltage perturbation (ΔVpv)** is applied, and the resulting **power change (ΔPpv)** determines the **duty ratio adjustment (ΔD)** of the S-I-C.

$$D_{new} = dP/dV = 0, Dold$$

$$dP/dV < 0, D_{old} - \Delta D$$

$$dP/dV > 0, D_{old} + \Delta D$$

In the implementation of the Perturb and Observe (P&O) MPPT algorithm, two key tuning parameters significantly influence the tracking performance: the perturbation step-size (ΔD\Delta DΔD) and the perturbation step-time [4], [8].

- The step-size ΔD\Delta DΔD determines the increment by which the duty cycle is perturbed in each cycle. A larger step-size enables faster convergence to the Maximum Power Point (MPP), but can lead to oscillations and reduced efficiency. On the other hand, a smaller step-size improves tracking accuracy but slows down the convergence speed.
- The perturbation step-time Ta defines how frequently the perturbation is applied. To ensure system stability, Ta must be greater than the system's settling time following a change in duty cycle. If not properly tuned, frequent perturbations may result in erroneous tracking and instability.

ISBN: 978-93-343-2006-0

In this study, the perturbation parameters are chosen to strike a balance between tracking speed and steady-state accuracy: Perturbation step-size: ΔD=0.01, Perturbation step-time: =25 ms

These values have been empirically selected to ensure stable and efficient MPPT performance across a variety of dynamic shading conditions [4], [9]. To assess the robustness of the proposed system and validate the effectiveness of the P&O algorithm under real-world environmental changes, the system is evaluated under four distinct partial shading patterns:

1. Row shading
2. Column shading
3. Diagonal shading
4. Narrow strip shading

These test conditions simulate common partial shading scenarios caused by nearby trees, poles, buildings, or debris on the PV surface. The system's response is analyzed in terms of MPPT accuracy, power extraction efficiency, and response time to verify its performance under mismatched irradiance conditions [1], [6], [9].

1. Uneven Row Shading: A cloud moves horizontally across the first row of PV short-strings, creating varying shading levels—from most dark to clear—on strings 11 to 14, while the rest receive full irradiance.
2. Uneven Column Shading: A vertically moving cloud shades the first column of PV short-strings with decreasing intensity from top to bottom, affecting strings 11, 21, 31, and 41.
3. Diagonal Shading: Diagonal PV short-strings (11, 22, 33, 44) are shaded unevenly by a cloud moving downward, simulating shading from one corner of the array to the opposite.
4. Long and Narrow Shading: A narrow cloud covers the first two columns of the array, with shading intensity decreasing from top to bottom across strings 11–12 to 41–42. The remaining array receives full sunlight. In this paper implementing the performance output of solar PV module as per different shading pattern in mat lab Simulink model.[1][6]

Table.1 Specifications of PV MPPT architecture

Specification	Values
Peak Output Power (Pmax)	62.006 Watt
No-Load Voltage (Vopen)	10.9 Volt
Max Current at Zero Voltage (Ishort)	7.82 Amp
Optimal Operating Voltage (Vopt)	8.6 Volt
Optimal Operating Current (Iopt)	7.21 Amp
Light-Induced Current (Ilight)	7.8503 Amp
Reverse Leakage Current (Isat	3.0763 * 10^-11
Internal Series Resistance (Rseries)	0.14761
Leakage Path Resistance (Rshunt)	38.1127
Cell Count per Module (Ncells)	18
S-I-C Specification	
Inductor current ripple ΔIl	10 %
Inductor Voltage ripple Δ_{PV}	3%
Voltage Fluctuation at Output (ΔVout)	3%
Converter Switching Rate (Fswitch)	10 KHz
PV Input Voltage Span (Vpv_range)	40 – 60 Volt
Boosted Voltage Range (Vout_range	50-125 volt
PV Current Variation Range (Ipv_range)	10 Amp
Output current Range	4.8 Amp
Inductance	2 mH
Input capacitance	100/100 micro farad
Output Capacitance	200/200 micro farad
Load Resistance	32.255 ohm
MPPT Specification	
Initial Duty ration	0.57
Max. Duty ratio	0.8
Min Duty ratio	0.2
Perturbation Step size ΔD	0.01

5) Result discussion from Here from output of matlab simulation

In this paper, a simulation of a 4 × 4 solar photovoltaic (PV) module array was carried out under various solar irradiance conditions to analyze the performance impact of different shading patterns. The shading scenarios include:

- Uniform (Full) Solar Irradiance
- Uneven Row Shading
- Uneven Column Shading
- Long and Narrow Shading

Each shading condition was simulated using MATLAB/Simulink (or specify your tool, if different) to evaluate its effect on the overall performance of the PV module array. The simulation results include the output voltage, current, and power generated under each condition. The results are summarized in Tables 2, 3, and 4, providing a comparative understanding of how shading patterns influence the electrical characteristics and efficiency of the PV module array.

Table no. 2 Sun Radiation Vs Output Current

Sun Radiation	output current
Full Radiation	13.12
Uneven Row sheading	12.22
Uneven column Sheading	12.22
Long and Narrow Sheading	11.93

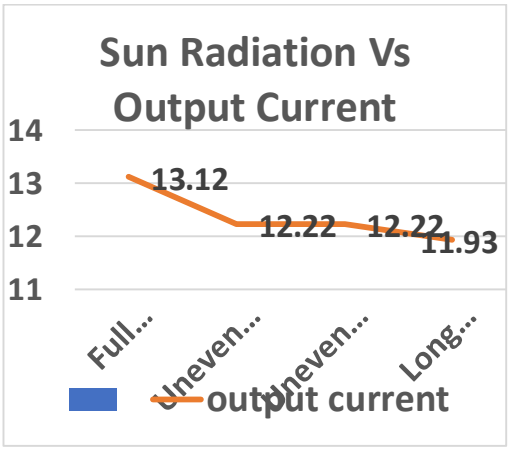


Fig. 4 Sun Radiation Vs Output Current

Table no. 3 Sun Radiation Vs Output Current

Sun Radiation	output voltage
Full Radiation	**428.5**
Uneven Row sheading	**398.9**
Uneven column Sheading	**398.9**
Long and Narrow Sheading	**389.6**

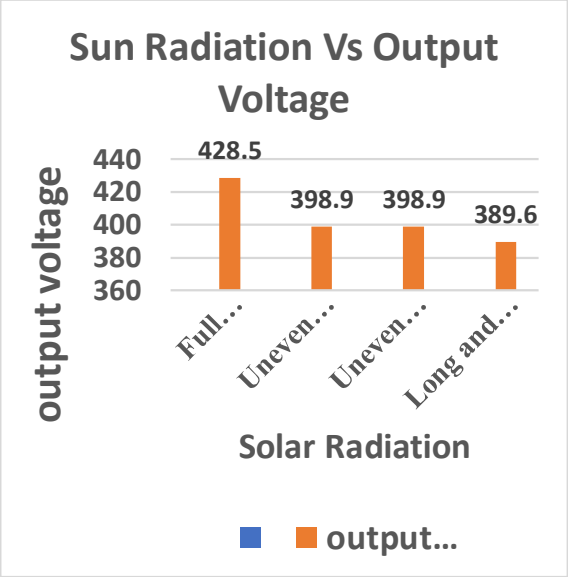


Fig. 5 Sun Radiation Vs Output Voltage

Table no. 4 Sun Radiations Vs Output Power

Sun Radiation	output Power
Full Radiation	5623
Uneven Row sheading	4875
Uneven column Sheading	4875
Long and Narrow Sheading	4650

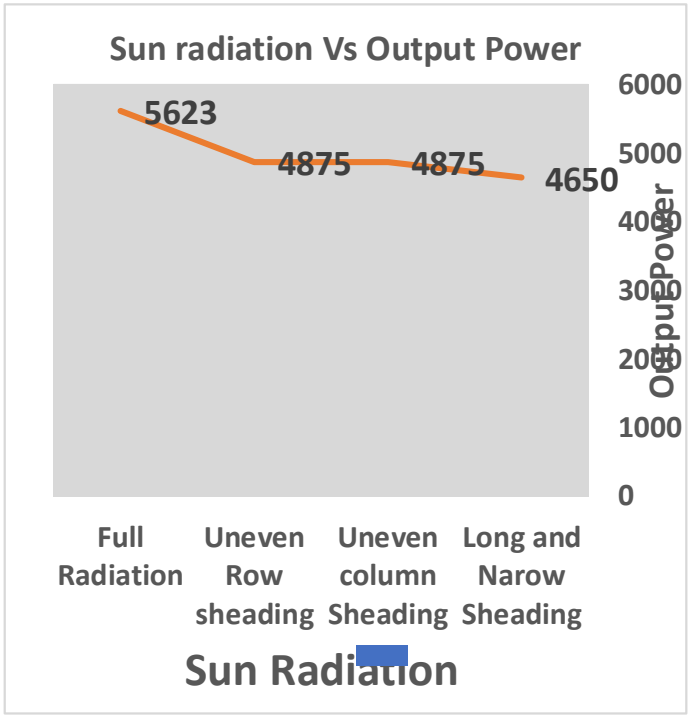


Fig. 6 Sun Radiation Vs Output Power

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Revolutionizing Mobility: An In-Depth Analysis of India's Electric Vehicle Market and Its Future Trajectory

Abhi Desai

New England College, Henniker, New Hampshire, US

adesai_gps@nec.edu | *desai.abhi94@gmail.com*

***Abstract*—The Indian Electric Vehicle (EV) mar- ket is undergoing a transformative shift driven by technological advancements, policy interventions, and changing consumer preferences. This report provides a comprehensive analysis of the EV ecosystem in In- dia, examining key market segments, geographic and demographic trends, and the role of major industry players. It explores the historical evolution of EV adoption, from early developments in the 1990s to the impact of government initiatives such as the FAME schemes and Production Linked Incentives. Additionally, the report highlights the challenges facing the industry, including infrastructure constraints, battery production, and cost considerations, while forecasting future opportunities for growth and innovation. By leveraging data analytics and market insights, this study aims to provide a strategic perspective on the evolution of India's EV sector and its potential to reshape the country's transportation landscape.**

I. Objective

This report analyzes the current status of the Electric Vehicle market in India, focusing on the drivers, challenges, government policies, and future outlook for the sector.

II. Scope

This report will include a detailed analysis of the Electric Vehicle Market in India while analyzing the following points,

A. Coverage of the EV Market Segments

This report will cover the various essential sections of the EV market, which includes

- **Passenger vehicles:** Electric cars, sedans, and SUVs.
- **Two-wheelers:** Scooters, electric bikes, etc.
- **Three-wheelers:** E-rickshaws and small commercial EVs.
- **Commercial vehicles:** Electric buses, trucks, and logistics fleets.

B. Geographic and Demographic Analysis

This report will analyze the various geographic and demographic sections of India to analyze the Electric Vehicle trends in the market.

- Geographic Locations:
  - Rural or Urban
  - Mountain or Valleys
  - Costal region analysis
- Demographic Analysis:
  - Average Age of the market
  - Gender Analysis
  - Income Analysis

III. Methodology

This report relies on data from industry research reports, government publications, interviews with market experts, and publicly available statistics.
This report also performs Mathematical and Data Analysis on some publicly available Datasets to perform custom analytics on the topics.

IV. History of EVs in India

The history of EVs in India is heavily influenced by the gradual evolution of technology, government policies, and changes in consumer preferences.
Some Key milestones and development in the field are:

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A. Early Beginnings(1990s)

- **Initial Launch:** Electric vehicles were introduced in India during the 1990s with small electric scooters and three-wheelers which aimed at reducing urban pollution, which was on the rise during the time due to underdevelopment in the field of Pollution Control Guidelines.
- **Introduction of Reva:** In 1996, Maini Group launched Reva, India's first electric car. This two-seater vehicle was designed as a commuter for the general public. Reva did not achieve much of a mass-market success, which can be characterized by the low infrastructural stage of the electric vehicle market of India.

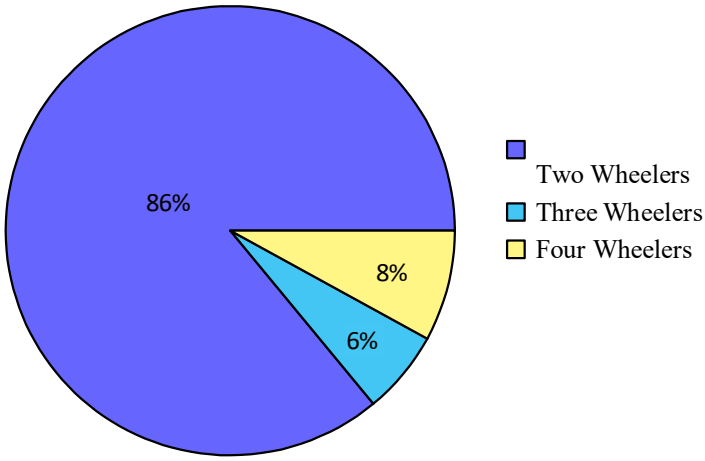


Fig. 1. India EV Automobile Distribution

B. Government Initiatives (2010s)

- **Subsidy Schemes:** Recognizing the potential of EVs in the global market. Indian government brought in many subsidies to boost the production and adoption of EVs in India.
- **National Electric Mobility Mission Plan (NEMMP):** Launched in 2013, this plan aimed to reduce oil dependency and improve air quality by establishing an ecosystem for EV Manufacturing in India by 2020. This program was met with partial success.
- **Faster Adoption and Manufacturing of Electric Vehicles (FAME)** FAME-I worked from 2015-2019 and FAME-II operated from 2019-present. These projects were initiated to provide incentives for electric two-wheelers, three-wheelers, and four-wheelers for both per- sonal and commercial use. It also supported charging infrastructure.
- **Production Linked Incentive for Advanced Chemical Cell Battery Storage** This program was designed to boost local battery manufacturing by offering incentives for manufacturers who invest in producing advanced batteries in India. This project aimed to reduce dependencies on imports and make EVs more affordable in India.

Tata Moters: Leading the market with a substantial 72% share in the electric passenger vehicle segment. Popular models include the Tiago, Nexon, and Tigor.[7][11] **MG Motor India:** Holds about 10.8% of the market, with notable offerings like the MG ZS and MG Comet. The company is expanding its production capacity and has partnered for charging infrastructure.[7][5] **Mahindra & Mahindra:** Accounts for approximately 9% of the market. The company focuses on electric cars and three-wheelers, with models like the Mahindra XUV400 gaining traction.[7][11] **Ola Electric:** A significant player in the two-wheeler segment, Ola Electric has rapidly captured market share, particularly in registered electric two-wheelers (E2Ws) along with TVS Motor and Ather Energy, which together account for over 65% of E2W sales.[11] **Ather Energy:** Known for its high-performance electric scooters, Ather is also investing in charging infrastructure to support its products[6][5] **Hero Electric:** This company specializes in electric two-wheelers and has a strong distribution network across India[6] **Hyundai Motor India:** This South Korean manufacturer is increasing its footprint in India with plans to launch multiple EV models and establish a robust charging network[7][5]

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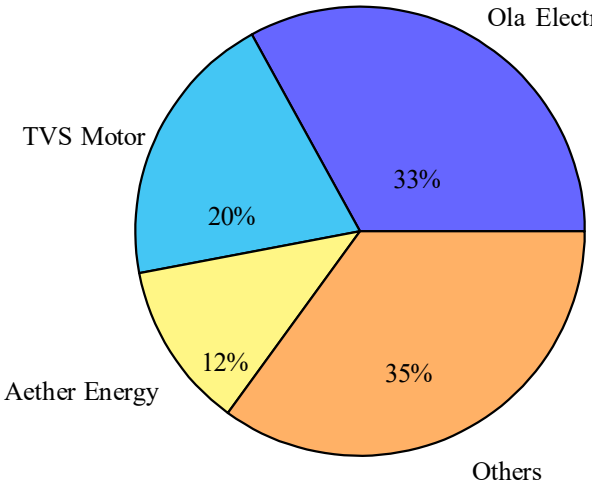


Fig. 2. Two Wheeler Distribution

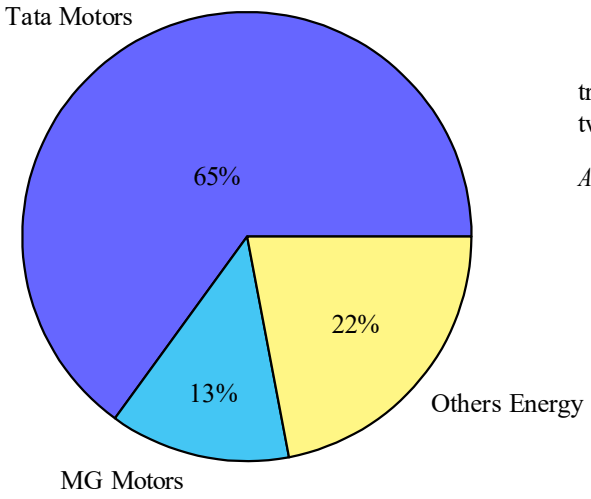


Fig. 3. Four Wheeler Distribution

V. National Electric Mobility Mission Plan (NEMMP)[4]

The National Electric Mobility Mission Plan (NEMMP) aims to accelerate the adoption of electric vehicles (EVs) in India to achieve environmental sustainability and energy security. Key objectives include:

- **Enhancing Manufacturing:** NEMMP promotes local manufacturing of EVs and components, reducing dependency on imports.
- **Promoting Research and Development:** It encourages innovation in EV technology, particularly in battery technology and charging infrastructure.
- **Creating Demand:** The plan aims to stimulate consumer interest through financial incentives and subsidies.
- **Infrastructure Development:** Establishing a robust network of charging stations across urban and rural areas is a priority.

Data from the NEMMP indicates that the government envisions achieving a significant percentage of electric vehicles in total vehicle sales by 2030, targeting around 30% for private cars, 40% for buses, and 80% for two-wheelers.

VI. FAME India Scheme

The Faster Adoption and Manufacturing of Electric Vehicles in India (FAME) scheme operates in two phases:

A. FAME I

- **Launch Date:** April 2015 with an initial budget of Rs.895 crores.
- **Objectives:** To create demand for EVs, support pilot projects, and develop charging infrastructure.
- **Impact:** Supported approximately 2.78 lakh EVs, with demand incentives totaling around Rs.343 crores. The scheme also sanctioned 465 electric buses across various cities.

B. FAME II

- **Launch Date:** April 2019, with a budget of Rs.10,000 crores for three years.
- Incentives:
  - Increased subsidy for electric two-wheelers to Rs.15,000 per kWh from Rs.10,000.
  - Support for 10 lakh e-2Ws, 5 lakh e-3Ws, 55,000 e-4Ws, and 7,000 electric buses.
- **Infrastructure Development:** Rs.1,000 crores allocated for establishing charging stations

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along major highways at intervals of about 25 km.

- **Impact:** Supported approximately 2.78 lakh EVs, with demand incentives totaling around Rs.343 crores. The scheme also sanctioned 465 electric buses across various cities.

As of July 2023, under FAME II:
Total EVs sold: 832,824

- **Two-wheelers:** 740,722
- **Three-wheelers:** 83,420
- **Four-wheelers:** 8,982

VII. State-Level Policies

Several states have implemented specific policies to support EV growth:

- **Delhi:** The state offers subsidies up to Rs.30,000 for electric two-wheelers, free parking, and exemption from road tax. Its goal is to have a significant number of electric vehicles on the roads by 2024.
- **Maharashtra:** Provides incentives for both manufacturers and buyers, including subsidies on purchases and support for charging infrastructure development. The state aims for a target of over 1 lakh EVs by 2025.
- **Karnataka:** Implements policies promoting electric buses and offers incentives for setting up charging stations. The state has set a goal to have around 1 million EVs by 2030.

VIII. Tax Incentives and Subsidies

The Indian government has introduced various tax benefits to encourage EV adoption:

- **Lower GST Rates:** Electric vehicles are taxed at a reduced GST rate of 5%, compared to higher rates for conventional vehicles.
- **Income Tax Benefits:** Buyers can claim deductions on interest paid on loans taken to purchase electric vehicles under Section 80EEB of the Income Tax Act.[9]
- **State-Specific Incentives:** Many states of- fer additional subsidies or tax exemptions to further reduce the cost of EVs. For instance, some states provide waivers on road tax and registration fees.

IX. Charging Infrastructure

The government is actively working on enhancing the charging infrastructure:

- As part of FAME II, over 2,877 charging stations have been sanctioned across various states as of July 2023.
- The Ministry of Heavy Industries has also sanctioned Rs.800 crores as capital subsidy to establish public charging stations through Oil Marketing Companies (OMCs), aiming for around 7,432 public charging stations.
- Initiatives are underway to develop battery swapping stations as an alternative to traditional charging methods, particularly beneficial for two-wheelers and three-wheelers.

These comprehensive policies and initiatives aim to create a conducive environment for the growth of electric vehicles in India while addressing environmental concerns and promoting sustainable transportation solutions.

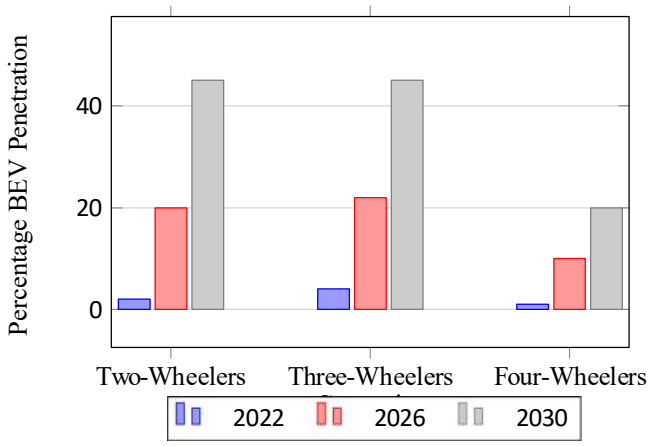
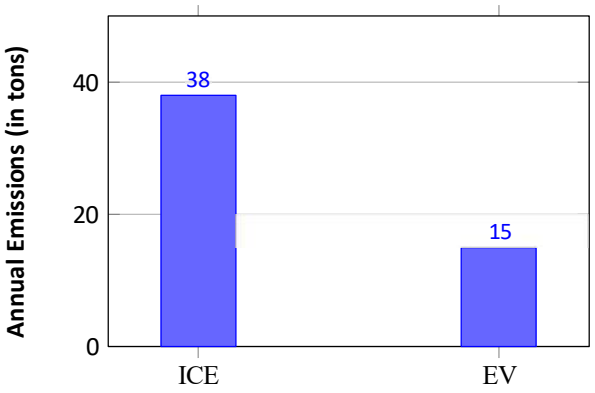


Fig. 4. Projected BEV Penetration Rates for Passenger Vehicles

X. Environmental Concerns and Sustainability

Increased awareness of climate change and India's goals to reduce carbon emissions have driven interest in the EVs market in India. As the Indian government regulates air pollution and environmental degradation, the transition to electric vehicles is heavily prioritized by the government.



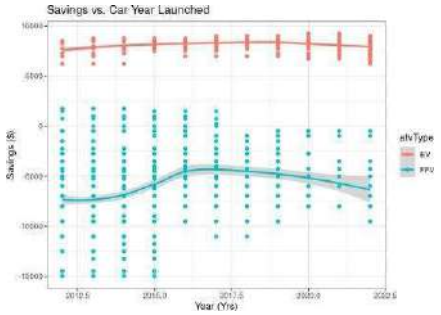


Fig. 5. Savings vs Car year Launched[10]

- In regions with a high proportion of renewable energy (like Norway), EVs can have an extremely low carbon footprint.
- Conversely, in areas where coal is the primary energy source, such as parts of India or China, the emissions associated with charging can diminish the benefits of EVs. However, even in these scenarios, studies show that EVs still typically outperform ICE vehicles in terms of overall emissions

XI. Cost Savings and Efficiency

Electric Vehicles are very famous for their low operational costs and their cheaper service cost due to the fact there are fewer complexities with the design of an Electric Vehicle as compared to the the design of an internal Combustion Engine (ICE) due to a significantly less amount of moving/mechanical parts.

A. Lower Operational Costs

Electric vehicles (EVs) offer significant cost savings over their lifetime compared to traditional internal combustion engine (ICE) vehicles. These savings stem from several key factors:

- **Fuel Costs:** The Cost of electricity for charg- ing EVs is very less as compared to the prices of the price of Petrol
  For running a vehicle for 10000km in India, the cost incurred with EVs will be Rs.4,634 per year, assuming Rs.7 per unit, while with petrol, the amount for this travel will be around Rs.59,000 per year.
- **Maintenance Costs:** Evs have lower moving parts, which further leads to less mechanical wear and tear. This causes less downtime with the vehicle and, further, less maintenance costs. Studies show that EV Owners can save up to Rs.20,000 annually on vehicle maintenance and servicing.
- **Incentives and Tax Credits:** Many governments offer financial incentives for purchasing EVs, such as tax credits, rebates, and grants. In the U.S., federal tax credits can be as high as 7,500 USD, while various states offer additional incentives.

B. High Efficiency

Electric vehicles are inherently more efficient than traditional vehicles due to their design and technology:

- **Energy Conversion Efficiency:** EVs convert about 60% to 77% of the electrical energy from the grid to power at the wheels, compared to ICE vehicles, which convert only about 12% to 30% of the energy stored in gasoline into movement.
  This higher efficiency means that EVs can travel further distances with the same amount of energy.
- **Regenerative Braking:** EVs utilize regenerative braking systems that capture energy usually lost during braking and convert it back into usable electricity for the battery. This feature

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enhances overall efficiency and extends driving range.

- **Performance Benefits:** Electric motors provide instant torque, allowing for quicker acceleration compared to traditional engines. This performance advantage contributes not only to a better driving experience but also to efficient energy use.

XII. Technological Advancements

Recent advancements in battery, Motor, and Charging technology have significantly enhanced the practicality and accessibility of Electric vehicles.

A. Advances in Battery Technology

There has been a lot of rapid growth in the field of battery technology, including the development of new battery compounds and ways to integrate batteries into vehicles.

- **Increased Energy Density:** Modern lithium- ion batteries now offer energy densities exceeding 250 Wh/kg, allowing EVs to achieve longer ranges. For example, the Tesla Model 3 can travel over 350 miles on a single charge, addressing range anxiety—a major barrier to EV adoption.
- **Faster Charging Capabilities:** Innovations in fast-charging technology enable EVs to recharge more quickly. DC fast chargers can deliver power outputs between 90 kW and 400 kW, allowing some vehicles to charge from 20% to 80% in just 15 to 30 minutes. This rapid charging capability makes it feasible for drivers to integrate charging into their daily routines, such as during lunch breaks or gro- cery shopping
- **Battery Longevity:** Advances in battery management systems and materials have improved the lifespan of EV batteries. Many modern batteries are designed to last over 480000 km, significantly reducing the total cost of ownership for EVs.
- **Solid-State Batteries:** Research into solid- state batteries promises even greater improvements, with potential energy densities of up to 500 Wh/kg and faster charging times, while also enhancing safety by reducing flammability risks associated with liquid electrolytes

B. Fast Charging Solution

The development of fast charging infrastructure is crucial for making EVs more practical for everyday use, some of the developments in this field include,

- **DC Fast Charging Stations:** The prolifera- tion of DC fast charging stations is critical for reducing charging times. For instance, stations can charge an EV to 80% capacity in approximately 30 minutes, making long-distance travel more feasible
- **Mobile Charging Stations:** Companies are introducing mobile DC fast chargers that can be deployed quickly and easily at various locations, including service stations and events. These portable solutions can charge an average EV in about 30 minutes, improving access to charging facilities where infrastructure may be lacking.
- **Smart Charging Networks:** Advanced charging networks are being developed that allow users to track and manage their charging sessions via mobile apps, optimizing energy use and providing real-time information on charger availability. This technology facili- tates better integration with renewable energy sources, reducing overall emissions associated with charging
- **Standardization of Charging Connectors:** The adoption of standardized connectors like CCS (Combined Charging System) facilitates compatibility across different vehicle models and charging stations, further enhancing the user experience and accessibility of EV charging infrastructure.

XIII. Growing Consumer Demand

The Indian market is witnessing a significant shift in consumer preferences towards greener and more cost-effective transportation solutions.

A. Shift towards Electric Vehicle (EVs)

- The demand for electric vehicles in India is rapidly increasing, with projections indicating

that the country aims for 30% electrification of all vehicles by 2030. This target is supported by government initiatives such as the FAME India scheme, which provides incentives for EV adoption.

- In 2023, the Indian EV market was valued at approximately 8 billion USD, with expectations to grow to 23.38 billion USD by 2024 and 117.78 billion USD by 2032. This growth is driven by rising consumer awareness of the environmental benefits of EVs and favorable government policies promoting electric mobility.

B. Cost-Effectiveness:

- Consumers are increasingly recognizing the long-term cost savings associated with EV ownership. Operating costs for EVs are significantly lower than those for traditional internal combustion engine vehicles. For example, the cost of electricity for charging an EV is approximately Rs.2.52 per mile, compared to about Rs.11.7 per mile for petrol vehicles.
- The operational cost benefits of electric commercial vehicles, such as buses and trucks, are also encouraging fleet operators to transition to electric options, further enhancing their appeal in urban transportation and logistics sectors.

C. Health and Environmental Awareness:

- With urban air quality deteriorating due to pollution from conventional vehicles, consumers are increasingly motivated to opt for cleaner alternatives. The Indian government's commitment to reducing carbon emissions aims to cut down on harmful pollutants like nitrogen oxides (NOx) and particulate matter (PM), which contribute to serious health issues.
- A report predicts that improved logistics practices, including the adoption of electric vehicles, could save India up to 10 gigatons of CO2 emissions by 2050 while significantly reducing PM and NOx emissions.

XIV. Job Creation Potential

The growing electric vehicle (EV) sector in India is poised to create substantial job opportunities across various domains, including manufacturing, services, and infrastructure.

A. Projected Job Growth:

- Direct and Indirect Job Creation:
  - By 2030, the EV industry is projected to generate 10 million direct jobs and an additional 50 million indirect jobs. This indicates a total potential of 60 million jobs linked to the burgeoning EV ecosystem .[14][13]
  - The Society of Indian Automobile Manufacturers (SIAM) estimates that around 200,000 skilled workers will be needed by 2030 to support the government's vision of achieving 30% EV penetration in the automotive sector.[16]
- Sector-Specific Opportunities:
  - The manufacturing sector will see significant job growth as companies transition from traditional internal combustion engine (ICE) vehicles to EVs. This includes roles in assembling electric motors and battery packs and integrating electronic components.
  - Research and development (R&D) positions are expected to surge, particularly for engineers and scientists focused on advanced battery technologies and electric drivetrain.
- Emerging Roles:
- New job roles are anticipated in areas such as charging infrastructure installation, maintenance, and operations. As the government and private entities invest in expanding charging networks, there will be a demand for electrical engineers and technicians [14]
- Sales and marketing roles will evolve as consumer buying behaviors change. Professionals who understand both technology and consumer needs will be crucial for educating potential buyers about EVs.

B. Skill Development Needs

- Skill Gaps:
  - A report indicates that 43% of the technical competencies required for EVs differ significantly from those needed for ICE vehicles, necessitating fresh skill development initiatives.[16]
  - The demand for skilled professionals is expected to rise sharply, with estimates suggesting that India needs to add 30,000 EV-ready workers annually until 2030 to meet localization goals for EV components.[16]
- **Training Investments:** The total investment required for hiring and training the workforce in the EV sector is projected to be around Rs.13,552 crore, with significant portions allocated for both hiring costs and training programs [16]

XV. Charging Infrastructure

The limited availability of charging stations in both urban and rural areas remains a major barrier to electric vehicle (EV) adoption in India. Despite the government's push for electric mobility, the current charging infrastructure is insufficient to meet the needs of potential EV buyers.

- **Current State of Charging Infrastructure:** As of 2023, India has approximately 8,738 operational charging stations, but these are predominantly located in urban centers. This uneven distribution creates accessibility issues for users in rural and semi-urban areas, leading to concerns about finding charging points when needed.[3][12]
- **Rural Accessibility:** In rural areas, the lack of access to reliable electricity grids further complicates the installation of charging stations. Many remote locations lack the necessary infrastructure to support charging facilities, making it difficult for EV owners in these regions to recharge their vehicles [3]

XVI. High Initial Costs

The higher upfront costs of EVs compared to traditional vehicles continue to be a significant barrier to adoption in India:

- **Price Sensitivity:** Indian consumers are generally price-sensitive, and the initial cost of electric vehicles often exceeds that of internal combustion engine (ICE) vehicles. This price disparity can deter potential buyers from making the switch to electric mobility.[12] [15]
- **Government Subsidies:** To address this is- sue, various state governments have intro- duced subsidies and incentives for EV buy- ers. For instance, Delhi provides a subsidy of up to Rs.1.5 lakhs for electric vehicle pur- chases, making them more accessible. How- ever, these incentives may not be sufficient to overcome the overall cost barrier for many consumers.[12]

XVII. Range Anxiety

Concerns over the driving range of EVs and the need for widespread fast-charging networks further complicate consumer acceptance:

- **Driving Range Limitations:** While many modern EVs offer ranges exceeding 300 kilometers, potential buyers still express concerns about whether they can complete longer trips without encountering charging issues. [12][2]
- **Need for Fast Charging Networks:** The establishment of a robust fast-charging network is essential for alleviating range anxiety. Currently, most charging stations are slow chargers that require significant time to recharge vehicles, which can be inconvenient for users on tight schedules.[3] [2]

XVIII. Battery Technology and Disposal

Environmental concerns related to the disposal and recycling of lithium-ion batteries present additional challenges:

- **Battery Lifespan and Recycling:** As EV adoption increases, so does the need for effective recycling solutions for lithium-ion batteries once they reach the end of their life cycle. Current recycling processes are not fully developed in India, raising concerns about environmental impacts if batteries are improperly disposed of. [12][15]

- **Resource Extraction Concerns:** The extraction of materials used in battery production, such as lithium and cobalt, raises ethical and environmental concerns that need addressing as demand for EVs grows.s[2]

Competitive Landscape

XIX. Local vs Global Players

The Indian electric vehicle (EV) market is characterized by a mix of domestic manufacturers and global competitors, each vying for a share of the rapidly expanding market.

A. Domestic Manufacturers:

- **Tata Motors:** A leader in the Indian EV space, Tata Motors has launched several suc- cessful models, including the Nexon EV and Tigor EV. The company is actively expanding its EV portfolio and aims to increase produc- tion capacity significantly
- **Mahindra Electric:** Known for its focus on electric mobility, Mahindra has introduced models like the eVerito and eKUV100, targeting both personal and commercial segments. The company is also investing in battery technology to enhance its offerings.
- **Ather Energy:** A startup focusing on elec- tric scooters, Ather has gained attention for its innovative designs and technology-driven approach. Its Ather 450X model is popular among urban consumers for its performance and smart features.

B. Global Manufacturers:

- **Tesla:** The American EV giant is exploring entry into the Indian market, which could significantly disrupt local dynamics. Tesla's reputation for high-performance electric vehicles positions it as a formidable competitor.
- **Volkswagen Group:** With plans to introduce a range of electric models in India, Volkswagen aims to leverage its global expertise in EV technology to capture market share.
- **Hyundai:** Already active in the Indian mar- ket with the Kona Electric, Hyundai plans to expand its electric offerings, capitalizing on its established brand presence.

XX. Innovation and Differentiation

Key product and technological innovations in the EV market in India.

- Battery Technology:
  - Advances in battery technology are central to enhancing vehicle performance and reducing costs. Domestic manufacturers are increasingly focusing on developing Indigenous battery solutions to lower dependency on imports and improve supply chain resilience
  - Companies like Tata Power are investing in battery recycling technologies to ad- dress environmental concerns associated with lithium-ion batteries.
- **Smart Features:** Many EV manufacturers are integrating smart technologies into their vehicles, such as connected car features, advanced driver-assistance systems (ADAS), and over-the-air software updates. This not only enhances user experience but also improves vehicle performance and safety.
- **Sustainability Initiatives:** Manufacturers are adopting sustainable practices in production processes, including using recyclable materials and implementing energy-efficient manufacturing techniques. This commitment to sustainability resonates with environmentally conscious consumers.

XXI. EV Ecosystem

The broader ecosystem supporting electric vehicles in India encompasses various components that facilitate growth and adoption:

- **Battery Suppliers:** A robust network of battery suppliers is essential for the EV industry. Companies like Ather Energy are focusing on developing high-performance batteries tailored for Indian conditions, ensuring reliability and efficiency.

- Charging Infrastructure:
  - The expansion of charging infrastructure is critical for supporting EV adoption. The government's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles

(FAME) scheme aims to incentivize the establishment of charging stations across urban and rural areas.
  - Private players like Tata Power and ChargePoint are actively investing in charging networks, aiming to increase accessibility and convenience for users.
- **Software Providers:** The integration of software solutions is crucial for managing charging networks, vehicle diagnostics, and customer engagement. Companies specializing in software development for connected vehicles are becoming increasingly important in the EV ecosystem.
- Public-Private Partnerships (PPP): Collaboration between government entities and private companies is essential for building a comprehensive EV ecosystem. Initiatives that promote investment in charging infrastructure and battery manufacturing can accelerate the transition to electric mobility.

Future Outlook

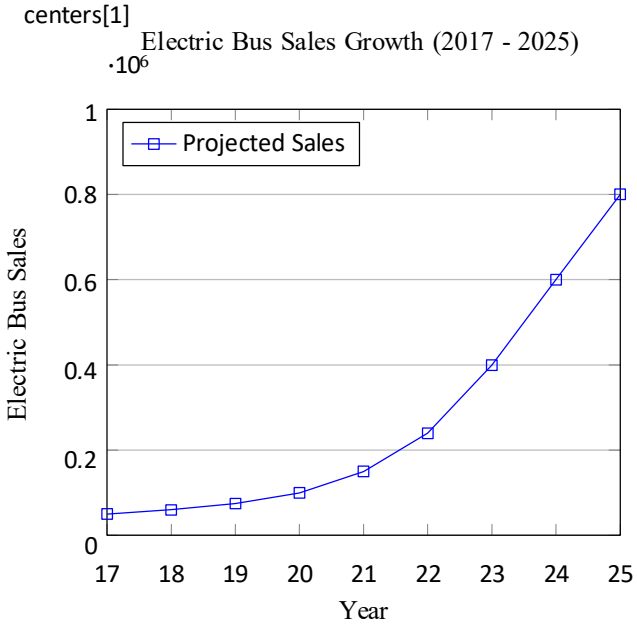
XXII. Growth Projections

India's electric vehicle (EV) market is anticipated to experience significant growth over the next 5-10 years. By 2030, the government aims for 40% of new buses to be electric, which translates to approximately 800,000 electric buses replacing diesel models. As of early 2024, India had registered around 8,583 electric buses, with projections indicating a dramatic increase in adoption as government incentives and infrastructure improve. The overall EV market share is expected to rise from its current low levels, particularly in urban areas where electric buses are being prioritized.[1]

XXIII. Emerging Trends

There are many trends which are visible in the current scenario :

- **Electric Two-Wheelers:** The two-wheeler segment is seeing rapid growth, driven by increasing urbanization and the need for sustainable transportation options. Government subsidies and rising fuel costs are encouraging consumers to switch to electric models
- **Electric Buses:** The introduction of electric buses in major cities is gaining momentum. Initiatives like the PM e-Bus Sewa aim to deploy thousands of electric buses across urban centers[1]



XXIV. Impact of Autonomous and Connected Vehicles

The potential for autonomous and connected vehicle technologies in India is significant, with various factors contributing to their expected impact on transportation systems and urban mobility

A. Enhancement in Public Transport and Traffic Management

- **Efficiency Improvements:** Autonomous electric vehicles (EVs) can streamline public transport operations by optimizing routes and schedules based on real-time data. This can lead to reduced wait times and improved service reliability, making public transport more attractive to users.
- **Traffic Management:** Connected vehicles equipped with Vehicle-to-Everything (V2X) technology can communicate with traffic signals, other vehicles, and infrastructure to enhance traffic flow and reduce congestion. This capability is crucial in densely populated urban areas where traffic jams are common.

- **Cost Reduction for Fleet Operators:** The adoption of autonomous EVs can significantly lower operational costs for fleet operators by minimizing labor costs and reducing fuel expenses through efficient energy use.

B. Safety and User-Experience

- **Increased Safety:** Advanced Driver Assis- tance Systems (ADAS) integrated into con- nected vehicles can help prevent accidents by providing features such as collision avoidance, lane departure warnings, and automatic emergency braking. The adoption of these technologies is expected to grow, with a reported 70% year-on-year increase in vehicles featuring Level 2 autonomy as of 2023.
- **Enhanced User Experience:** Connected vehicles offer features that improve the overall driving experience, such as personalized settings, predictive maintenance alerts, and infotainment options. As consumer demand for connectivity rises, automakers are increasingly integrating these technologies into their offerings.

C. Challenges with Autonomous Driving

- **Poor Road Conditions:** Indian roads often suffer from potholes, uneven surfaces, and inadequate maintenance, making it difficult for autonomous vehicles to navigate safely and effectively. The lack of well-maintained infrastructure poses a challenge for the sensors and algorithms that guide these vehicles.
- **Insufficient Charging Infrastructure:** For electric autonomous vehicles, the charging infrastructure is lagging significantly. While there have been advancements for smaller elec- tric vehicles, dedicated charging facilities for buses and larger vehicles are still underdevel- oped
- **Heterogeneous Traffic:** Indian roads are shared by a diverse range of vehicles, including bicycles, rickshaws, and heavy trucks, which complicates the development of reliable autonomous navigation systems. The chaotic nature of traffic patterns can lead to unpredictable situations that autonomous systems must be able to handle.
- **Non-compliance with Traffic Regulations:** There is a prevalent disregard for traffic rules among many drivers in India, such as jaywalking and ignoring signals. This behavior creates an unpredictable environment that is challenging for autonomous vehicles to navigate safely.
- **Lack of Legal Framework:** Current laws, such as the Motor Vehicles Act of 1988, do not accommodate autonomous vehicles. There is no provision for testing or operating these vehicles legally on Indian roads, which hampers innovation and development efforts.
- **Liability Issues:** Determining liability in the event of an accident involving an au- tonomous vehicle presents complex legal chal- lenges. Questions arise regarding whether the vehicle owner, manufacturer, or software de- veloper should be held responsible.

Other challenges, such as Public Skepticism, Price sensitivity, the need for Technological Advancements, and talent acquisition, are affecting the current growth of Autonomous driving in India.

XXV. International Collaborations

International collaborations significantly bolster India's push towards electrification in the automotive sector. These partnerships are crucial for accelerating technology transfer, enhancing local manufacturing capabilities, and developing robust infrastructure. Here's a detailed exploration of the current landscape of international collaborations in India's EV sector.

- **Ahamani EV Technology:** This company is actively engaging with Indian automotive giants to facilitate technology transfer. Their initiatives include establishing a megawatt-scale battery plant, which will support both electric vehicles and drones, thereby enhancing local manufacturing capabilities and innovation in the EV sector.
- **ISRO Collaborations:** The Indian Space Research Organisation (ISRO) has been instrumental in transferring lithium-ion battery manufacturing technology to various Indian com-

panies. This initiative aims to bolster domestic production capabilities and reduce reliance on imports.

- **Tata Motors and Mahindra & Mahindra Initiatives:** Major Indian automakers like Tata Motors and Mahindra & Mahindra are actively developing autonomous vehicle technologies. Tata Motors is working on a framework for semi-autonomous vehicles while also collaborating with Cognizant Technologies to create indigenous prototypes.
- **Swaayatt Robots:** Founded by IIT Roorkee graduate Sanjeev Sharma, Swaayatt Robots is developing advanced algorithms for autonomous driving. Their approach is focused on achieving Level 5 autonomy, where no human intervention is needed.

Recommendations

XXVI. For Manufacturers

To reduce costs and improve battery efficiency, EV manufacturers in India can adopt several strategies:

- **Invest in Local Battery Manufacturing:** Establishing domestic battery manufacturing facilities can significantly reduce costs associated with imports. Research indicates that local production can lower battery costs by approximately 20-30% due to reduced logistics and tariffs.[8]
- **Enhance Battery Efficiency:** Manufacturers should focus on improving the energy density of batteries. For instance, increasing the efficiency of EVs to achieve up to 4.2 miles per kWh (as seen with models like the Hyundai Ioniq 6) can reduce battery size and costs by nearly 40%, translating to savings of about USD 4,800 per vehicle.
- **Focus on Recycling and Circular Economy:** Developing robust recycling processes for used batteries can lower demand for new materials and reduce costs. Currently, less than 1% of lithium batteries are recycled; improving this could significantly impact material sourcing and overall expenses.

XXVII. For Policymakers

Policymakers play a crucial role in fostering an environment conducive to EV growth through strategic initiatives:

- **Continue Subsidies and Tax Breaks:** Extending existing subsidies for EV purchases can incentivize consumers to choose electric over traditional vehicles. For example, main- taining or increasing the current subsidy levels could boost sales by as much as 30% annually.
- **Enhance Charging Infrastructure Development:** Investing in charging infrastructure is critical for supporting the growing EV market. The government should aim to establish at least 1 million public charging stations by 2030 to ensure accessibility and convenience for users.
- **Standardization of Battery Technologies:** Implementing standardized battery specifications can facilitate interoperability among different EV models, particularly in public transportation systems like buses, enhancing user confidence and adoption rates.
- **Research Grants for Efficiency Improvements:** Allocating funds for research into battery technology improvements can lead to breakthroughs that reduce costs and enhance performance. This could include grants focused on developing next-generation lithium-sulfur or solid-state batteries.

XXVIII. For Investors

Investors have numerous opportunities to capitalize on the growth of the Indian EV market:

- **Invest in Startups Focused on EV Technol- ogy:** The Indian startup ecosystem is bur- geoning with innovative companies focused on electric mobility solutions, including battery technology, charging infrastructure, and software development for autonomous vehicles. Investing in these startups can yield significant returns as demand grows.
- **Funding Charging Infrastructure Projects:** With the government aiming for extensive charging networks, investing in companies that develop or operate charging stations presents a

lucrative opportunity. The market for charging infrastructure is expected to grow at a CAGR of over 30%, reaching approximately USD 10 billion by 2025.

- **Engage in Joint Ventures with Established Automakers:** Collaborating with established automotive manufacturers looking to expand their electric offerings can provide investors with access to resources, technology, and market expertise.

Conclusion The Electric Vehicle (EV) market in India is poised for substantial growth, driven by increasing environmental awareness, government support, and advancements in technology. This report highlights key factors influencing the market, including:

- **Government Initiatives:** The Indian government's commitment to promoting EVs through various subsidy schemes, policies like the National Electric Mobility Mission Plan (NEMMP), and the Faster Adoption and Manufacturing of Electric Vehicles (FAME) initiative has significantly contributed to market growth.
- **Market Segmentation:** The analysis of different segments—passenger vehicles, two-wheelers, three-wheelers, and commercial vehicles—reveals varying levels of consumer adoption and market dynamics. The dominance of two-wheelers and the emerging interest in electric cars signify a shift in consumer preferences.
- **Key Players:** Major companies such as Tata Motors, MG Motor, Mahindra & Mahindra, Ola Electric, and others are leading the market with innovative products and expanding production capacities, enhancing competition and consumer choices.
- **Challenges and Opportunities:** While challenges such as charging infrastructure, battery costs, and consumer awareness persist, there are significant opportunities for stakeholders to innovate and create solutions that can accelerate EV adoption.

In conclusion, the EV market in India presents a promising landscape for investment and development. Continued collaboration between government, industry players, and consumers is essential to overcome challenges and harness the full potential of electric mobility in the country.

Appendix

- **Electric Vehicle (EV):** A vehicle that operates on electric power, typically using an electric motor instead of a conventional internal com- bustion engine, resulting in reduced emissions and lower operational costs.
- **FAME (Faster Adoption and Manufactur- ing of Electric Vehicles):** A government ini- tiative in India aimed at promoting electric ve- hicle adoption through incentives and subsidies to consumers and manufacturers.
- **FAME-I:** The first phase of the FAME initia- tive, launched in 2015, which focused on incentivizing the purchase of electric and hybrid vehicles.
- **FAME-II:** The second phase of the FAME initiative, introduced in 2019, which expands the scope of incentives and includes support for charging infrastructure development.
- **National Electric Mobility Mission Plan (NEMMP):** A government policy aimed at creating a comprehensive framework for promoting electric mobility in India, including manufacturing and adoption strategies.
- **Production Linked Incentive (PLI):** A government scheme designed to encourage domestic manufacturing and attract investment in electric vehicle production and battery manu- facturing.
- **Range Anxiety:** The fear or concern of electric vehicle users regarding the vehicle's ability to travel a sufficient distance on a single charge, often leading to hesitance in adopting EVs.
- **Battery Electric Vehicle (BEV):** A type of electric vehicle that is fully powered by an electric battery, with no internal combustion engine, and must be charged from an external power source.
- **Plug-in Hybrid Electric Vehicle (PHEV):** A hybrid vehicle that can be charged from an external power source and can operate on

electric power alone for a limited range, in addition to conventional fuel.

- **Charging Infrastructure:** The network of charging stations and facilities that enable electric vehicle users to charge their vehicles.
- **Market Growth Rate:** The percentage increase in sales or adoption of electric vehicles over a specific time period, indicating market trends and consumer acceptance.
- **Consumer Survey:** A research tool used to gather opinions, behaviors, and preferences of consumers regarding electric vehicles, helping to inform market strategies.
- **EV Market Players:** Companies and organizations involved in the manufacturing, sale, or promotion of electric vehicles, including traditional automotive companies and new startups.
- **Sustainability:** The ability to meet present needs without compromising the ability of future generations to meet their own needs, of- ten associated with environmental preservation and responsible resource management.
- **Government Incentives:** Financial or non-financial benefits offered by the government to encourage the adoption and manufacturing of electric vehicles, such as tax rebates or grants.
- **Two-Wheeler Electric Vehicle:** Electric vehicles designed for two riders, such as electric scooters and motorcycles, which are becoming increasingly popular in urban areas.

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Solar Powered Small Scale Refrigerator

Mr. Altaf Badshah Shaikh KJ College of Engineering &

Management Research, Pune

Mr. Ambavkar Rushikesh Arvind KJ College of Engineering & Management Research, Pune

Mr. Vadluri Maheshkumar Narayan KJ College of Engineering & Management Research, Pune

Ms. Vaishnavi Rajesh Chikhalkar

KJ College of Engineering & Management Research, Pune

Mr. Rohit Tukaram Hanwate KJ College of Engineering & Management Research, Pune

Dr. Rohan Kulkarni

KJ College of Engineering & Management Research, Pune

Abstract

This project focuses on creating a small refrigerator powered by solar energy to help preserve food in areas without regular electricity. The refrigerator uses solar panels to generate power, keeps cool with good insulation, and uses a simple cooling system. Tests show that it reduces food spoilage, saves energy, and helps improve food safety in communities with limited power. The aim is to provide a sustainable, cost-effective, and eco-friendly solution for food storage challenges in rural and off-grid areas.

1. Introduction

Keeping food fresh is a big challenge in places without steady electricity. Regular fridges rely on conventional power sources, which can be unreliable and expensive in remote areas. This leads to food going bad quickly, causing health risks and economic losses.

Solar-powered refrigerators offer a promising solution. By using solar panels to convert sunlight into electricity, these fridges can work efficiently even in remote places. Solar energy is clean, renewable, and abundant in many parts of the

ISBN: 978-93-343-2006-0

world. This project aims to design and test a small solar-powered refrigerator that can help families and small businesses keep their food fresh without depending on regular electricity.

This project aims to explore the design, implementation, and performance evaluation of a solar energy-
powered food refrigerator. By examining the potential benefits and challenges of this technology, we seek to demonstrate its viability as a sustainable solution for food preservation. The findings will contribute to the broader discourse on renewable energy applications and their role in addressing global food security
challenges, particularly in underserved communities. Through this initiative, we hope to promote environmentally friendly practices and enhance the quality of life for those facing food access issues.

2. Literature Review

Many studies have shown that solar-powered fridges can save energy and reduce costs.

Solar Energy Utilisation: Khan et al. (2020) highlighted how solar refrigerators reduce energy costs and carbon emissions. They work best in sunny regions, making them ideal for rural communities.

Thermoelectric Cooling Technology: Research by Zhang et al. (2019) showed that thermoelectric coolers are compact, need little maintenance, and can control temperatures effectively.

Performance Evaluation:

Patil et al. (2021) tested solar fridges with thermoelectric modules, proving they maintain safe food storage temperatures even when sunlight varies.

Real-World Applications:

Sinha et al. (2022) conducted field studies in rural areas, showing that solar refrigerators help reduce food spoilage and improve access to fresh produce.

These studies confirm the potential of solar-powered



refrigeration systems, guiding the development of our project.

3. Problem Statementand Proposed System

Problem Statement:

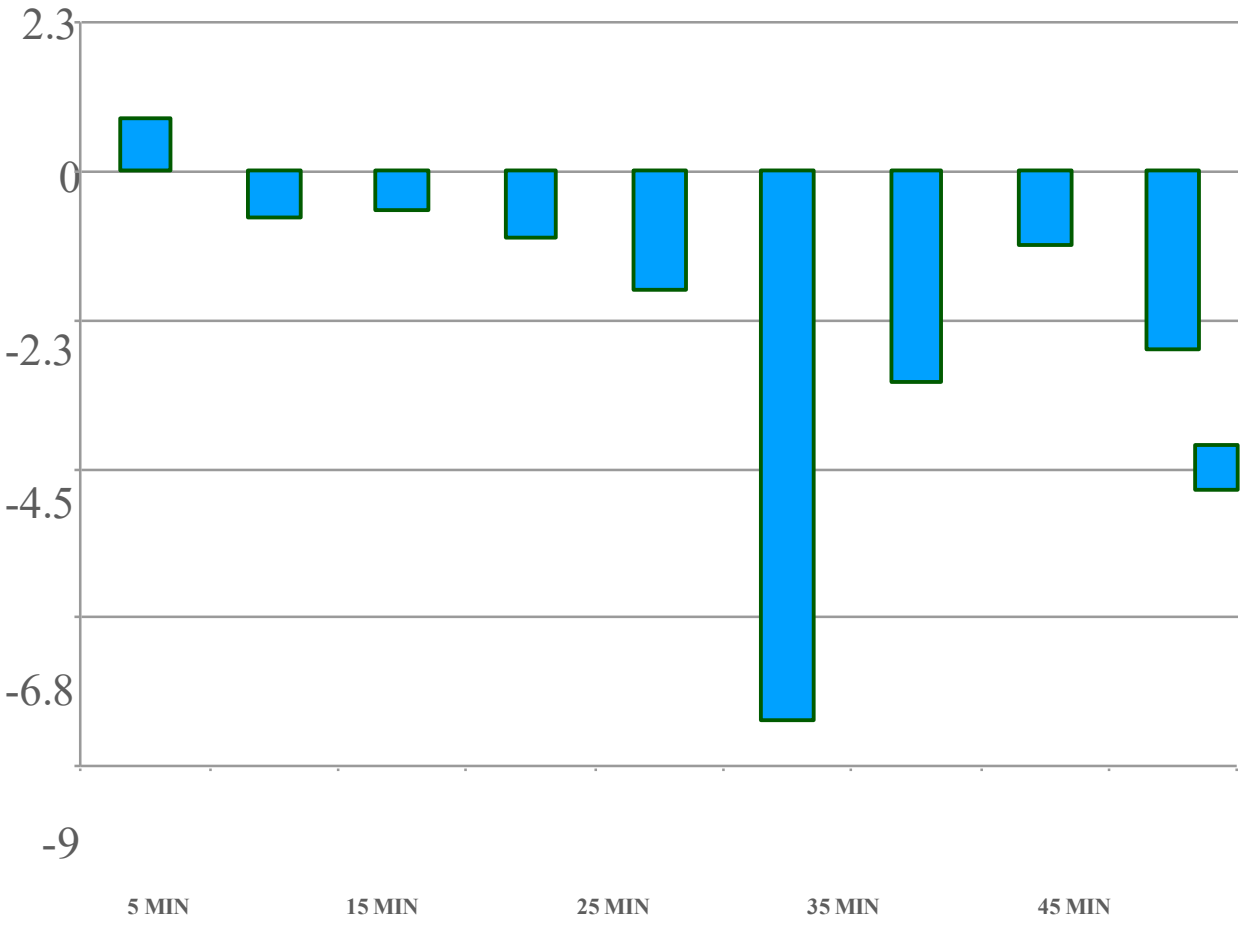
In many remote areas, people face the constant challenge of preserving food without reliable electricity. Traditional fridges are not practical because they need continuous power, which isn't always available. This leads to food spoilage, health issues, and economic losses.

Proposed System:

To solve this problem, we propose a solar-powered small-scale refrigerator. It uses solar panels to generate electricity, a battery to store extra energy for nighttime use, and a thermoelectric cooler to keep food fresh. The system is designed to be energy-efficient, easy to use, and affordable.

Key Components of the Proposed System

1. Solar Energy Collection Photovoltaic Panels: High- efficiency solar panels will be installed to capture sunlight and



ISBN: 978-93-343-2006-0

convert it into electricity. The design will include adjustable mounting options to optimize sunlight exposure based on seasonal changes.

2. **Solar Thermal Collectors (Optional):** For enhanced performance, thermal collectors can be integrated to support an absorption cooling cycle.

102.

3. Energy Storage System Lithium-Ion Battery Bank:

A robust battery storage system will store excess energy generated during the day, providing power during nighttime and cloudy days. This will ensure continuous operation and reliability.

4. **Smart Energy Management:** An intelligent control system will monitor energy production and consumption, optimizing the use of stored energy based on demand.

4. Cooling Mechanism Thermoelectric Cooler (TEC):

Thesystem will utilize a thermoelectric cooling module to provide efficient temperature control. TECs are compact and can maintain stable temperatures, making them ideal for food preservation.

Backup Vapor Compression

regions with highly variable solara ailability a backup vapor compression system can be incorporated to provide additional cooling when needed.

5. Insulation and Design

- **High-Quality Insulation:** The refrigerator will be constructed with advanced insulation materials to minimize heat transfer and maintain internal temperature effectively.
- **User-Friendly Features:** The design will prioritize ease of use, with adjustable shelves, clear temperature indicators, and easy access to the storage compartment.

6. Control System

- **Microcontroller-Based Monitoring:** A microcontroller will manage the system's operations, including temperature regulation, battery status, and energy flow. It will provide real-time data and alerts to users, ensuring optimal performance.
- **TemperatureSensors:** Sensors will continuously monitor the internal temperature, allowing for adjustments to maintain safe food storage conditions.

7. Durability and Portability

- **Rugged Design:** The refrigerator will be built to withstand varying environmental

conditions, ensuring durability and longevity.

- **Portable Options:** Lightweight models will be available for users needing mobility, such as farmers or families in remote areas.

4. System Design

The solar-powered refrigerator consist of several keys components working together: **Solar Panels:**

These capture sunlight's and convert it into electricity. The panels are positioned to get maximum sunlight during the day. **Battery Storage:**

The battery stores extra energy generated during the day, allowing the fridge to work at night or on cloudy days.

Thermoelectric Cooler (TEC):

This cooling device uses electricity to maintain low temperatures inside the fridge. It's simple, compact, and requires minimal maintenance.

Insulation:

The fridge is built with high-quality insulation materials to keep the cold air inside, reducing the need for constant cooling.

Control System:

A simple control panel lets users adjust the temperature and check battery levels. Temperature sensors ensure the fridge maintains a safe range for food storage.

5. Results and Discussion

We tested the refrigerator in different conditions to measure its performance:

Observation:

The fridge was able to maintain a steady temperature even when the sunlight varied. It worked efficiently with the battery during nighttime.

Energy Consumption:

The system used very little energy, showing that it's suitable for areas with limited sunlight.

Cooling Performance:

The thermoelectric cooler maintained temperatures between -2.7°C and -3.2°C after 30 minutes of operation, which is ideal for preserving perishable food.

6. Conclusion and Future Work Conclusion:

Our project demonstrates that a solar-powered small-scale refrigerator is both effective and reliable. It helps reduce food spoilage, works without a constant power supply, and is environmentally friendly.

Future Work:

We plan to improve the system by:
Enhancing battery life for longer use without sunlight. Making the fridge more portable for mobile applications. Adding smart future like temperature alerts and energy usage reports.

Conducting long-term field tests to gather more performance data.

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Solar Powered Battery to Battery EV Charging Station

Nikita N. Mhetre., Nikita B. Solanke., Sagar S. Dharmsale., Prajwal S. Pote., Prof. Devendra Goyar.

Electrical Department, KJCOEMR, Pune, India.

nikita.mhetre111@gmail.com , nikitasolanke383@gmail.com, prajwalpote2002@gmail.com, dharmsalesagar@gmail.com

Abstract

This paper presents a novel implementation of a solar-powered battery-to-battery (B2B) electric vehicle (EV) charging station aimed at enhancing sustainable transport infrastructure. By integrating solar photovoltaic (PV) panels with stationary battery storage, this system enables off-grid energy generation and subsequent direct DC charging of EVs. The proposed B2B mechanism ensures energy can be transferred efficiently from the stationary battery bank to the EV battery without needing AC conversion, thereby reducing conversion losses. We analyze energy yield, storage requirements, and the feasibility of scaling this solution for urban and remote areas.

Simulation and prototype testing results confirm improved energy efficiency and grid independence. The system offers potential for deployment in regions with limited power infrastructure, promoting green mobility with minimized environmental impact.

Keywords: Solar charging, Battery-to-battery charging, EV infrastructure, Off-grid power, Sustainable energy

1 Introduction

The increasing adoption of electric vehicles (EVs) calls for innovative charging infrastructures that are both sustainable and efficient. Traditional EV charging stations depend on the power grid, which may not always align with goals for carbon neutrality or energy independence. Integrating solar energy with battery storage provides a promising alternative. This paper explores a design for a solar-powered battery-to-battery (B2B) EV charging station, offering off-grid capabilities and reduced power conversion losses.

SYSTEM OPERATION

The solar-powered battery-to-battery EV charging station operates by harnessing solar energy through photovoltaic (PV) panels, which charge a stationary battery storage system. This stored energy is then transferred to an electric vehicle (EV) using a **bidirectional buck- boost DC-DC converter**. The converter plays a critical role by adjusting voltage levels between the source battery and the EV battery, enabling efficient energy transfer regardless of their voltage differences. During charging, the system dynamically switches between buck or boost modes depending on the relative voltages, ensuring safe and optimal charging. A battery management system (BMS) and maximum power point tracking (MPPT) controller are integrated to enhance safety, protect against overcharging, and maximize energy harvesting from solar input.

BLOCK DIAGRAM

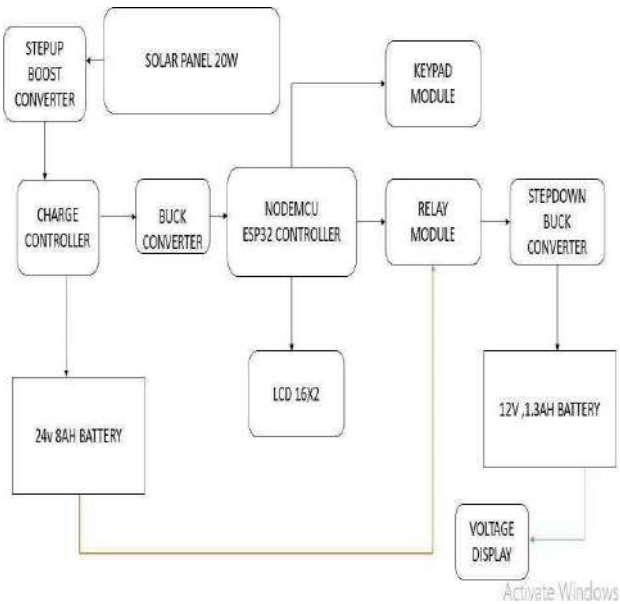


Fig . 1 System Infrastructure

COMPONENT SPECIFICATION AND CALCULATION

State of Charge (SoC)	Battery Voltage (V)	Charge Current (A)*	PWM Duty Cycle (%)	Charging Time (Hours)	Comments
0% (Fully Discharged)	11.5	1.1	100%	~6-7	Bulk charge mode; solar panel at max current.
20%	11.9	1.0 - 1.1	90 - 100%	~5-6	Bulk charge continues.
40%	12.2	0.9 - 1.0	75 - 90%	~3-4	Still in bulk charge mode.
60%	12.5	0.8 - 0.9	60 - 75%	~2-3	Absorption mode begins.
80%	12.8	0.5 - 0.7	40 - 60%	~1.5-2	Current tapers as voltage reaches 14V.
90%	13.0	0.3 - 0.5	20 - 40%	~1-1.5	Absorption mode; slower current tapering.
100% (Fully Charged)	13.8 - 14.2	<0.1	0 - 10%	Float mode; no significant charge time.	

State of Charge (SoC)	Battery Voltage (V)	Charging Current (A)	Estimated Charging Time (Hours)	Comments
0% (Fully Discharged)	22.0	~1.0	~1.5	Bulk charge starts, current high at the beginning.
20%	22.8	0.8–1.0	~1.4	Charging continues, current begins to taper as voltage increases.
40%	23.4	0.6–0.8	~1.2	Charging slows down further as the voltage approaches 24V.
60%	23.8	0.4–0.6	~1.0	Transition to slower charging as battery voltage nears supply voltage.
80%	24.0	0.2–0.4	~0.8	Current is much lower now; nearing maximum charge capacity.
100% (Practical Full)	25.78	~0.1	~2.0 (Approx.)	Full charge in practical terms (as each battery of 12v get full charge at 12.89 of lead acid)

Table No. 2 Battery to battery Charging Table

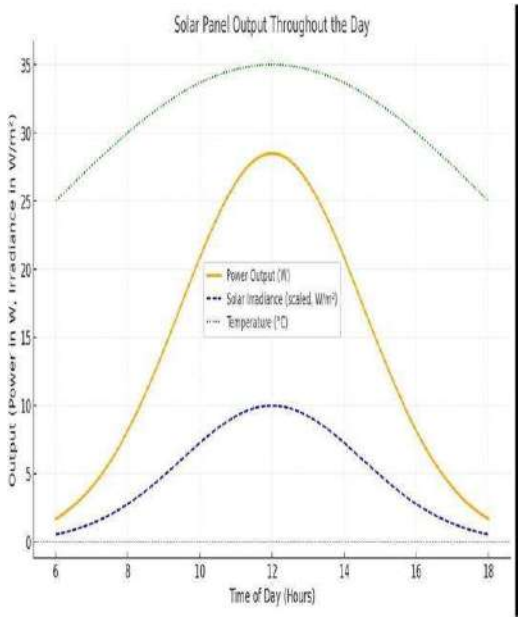


Fig. 2. Solar output characteristics

Time (Hours)	Irradiance (W/m²)	Temperature (°C)	Power Output (W)	Current (A)	Voltage (V)
6:00	56.1	25.0	1.68	0.14	12
9:00	493.8	32.1	14.29	1.19	12
12:00	999.7	35.0	20.0	1.67	12
15:00	493.8	32.1	14.29	1.19	12
18:00	56.1	25.0	1.68	0.14	12

ECONOMIC BENEFITS

1. Zero Emissions Power Supply

- Solar energy is a **clean, renewable source**. It produces **no greenhouse gases** or air pollutants during operation.
- Charging EVs using solar power instead of grid electricity (which may come from fossil fuels) significantly reduces their **carbon footprint**.

2. Energy Independence and Decentralization

- These stations reduce reliance on large, centralized power grids, which often use coal or gas.
- Encourages **distributed generation**, minimizing energy losses from transmission and reducing pressure on grid infrastructure.

CONCLUSION

The solar-powered battery-to-battery EV charging station represents a **sustainable, forward-thinking solution** for the future of transportation and energy. By harnessing clean, renewable solar energy and storing it in batteries for EV charging, this system offers a powerful combination of **environmental protection** and **economic opportunity**. Environmentally, it significantly reduces greenhouse gas emissions, decreases dependence on fossil fuels, and promotes clean energy usage. Economically, it lowers operational costs, creates new business and job opportunities, enhances energy independence, and benefits from government incentives. Overall, this technology supports the global transition to **greener mobility and cleaner energy systems**, making it a smart and responsible investment for both public and private sectors.

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Neural Operator-Based Prediction of Temperature Dynamics in Lithium Iron Phosphate Batteries for Electric Vehicles

Abhishek Baer
abaer@ltu.edu

Abstract—This paper presents a novel approach for modeling temperature evolution in Lithium Iron Phosphate (LiFePO4) electric vehicle batteries using Neural Operators. The method overcomes limitations of traditional heat transfer models by learning a data-driven surrogate that accurately predicts battery temperature as a function of driving diagnostics and environmen tal conditions. The study explores regularization techniques and a time stability loss function to enhance the model's robustness and accuracy. Results demonstrate the efficacy of the proposed Neural Operator framework for estimating battery temperature dynamics.

I. Introduction

The global automotive industry is undergoing a transforma tive shift driven by the convergence of environmental impera tives, depletion of fossil fuels, and aggressive policy mandates aimed at decarbonization. At the forefront of this evolution are electric vehicles (EVs), which are becoming viable and scalable alternatives to traditional internal combustion engine (ICE) vehicles. Among the critical components that determine the performance and viability of EVs are the energy storage systems—most notably lithium-ion batteries.

Lithium Iron Phosphate ($LiFePO_4$), a subclass of lithium ion chemistries, has garnered significant attention in recent years due to its superior safety, thermal stability, and longevity. Compared to traditional Li-ion cells (e.g., NMC or LCO types), $LiFePO_4$ batteries exhibit:

- Enhanced thermal tolerance: Operate reliably across a wider temperature range without thermal runaway.
- Superior safety characteristics: Due to their chemical composition and robust phosphate framework, they are less prone to overheating or combustion.
- Longer lifecycle: Capable of sustaining thousands of charge-discharge cycles with minimal capacity fade.
- Cost-effectiveness and sustainability: Use of non-cobalt materials reduces environmental impact and material scarcity issues.

For instance, Tesla's Model 3 uses $LiFePO_4$ cells to optimize for both economic scalability and operating safety. Despite these advantages, $LiFePO_4$ batteries still face crit ical challenges, particularly related to temperature sensitivity. Battery temperature influences electrochemical kinetics, inter nal resistance, energy efficiency, and long-term degradation. Hence, precise prediction and management of temperature dynamics are essential for ensuring safe and optimal battery operation.

Traditional modeling approaches employ physics-based thermal models rooted in energy balance equations. While these offer interpretability, they often suffer from limited scalability in dynamic and uncertain real-world environments due to computational overhead and the need for accurate parameter estimation.

In contrast, this work introduces a *neural operator*-based approach for learning the temperature evolution of $LiFePO_4$ battery cells. Unlike conventional neural networks or recurrent models, neural operators learn mappings between function spaces. This makes them uniquely suited for modeling con tinuous spatiotemporal dynamics under varying inputs. Neural operators generalize better across unseen driving conditions and support fast inference suitable for embedded applications.

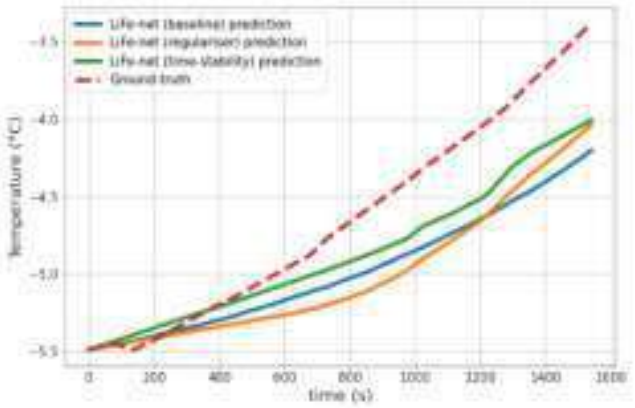


Fig. 1. Training pipeline of LiFe-net incorporating time-stability loss. The model captures temporal dependencies and corrects deviations through multi step residual feedback.

Figure 1 illustrates the proposed training architecture. A novel time-stability loss ensures consistency across succes sive temporal predictions, thereby preventing divergence—a common issue in autoregressive

ISBN: 978-93-343-2006-0

sequence models. This is especially beneficial in modeling battery behavior during highly transient driving scenarios, such as stop-and-go traffic or sudden temperature shifts.

In summary, this paper contributes a neural operator-based framework for accurate, stable, and generalizable prediction of temperature dynamics in EV batteries. By leveraging real world telemetry from Tesla Model 3 vehicles, the model is designed to operate in noisy, variable conditions and lays the groundwork for future adaptive thermal management systems.

II. Methodology

This section delineates the experimental design, neural operator modeling approach, and the various enhancements introduced to improve robustness, generalizability, and in terpretability of the proposed battery temperature modeling framework. Additionally, we detail the development of a surrogate model for estimating charging characteristics from predicted thermal states.

A. Experimental Setup and Data Acquisition

The experimental configuration is illustrated in Fig. 3 (Ap pendix A), which provides a schematic overview of sensor placement and data logging mechanisms. Thermal readings were continuously captured using an Inkbird IBS-TH1 Blue tooth thermometer placed directly beneath the driver's seat of a Tesla Model 3, a configuration selected to approximate the internal cabin temperature and infer subsurface battery heating effects.

The Tesla Model 3 employed in this study was equipped with a CATL-manufactured lithium iron phosphate ($LiFePO_4$) battery pack. This specific chemistry was selected due to its known stability and temperature sensitivity, which make it a compelling candidate for thermal modeling. Alongside thermal data, auxiliary driving telemetry was gathered via Tesla's onboard API, including vehicle velocity, energy consumption, battery percentage, and ambient environmental conditions such as temperature, humidity, and elevation gradient. These pa rameters were recorded at 1 Hz intervals and were aligned temporally to ensure consistent feature synchronization.

B. Neural Operator Modeling Framework

tion (ODE) framework. The model assumes the following continuous-time formulation:

$$\frac{du(\tau,\ \mathrm{e})}{d\tau} = \phi_\theta(\tau,\ \mathrm{e}),\ u(\tau_0,\ \mathrm{e}_0) = u_0 \quad (1)$$

To capture the dynamic evolution of the battery tem perature during real-world driving conditions, we employ a neural operator-based parametric ordinary differential equa

This loss function penalizes divergence between the ob served temporal gradient and the neural operator's predicted evolution rate. The temporal propagation of temperature is computed through explicit Euler integration:

$$u_{i+1} = u_i + \delta \cdot \phi_\theta(\tau_i,\ \mathrm{e}_i) \quad (3)$$

where δ denotes the time step interval. This forward Euler method is computationally efficient and enables deployment in embedded or real-time inference settings.

C. Comparison with Traditional Modeling Approaches

Traditional thermal models such as equivalent circuit models (ECMs), empirical regression, and partial differential equa tions (PDEs) provide structured, physics-based insights but struggle under stochastic real-world conditions due to high computational overhead and parameter sensitivity. While re current neural networks (RNNs) and long short-term memory (LSTM) architectures offer temporal modeling capabilities, they typically require fixed-length sequences and exhibit van ishing gradient issues.

In contrast, neural operator methods operate in function space, enabling them to generalize across varying temporal trajectories and environmental configurations. This property makes them especially well-suited for systems where the input-output relationship evolves over time, such as battery thermal dynamics in electric vehicles. Furthermore, operator based models inherently support continuous-time forecasting and can integrate domain constraints directly into their archi tecture, enhancing interpretability and physical coherence.

D. Smoothing Regularization for Stability

Although powerful, neural operators are prone to overfitting transient patterns and may exhibit erratic predictions when exposed to minor fluctuations in environmental inputs. To combat this, we introduce a smoothness regularization term that penalizes sharp gradients in the output with respect to the input feature space:

$$L_{\text{smooth}} = \frac{1}{M}\sum_{j=1}^{M} \left\| \frac{\partial \phi_\theta(\tau,\ \mathrm{e})}{\partial e_j} \right\|_2^2 \quad (4)$$

Here, $u(\tau,\ \mathrm{e})$ denotes the temperature state at a relative time τ under environmental features $\mathrm{e} \in \mathrm{R}^d$, which include telemetry-based variables such as speed,

SoC, and ambient temperature. The function ϕ_θ, parameterized by learnable weights θ, approximates the unknown temporal derivative of the temperature. This formulation allows the system to gen eralize beyond fixed-length sequences and model continuous trajectories effectively.

The model is trained by minimizing a discrete approxima tion of the temporal residual error, expressed as:

Here, e_j represents the j-th component of the environmen tal feature vector. This term encourages the model to learn smoother, more physically plausible transitions and reduces sensitivity to sensor noise. The total training loss is thus:

$$L_{\text{reg}} = L_{\text{NO}} + \lambda L_{\text{smooth}} \quad (5)$$

where λ is a tunable regularization coefficient that balances model fidelity with generalization.

E. Time-Consistency Augmentation for Multi-Step Forecasting Real-world driving scenarios demand stability across multi step predictions. A common issue in autoregressive inference

$$L_{\text{NO}} = {}^{N}\text{X}^{-1}{}_{i=0} \quad \tau_{i+1} - \tau_i - \phi_\theta(\tau_i, \text{e}_i) \quad {}_2 \quad u_{i+1} - u_i \quad (2)$$

is compounding error. To alleviate this, we integrate a time consistency augmentation loss that enforces agreement be tween true and recursively predicted thermal states:

$$L_{\text{TS}} = {}^{N}\text{X}^{-1}{}_{i=1} \quad u^{\text{true}} \quad {}_i - (\phi_\theta(\tau_{i-1}, \text{e}_{i-1}) \cdot \delta + \hat{u}_{i-1})^2 \quad (6)$$

This term minimizes the deviation between the ground truth and the rolling forecast estimate over a sequence of time steps. It plays a critical role in preventing divergence during long horizon simulations, as visualized in Fig. 1.

F. Surrogate Modeling for Charging Characteristics Beyond thermal prediction, a secondary objective is to infer charging characteristics from the modeled temperature profile. Toward this, we define a linear surrogate model that estimates charging metrics as a function of both thermal and SoC derived features:

$$p_c = \beta_1 C + \beta_2 u_i + \gamma$$

$$t_c = \delta_1 C_s + \delta_2 C_e + \delta_3 u_i + \eta \quad (7)$$

Here, p_c denotes peak charging power and t_c represents estimated charging time. Variables C, C_s, and C_e correspond to instantaneous SoC, SoC start, and SoC end respectively, while $u_i$is the inferred battery temperature at time i. Coef ficients (β_1, β_2, γ) and (δ_1, δ_2, δ_3, η) are learned via ordinary least squares regression.

This auxiliary model helps quantify the downstream im pact of thermal dynamics on EV charging performance and provides interpretable outputs that can inform battery man agement strategies. This surrogate mapping is grounded in the empirical observation that thermal stress directly influences charge acceptance and internal resistance. By using predicted temperature trajectories from the neural operator, we obtain a reliable intermediate feature that captures system-level state, enabling downstream applications like adaptive charging con trol or thermal-aware scheduling for fleet vehicles.

G. Implementation and Training Details

The neural operator ϕ_θ is implemented using a multilayer perceptron (MLP) architecture with ReLU activations, batch normalization, and dropout layers for regularization. Feature scaling was performed using z-score normalization. The model was trained using the Adam optimizer with a learning rate of $1\times10^{-4}$for 300 epochs. Hyperparameters λ and δ were tuned via cross-validation.

All experiments were conducted using PyTorch on an NVIDIA RTX 3090 GPU. Inference time per trajectory was under 20 ms, indicating suitability for deployment in low latency environments such as EV onboard systems.

III. Evaluation and Results

To rigorously assess the efficacy of the proposed neu ral operator-based framework, a dataset comprising 445,000 timestamped entries was compiled from 99 distinct driving events. These drives were conducted under diverse environ mental conditions, including varying ambient temperatures, humidity levels, and driving velocities. Data collection in cluded not only thermal sensor readings from beneath the

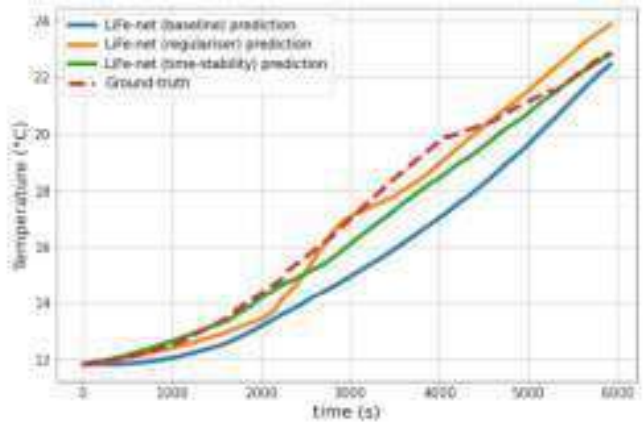


Fig. 2. All models perform well on test data that is well represented by our training data.

driver's seat but also system-level telemetry such as energy draw, state-of-charge (SoC), and external climate variables obtained via the Tesla onboard interface.

The dataset was partitioned into a training subset consisting of 92 driving instances and an evaluation set of 7 unseen drives to assess generalizability. Several model variants were trained using this dataset and benchmarked using Mean Absolute Er ror (MAE), Mean Squared Error (MSE), and Relative Percent age Error (RPE). These metrics collectively provide insight into both the magnitude and variance of prediction deviations. In addition to accuracy, the computational overhead (epoch training time) was monitored to evaluate model scalability and suitability for real-time deployment scenarios.

Table I presents the quantitative outcomes across three principal model configurations: a baseline neural ODE model, a regularized version incorporating smoothness constraints, and a time-consistent model featuring temporal stability aug mentation.

TABLE I
PERFORMANCE METRICS ACROSS MODEL VARIANTS

Model	MAE	MSE	Rel. Error (%)	Epoch Time (s)
Baseline	0.706	0.934	4.6452 3.6223	104.89
Regularize	8	2	2.7715	123.46
d	0.544	0.631		1151.25
Time-Stabl	5	2		
e	0.384	0.269		
	5	2		

The baseline model demonstrated acceptable performance with moderate error margins; however, its prediction variance was sensitive to abrupt changes in environmental inputs. The regularized variant reduced both MAE and MSE significantly by enforcing local smoothness in the learned temporal dynam ics, thereby improving stability in transitional phases such as acceleration or sudden braking.

The most advanced variant, incorporating time-consistency penalties, achieved the best performance across all three accuracy metrics. Despite its longer epoch time (an order of magnitude greater due to multi-step backpropagation), it maintained superior alignment between predicted and actual temperature profiles. This highlights the value of incorporating higher-order dynamics and recursive correction into temporal modeling tasks for electric vehicle systems.

A. Interpreting Charging Characteristics

Following temperature prediction, inferred thermal readings were employed in a linear regression framework as described in Equation (7) to estimate two key charging metrics: peak charging power (p_c) and total charging duration (t_c). Regres sion was performed using a standard least-squares approach across the evaluation set.

The resulting regression coefficients demonstrated strong correlation between thermal states and charging behaviors. Specifically, the R^2coefficient for p_c was found to be 0.726, indicating a moderately strong relationship between predicted thermal levels and peak charging power. In contrast, the R^2 score for t_c was 0.884, suggesting a very strong association with thermal state and other SoC-derived features. These findings validate the hypothesis that thermal evolution profiles derived from the neural operator can serve as viable surrogates for estimating charging behavior in real time.

Moreover, this mapping opens avenues for closed-loop control systems that dynamically modulate charging profiles based on inferred thermal stress, enabling smarter energy management and improved battery longevity.

IV. CONCLUSION

In this work, we introduced a neural operator-driven ap proach for learning and forecasting the thermal evolution of lithium iron phosphate ($LiFePO_4$) battery cells in electric vehicles, leveraging real-world telemetry collected from a Tesla Model 3. By treating the temporal temperature profile as a solution to a learned parametric ODE, our methodology encapsulates complex dependencies between environmental conditions and internal thermal dynamics.

Three variants of the neural architecture were compared: a baseline model, a regularized model with environmental input smoothing, and a time-stable model

incorporating temporal consistency across multi-step forecasts. The time-stable vari ant significantly outperformed others in terms of prediction accuracy, demonstrating the utility of multi-step penalization in learning temporally coherent dynamics. The inclusion of smoothing and stability regularizers ensured generalizability and resilience against spurious environmental fluctuations.

Furthermore, we demonstrated that these temperature pre dictions could be effectively used as inputs to a secondary regression model to estimate peak charging power and total charging duration. The high correlation values obtained in this stage affirm the potential for integrated diagnostics, whereby thermal evolution acts as an intermediate signal bridging telemetry with power system management.

Looking ahead, this framework can be extended to in corporate uncertainty quantification through Bayesian neural operators, or fused with spatial sensors to enable full 3D thermal mapping. Additionally, adaptive integration schemes

could further improve long-range predictive fidelity without incurring high computational costs. Ultimately, the presented approach contributes toward more intelligent, thermal-aware energy systems in next-generation electric vehicles.

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Sensor-Based Signal Pattern Recognition and AI-Driven Fault Detection: A Comprehensive Review for Predictive Health Monitoring in Electric Vehicle Powertrain Systems

Authors

[1]Bapu Kokare, *Research Scholar, Department of Technology, Savitribai Phule Pune University, Pune, India*

[2]Sanjay Deokar, *Principal, Sharad Pawar College of Engineering, Someshwarnagar, Savitribai Phule Pune University, India*

[3]Mangesh Kale, *Principal Engineer, Eaton Ltd., Pune, India*

Corresponding Author

Mr. Bapu Kokare

Research Scholar, Department of Technology, Savitribai Phule Pune University, Pune, India

bapu.kokare1990@gmail.com

8999370231

Abstract

The current Emerging electric vehicles (EVs) call for sophisticated and enhanced predictive health monitoring (PHM) systems to guarantee reliability, performance, and safety of powertrain system. This review presents a detailed analysis of the existing literatures on the implementation of signal pattern recognition techniques supported by sensors and AI for fault detection in the application of PHM in EV powertrain systems. The aspects of multi-sensor networking, vibration and acoustic patterns, thermal and electrical signals, and their perhaps earliest signs of a problem are discussed. The performances of the models in the feature extraction, pattern recognition, and fault classification metrics are compared for AI and machine learning methodologies such as supervised, unsupervised, and deep models. This paper discusses some new advancements, evaluates the performance of the algorithms used in the modern approaches and also some of the issues like the limitation of the data constraint, the challenges involved in the fusion of the sensor data, and the issues of real time application of the techniques. In addition, the future trends such as edge computing, digital twins, and hybrid artificial intelligence models are revealed further, which, in turn, contribute to increasing the predictive reliability and minimizing false-positive production. The opinion of this paper is to equip researchers and industry professionals with insights into the current solutions and directions for future developments of robust, scalable, and smart PHM solutions for EV powertrains.

Keywords: electric vehicles, predictive health monitoring, powertrain system, pattern recognition techniques, smart fault detection methods.

[1]INTRODUCTION

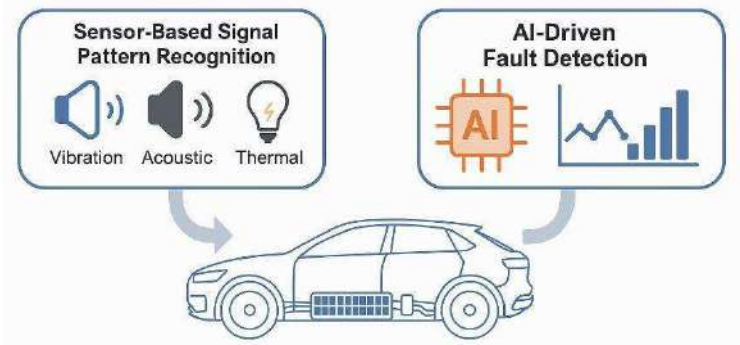


Figure 1: Predictive health monitoring in electric vehicle powertrain systems

PHM means the regular state appraisal of details and systems without main focus on sensor information and probabilities to use analysis and models that anticipate failings before they happen. In the context of EV powertrain systems, PHM refers to identifying conditions of those elements responsible for power train in the vehicle such as the battery, electric motor, inverter, gearbox, and coolants indicating signs of wear, degradation, or failure. PHM, on the other hand, is more strategic, as it applies maintenance plans according to the information that is received and is not like the other maintenance schedules where maintenance can be performed even when it is not necessary.

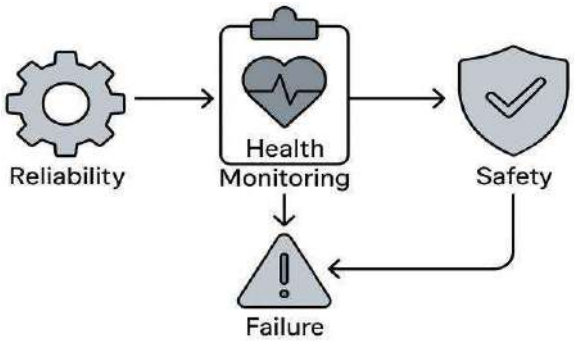


Figure 2: Importance of health monitoring for reliability and safety

The relevance of the proposed concept in EV powertrains is based on the electrical, mechanical, and thermal loads that these systems experience during operation. Malfunction of any element negates performance yet it is also a recipe for steep vehicle recalls or worse still, an explosion or fire in batteries. Thus, PHM helps to increase operational dependability, determine the proper timing for the maintenance of the EV's powertrains without compromising its safety, and prolong the powertrain's useful life. This is an important factor in determining the worth of an EV's powertrain because it is directly related to the vehicle's dependability, cost, safety, and longevity. Durability is crucial to guarantee safe and stable drive without mechanical failures at all sorts of conditions, which is rather important for transport vehicles, commercial fleet, and intercity traveling. The cost consequences are because of powertrain repairs are significantly high, and battery replacements are some of the most costly events an EV's lifespan. As a result, based on

the forecast and in order to avoid increasing time off and unanticipated costs, the owners of vehicles and fleet managers can minimize them. Another major issue is safety and reliability of electrical systems; for instance, issues such as short circuitry, fire outbreak or absence of power supply during the use of the transportation system becomes life threatening to passengers, and also other road users. Last but not the least, health monitoring allows using the equipment in and charging behavior of components during their lifecycle in a more efficient way and thus it limits their usage in a way that they are not over stressed and finally reduces the degradation rate of fail costly components such as batteries or motors. All of these reasons explain why there is a need for accurate monitoring systems to ensure the proper functioning, safety, and durability of EV powertrains. This paper review focuses towards presenting a systematic and organized understanding of state of art information on sensor signal pattern analysis and AI based fault diagnosis for prognostic health monitoring of electric vehicle powertrain. The area of concern spans across all the monitoring stages ranging from the sensor technologies, data acquisition methodologies, signal processing and analysis, and artificial intelligence techniques used in diagnosing the faults. The review synthesizes scholarly and applied literature through identification of how multi-sensor data and machine learning models are used in fault pattern recognition and prediction for the purpose of implementing preventive maintenance strategies.

1.1 Problem Statement

Electric vehicles (EVs) are currently under much scrutiny as they are currently the main solution in transitioning to sustainable transport systems globally due to issues concerning the reliability, safety, and maintainability of the powertrain systems of such vehicles. Since battery, inverter, motors and drivetrains are the main parts of the electric vehicle which is subjected to a wide range of mechanical, thermal and electrical stresses during its operation it is highly susceptible of having sudden failures or progressive degradation. Previous countermeasures are employed to a considerable extent by time-bound or repair-based current approaches, which have become ineffective due to the dynamically changing environment of electric vehicle (EV) operations. It can be seen that while the sensor-based health monitoring systems have been developed, most cannot transform the patterns from the signals into understandable early signs of faults. Moreover, most of the developed AI models considering the fault detection problem are limited in their scope to a single component or some failure modes, and very often, do not address the problems of integration of the models or their scalability to the entire system. There is thus a growing urge to figure out elaborate, smart diagnostic and prognostic frameworks that would use signal processing and sophisticated machine learning algorithms for EM detection, identification, and prognosis in EV powertrain vehicular systems.

1.2 Novelty of the Work

The novelty of this review is in the first view of evidence synthesis and cross-disciplinary nature of the work which is built on sensor based signal pattern recognition working in conjunction with modern AI and state-of-art machine learning techniques for prognosis of health of EV powertrain systems. In contrast, this review assumed a more comprehensive approach when considering the

system's components, as different investigations were mainly focused on specific issues, ranging from battery fault detection or motor anomaly diagnosis. It goes a step further from other surveys by not only revealing and comparing supervised learning, unsupervised learning and deep learning models, and their performances as well as data demands, but also discussing the concept of real-time implementation. This work also reveals some novel and less-discussed topics like AI integration, digital twin, and edge compute that has not been included into the contemporary scope of EV powertrain PHM yet. As such this paper aims at sharing ideas and recommendations for furthering next-generation, integrated PM systems research and development for both academics and industries.

1.3 Research Gap

Nevertheless, there are several important research gaps regarding both sensor technologies and AI-based fault detection even with the knowledge advancement in these areas. First, most of the current studies only consider monitoring individual components such as batteries or motors but overlook on the interaction between different levels of an EV powertrain. Second, all datasets are not standard or of sufficient quality, and this poses challenges in comparing the results of different studies or comparing it to similar results or even testing its performance under field conditions. Third, it must be noted that most of the emerging AI models are complex and are not designed to operate in real-time on onboard systems, which is crucial to the implementation of PHM techniques. At the same time, the integration of data from multiple sensors (sensor fusion), processing of noisy or partial signals, as well as the creation of AI-analysis models that provide understandable information about identified defects remain the promising and underdeveloped fields. These gaps are necessary for the development of robust and predictive health management systems that are useful in the fast-growing electric vehicle market.

1.4 Objectives

The objectives are to,

- Systematically summarize the state-of-the-art methods and tools available for EV powertrain PHM.
- To design algorithm and to distinguish between real time fault and transient fault by using machine learning process ANN.
- To design and automate health monitoring of powertrain vehicle, which helps for user to complete preventive maintenance schedule within the duration by using combination of techniques.
- Compare the performance, advantages, and limitations of various AI and machine learning models used for fault detection,
- highlight key challenges such as data scarcity, real-time implementation, and integration with vehicle systems,
- To improve the vehicle stability under a fault condition by using different technique and Outline emerging trends and future research directions that could advance the field, such as edge computing, digital twins, and hybrid AI models.

This review could benefit academicians, engineers, and practitioners who intend to explore or implement reliable and efficient PHM solutions aimed at addressing the emerging issues in the electric vehicle market.

[2]OVERVIEW OF ELECTRIC VEHICLE POWERTRAIN SYSTEMS

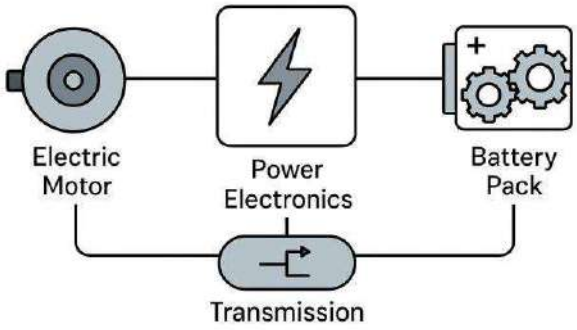


Figure 3: Brief Overview of electric vehicle powertrain systems

The vehicles include lithium-ion battery pack that stores and distributes electric energy in the form of electricity, inverter or power electronics that convert electrical energy into mechanical energy, electric motor such as permanent magnet synchronous motor or induction motor that adjusts the speed for the motor, gearbox that gear the motor's rotation and a cooling system which regulates the temperature of the powertrain or EV. The following are among the operations stresses of solar power modules: batteries can degrade because of thermal runaway, reduced capacity, or mechanical deterioration; inverters can fail due to heat generation, excessive voltage, or component strain; motors are subject to insulation breakdown, demagnetization, or bearing wear; there is always wear and tear of gear tooth and loss of lubrication in gearboxes; cooling systems may involve pump failure or blockage in heat exchangers. For example, one's stress in one of the given subsystems may transfer to other subsystems, thus requiring early identification. Vibration signals (for mechanical fault), Acoustic emission signals (for gear & bearing fault), Thermal data (for situation which is heated and may lead to failure), Electrical signals (for battery, inverter, motor health check) and Magnetic field signal (motor abnormalities) minute signs of failure, thus for effective health monitoring to be achieved multi-domain signal will have to be captured and analyzed.

2.1 Sensor Technologies for Health Monitoring

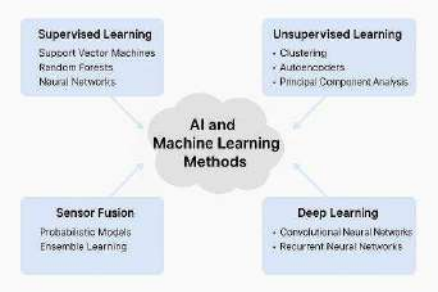


Figure 4: AI and machine learning methods

Current AI and machine learning methods play a central role in analyzing multi-sensor data for predictive health monitoring of EV powertrain systems by extracting patterns, learning fault signatures, and enabling early anomaly detection. Techniques such as supervised learning (e.g., support vector machines, random forests, neural networks) are used to classify known fault types based on labeled training data, while unsupervised methods (e.g., clustering, autoencoders, principal component analysis) detect unknown or emerging anomalies by identifying deviations from normal patterns. Deep learning approaches, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are increasingly applied to process large-scale, multi-modal time-series data like vibration, thermal, and electrical signals, capturing complex temporal and spatial relationships. Additionally, sensor fusion frameworks integrate diverse signals using probabilistic models (e.g., Bayesian networks) or ensemble learning to improve robustness and reduce false alarms. These AI-driven methods significantly enhance the precision, scalability, and adaptability of EV powertrain health monitoring systems, moving beyond traditional threshold-based diagnostics toward intelligent, predictive, and real-time fault management.

2.2 Signal Pattern Recognition Techniques

Table 1: Time-domain, frequency-domain, and time–frequency domain analysis

Analysis Type	Advantages	Disadvantages	Applications in EV Powertrain PHM
Time-Domain Analysis	Simple implementation; directly relates to physical events; requires less computational power.	Less effective at isolating frequency-specific phenomena; sensitive to noise; may miss subtle faults.	Monitoring sudden changes in signals (e.g., current, voltage spikes); detecting abrupt mechanical events like impacts or bearing faults in the motor or gearbox.
Frequency-Domain Analysis	Identifies periodic components; effective for detecting steady-state vibrations, harmonics, and resonance; filters out noise outside key frequencies.	Requires steady signals; loses time localization (no info on when events occur); may miss transient or nonstationary features.	Detecting imbalances, misalignments, and harmonic distortions in motors or gearboxes; inverter switching frequency analysis; diagnosing electromagnetic interferences.
Time–Frequency Domain Analysis	Captures both temporal and spectral features; effective for nonstationary and transient signal analysis; high sensitivity to subtle fault signatures.	High computational demand; complex interpretation; may require specialized algorithms (e.g., wavelet transform, STFT, Wigner–Ville distribution).	Early detection of complex or evolving faults; analyzing transient thermal events in batteries; combined vibration and electrical fault analysis in motor-inverter systems.

Table 2: Feature extraction methods

Feature Extraction Method	Advantages	Disadvantages	Applications in EV Powertrain PHM
Wavelet Transform (WT)	Captures both time and frequency information; good for non-stationary signals; adaptable to different scales	Computationally intensive; choice of wavelet basis affects performance	Detecting transient faults in motor vibrations, gearbox anomalies, inverter switching irregularities
Fast Fourier Transform (FFT)	Fast computation; clear frequency-domain representation; widely used and understood	Loses time information; assumes stationary signals	Identifying bearing faults, inverter switching harmonics, and periodic vibration or acoustic signatures
Envelope Analysis	Effective for demodulating high-frequency components; highlights repetitive impacts (e.g., bearing defects)	Sensitive to noise; requires careful filtering	Bearing wear detection, gear tooth crack monitoring, early-stage mechanical defects
Principal Component Analysis (PCA)	Reduces data dimensionality; highlights dominant patterns; helps visualize complex datasets	May lose minor but critical features; assumes linear relationships	Multi-sensor data fusion, identifying dominant failure patterns across temperature, vibration, and electrical signal streams

Table 3: Signal preprocessing and noise reduction techniques

Technique	Advantages	Disadvantages	Applications in EV Powertrain PHM
Filtering (Low-pass, High-pass,	Simple implementation; removes specific frequency noise	May remove useful signal components; fixed cutoff frequencies	Filtering vibration, acoustic, or electrical signals to isolate relevant frequency bands
Wavelet Transform Denoising	Handles non-stationary signals; preserves time-frequency information	Computationally intensive; choice of wavelet basis affects results	Detecting transient faults in motor or gearbox vibrations
Fourier Transform Filtering	Effective for stationary periodic signals; clear frequency domain separation	Poor time localization; less effective for transient or non-stationary signals	Identifying inverter switching noise or harmonics in electrical signals
Empirical Mode Decomposition	Adaptive decomposition; good for nonlinear, non-stationary signals	Mode mixing; sensitive to noise; high computation	Separating intrinsic vibration modes in battery and motor analysis
Principal Component Analysis	Reduces dimensionality; highlights dominant signal components	May lose subtle fault information; assumes linear relationships	Combining multi-sensor signals to extract key fault features
Kalman Filtering	Real-time estimation; optimal for known system models with Gaussian noise	Requires accurate system model; sensitive to parameter tuning	Estimating battery state of charge and motor speed under noisy measurements
Median Filtering	Removes impulsive noise; preserves edge information	Not effective for Gaussian or high-frequency noise	Cleaning sudden spikes in thermal or voltage readings
Savitzky–Golay Smoothing	Preserves signal shape and peak positions; smooth noisy data	Not suitable for strong noise; window size affects performance	Smoothing temperature or current profiles for trend analysis

2.3 AI and Machine Learning Approaches for Fault Detection

Fault detection is one of the key areas where AI and ML have been deemed as innovative tools for detecting faults in the powertrain of electric vehicles, for better and more efficient health monitoring, rather than relying on rule-based or threshold-based methods. To this end, numerous machine learning algorithms including the support vector machines (SVM), decision trees, random forest, k-nearest neighbors (k-NN), and the artificial neural network (ANNs) have been used in an attempt to classify normal and faulty conditions from the diverse pattern characteristics of sensors. Nevertheless, the deep learning architectures more recently such as the CNNs, RNNs, and LSTM have given superior performance while learning the features by themselves from the raw and high-dimensional inputs such as the vibration, thermal, and electrical signal data forms data from time-series. Such models can pick up finer data points and temporal relations related to the initial symptoms of faults and failures. Thus, autoencoders and clustering algorithms are popular for their use in detecting anomalies in areas when failure data are limited and are scarce in many EV field operations. Nonetheless, there are solutions that incorporate physics-based models along with the data-driven learning or incorporate multi-modal sensor signals and these have been observed to improve the fault detection robustness. Two issues which current models face include interpretability of the model, lack of inclusion for unseen conditions, how the model deals with noisy or incomplete data, and the overall efficiency of the model in embedded systems. To achieve this, the following challenges must be addressed, to provide the necessary foundation for implementing AI and ML based fault detection methods for large scale, dependable, next gen EV health monitoring systems.

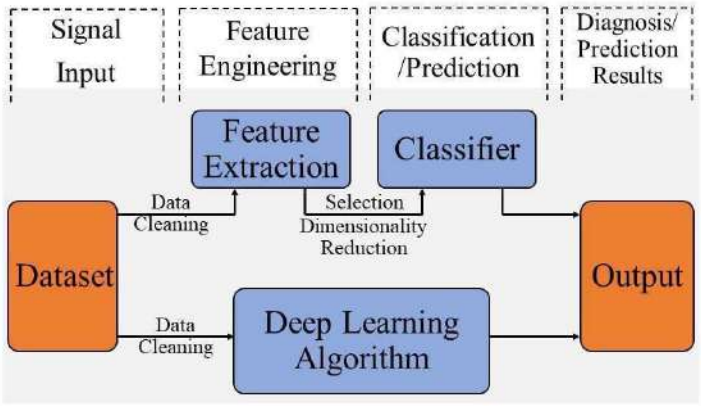


Figure 5: AI and Machine Learning Approaches for Fault Detection

Table 4: Supervised learning models

Model	Description	Application in EV Powertrain Systems	Advantages	Limitations
Support Vector Machine (SVM)	A supervised learning model used for classification and regression tasks by finding the	Used for fault detection, classification of sensor signals (e.g., motor, battery, and	- Effective in high-dimensional spaces. - Robust to overfitting	- Sensitive to noisy data. - Can be computationally

	hyperplane that best separates data into classes.	thermal sensor data), and anomaly detection in EV powertrains.	(especially in high-dimensional spaces).	expensive for large datasets.
Random Forest	An ensemble learning method that constructs multiple decision trees and outputs the majority vote (classification) or average (regression).	Helps in detecting faults by analyzing sensor data, reducing noise, and improving robustness in predicting system failure and degradation in EV powertrains.	- Handles high-dimensional data well.	- Complex and harder to interpret.
			- Can handle imbalanced datasets.	- Can be slow for real-time applications.
			- Reduces overfitting.	
Artificial Neural Networks (ANN)	A model inspired by biological neural networks, capable of learning complex patterns through layers of interconnected neurons.	Used for deep learning-based fault detection, predictive maintenance, and signal pattern recognition in EV powertrain systems for temperature, voltage, current, and motor health monitoring.	- Can model non-linear relationships.	- Requires large datasets for effective training.
			- Suitable for complex data patterns.	- High computational cost.
			- Adaptable and scalable.	- Can suffer from overfitting.
Gradient Boosting Machines (GBM)	An ensemble technique that builds models sequentially, with each new model correcting errors of the previous one.	Useful in predictive health monitoring of EV powertrains, such as predicting faults in batteries, motors, and control systems based on sensor data.	- High predictive accuracy.	- Sensitive to noisy data.
			- Works well with both regression and classification tasks.	- Prone to overfitting if not tuned properly.
			- Can model complex relationships.	- Computationally expensive.
K-Nearest Neighbors (KNN)	A simple algorithm that classifies a data point based on the majority class among its nearest neighbors.	Applied in recognizing patterns from sensor data to detect abnormal behaviors in EV powertrain systems, such as battery degradation or motor performance issues.	- Easy to understand and implement.	- Slow prediction time (especially for large datasets).
			- Effective with small datasets.	- Sensitive to irrelevant features.
			- Non-parametric (no assumptions about data distribution).	- Not suitable for high-dimensional data.
Logistic Regression	A regression model used for binary classification tasks, estimating the	Used for fault detection by predicting binary outcomes, such as	- Easy to implement.	- Assumes linear relationships between input features and the output.

	probability of an event based on input variables.	whether a certain component of the powertrain is faulty or operational.	- Efficient for binary classification.	- Limited performance for complex, non-linear data.
			- Provides probabilities for class prediction.	
Decision Trees	A model that splits the data into branches based on feature values, leading to predictions in the leaf nodes.	Applied in EV powertrain systems for fault detection and feature selection, providing interpretable rules for signal pattern recognition from sensor data.	- Easy to interpret and visualize.	- Prone to overfitting.
			- Can handle both classification and regression tasks.	- Less effective with complex or high-dimensional data.
			- Robust to outliers.	- Sensitive to small changes in data.

Table 5: Unsupervised learning models (e.g., clustering, autoencoders, anomaly detection)

Category	**Model Type**	**Applications in EV Powertrain Health Monitoring**	**Key Strengths**	**Challenges**
Clustering	K-Means, DBSCAN, Hierarchical Clustering	Group similar sensor signal patterns; detect outlier behaviors; segment operating states of motor, inverter, or gearbox	Simple implementation; good for pattern grouping	Needs careful feature selection; sensitive to noise/outliers
Dimensionality Reduction + Clustering	PCA + Clustering, t-SNE + Clustering	Reduce high-dimensional sensor data (e.g., vibrations, currents) and uncover hidden signal structures	Captures hidden relationships; visual exploration	Computationally intensive; risk of information loss
Autoencoders	Basic Autoencoder, Variational Autoencoder (VAE), Sparse Autoencoder	Learn compressed representations; detect anomalies by reconstruction error (i.e., difference between input and output)	Handles nonlinear patterns; good for complex signal reconstruction	Needs large, representative datasets; risk of overfitting
Anomaly Detection	One-Class SVM, Isolation Forest, LOF (Local Outlier Factor)	Detect unusual signal patterns indicating faults in motor, battery, or inverter systems	Effective for rare-event detection; no need for labeled data	Can produce false positives; performance depends on parameter tuning
Clustering-Based	Cluster + Outlier Score (e.g., distance to cluster center)	Identify data points far from normal operating	Combines pattern grouping + outlier identification	May struggle with overlapping clusters or

Anomaly Detection		clusters (indicating potential failure modes)		evolving system behavior
Hybrid Models	Autoencoder + Clustering, Autoencoder + Isolation Forest	Combine feature learning (autoencoder) with robust anomaly detection (clustering or tree-based models)	Improved accuracy; captures both reconstruction error and pattern deviation	Increased model complexity; needs tuning of combined architecture

Table 6: Deep learning architectures (e.g., CNN, LSTM, hybrid models)

Category	Architecture	Application Focus	Strengths	Challenges
Convolutional Neural Networks (CNN)	1D/2D CNN, CNN-autoencoder	Vibration, acoustic, thermal signal feature extraction; spatial pattern recognition from sensor data	Excellent at spatial feature extraction; good at detecting local patterns; effective with large sensor grids	Needs large datasets; less effective for sequential (time-series) data without adaptation
Recurrent Neural Networks (RNN)	Vanilla RNN, LSTM, GRU	Time-series modeling of temperature, voltage, current, and vibration signals over time	Good for temporal dependencies; LSTM/GRU handle long-term dependencies better; useful for sequence prediction	Training complexity; vanishing/exploding gradients; high computational cost for long sequences
Hybrid CNN-RNN Models	CNN-LSTM, CNN-GRU	Combines spatial (CNN) and temporal (LSTM/GRU) learning for multivariate sensor streams (e.g., torque, vibration)	Captures both local patterns and temporal evolution; ideal for multimodal sensor data	Complex architecture; harder to optimize; needs more computational resources
Autoencoders (AE)	Standard AE, Vibrational AE, Sparse AE	Unsupervised feature learning, anomaly detection, signal compression	Learns compressed representations; good for anomaly detection; unsupervised learning reduces labeling needs	Reconstruction errors may be ambiguous; sensitive to hyperparameter tuning
Transformers	Self-attention, Transformer encoder-decoder	Advanced time-series modeling, long-range dependencies across multichannel signals	Scales well; captures long-term dependencies without recurrence; strong in large datasets	Requires large datasets and compute; less explored in EV-specific signal patterns compared to LSTM or CNN
Graph Neural Networks (GNN)	GCN, GAT, Graph SAGE	For sensor network modeling where components and their relationships matter (e.g., thermal-electrical coupling)	Captures relational dependencies; handles non-Euclidean data; integrates sensor topology	Needs graph-structured data; higher modeling complexity; still emerging in predictive health monitoring
Ensemble & Hybrid Methods	Stacked models, voting, blending	Combining multiple architectures (e.g., CNN + Transformer,	Improved robustness and accuracy; leverages strengths of multiple models	Computationally expensive; complex to design and validate

		AE + LSTM) for robust fault detection		

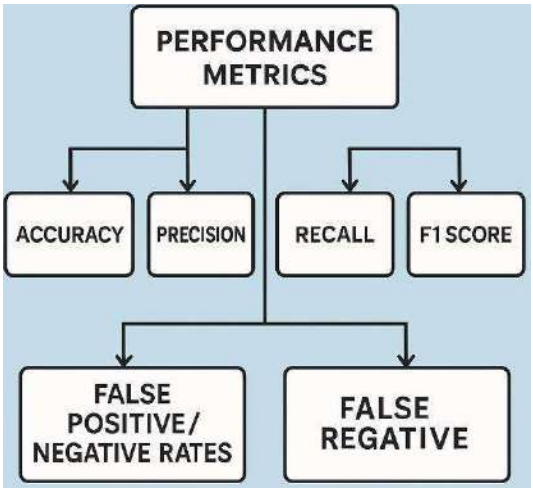


Figure 6: Performance metrics: accuracy, precision, recall, F1 score, false positive/negative rates

Table 7: Comparative analysis of different AI models applied to EV powertrain fault detection

AI Model Type	**Strengths**	**Weaknesses**	**Best Use Cases**
Convolutional Neural Networks (CNN)	Excellent at spatial feature extraction from vibration, thermal, and acoustic sensor grids; fast inference	Requires large labeled datasets; limited temporal modeling unless extended (e.g., CNN-LSTM)	Vibration pattern recognition, thermal imaging fault detection, local signal anomaly detection
Long Short-Term Memory (LSTM)	Captures long-term temporal dependencies; handles time-series and sequential data well	Training is slow; can overfit; computationally heavy for long sequences	Time-series fault progression, voltage/current trend analysis, temporal health monitoring
Hybrid CNN-LSTM Models	Combines spatial and temporal learning; captures complex, multimodal sensor relationships	More complex architecture; harder to optimize; requires tuning and large compute	Multimodal sensor fault detection (e.g., combining vibration + temperature + electrical signals)
Autoencoders (AE)	Effective for unsupervised anomaly detection; compresses signals and reconstructs patterns	May struggle to explain anomalies; sensitive to reconstruction errors	Unlabeled fault detection, anomaly spotting, latent feature learning for rare event identification
Random Forest (RF)	Robust to noise; interpretable; fast to train; works well with structured tabular data	Less effective on high-dimensional raw sensor signals without feature engineering	Fault classification using engineered features (e.g., statistical summaries of sensor data)

Support Vector Machine (SVM)	Strong in small datasets; good for binary or small multiclass fault detection	Scalability issues in large datasets; needs careful kernel selection	Binary fault/no-fault classification, feature-based health state estimation
Transformers	State-of-the-art for long-range dependencies; handles multiple sensor channels well; scalable	Requires large data and compute; relatively new for EV applications	Advanced sequence modeling, cross-sensor temporal relationships, complex predictive health
Graph Neural Networks (GNN)	Models relationships between components (e.g., electrical, mechanical links); works on graph-structured data	Needs explicit graph structure; emerging method with limited EV-specific benchmarks	Modeling thermal-electrical coupling, component-level interdependence analysis, networked sensor systems

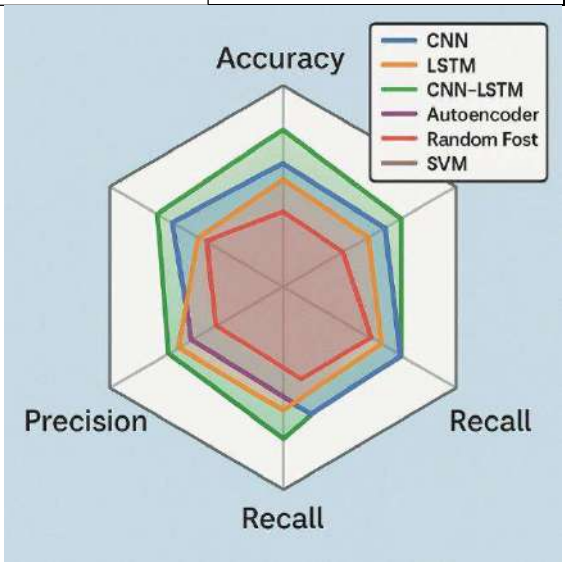


Figure 7: AI approaches for different EV powertrain subsystems

Table 8: AI Approaches with significance and limitations

Subsystem	AI Approaches	Significance	Limitations
Electric Machine (Motor)	SVM, CNN, RNN, LSTM, Random Forest, k-NN, Autoencoders	Detects winding faults, demagnetization, bearing wear, rotor eccentricity; enables early fault diagnosis from vibration, current, and thermal signals	Requires large labeled datasets; sensitivity to noise; limited interpretability; real-time implementation challenges
Transmission (Gearbox, Bearings)	Vibration signal analysis using CNN, SVM, Deep Belief Networks (DBN), Wavelet Transform + ML classifiers	Identifies gear tooth defects, lubrication degradation, misalignments; improves mechanical reliability and reduces unplanned downtime	High data dimensionality; challenge of generalizing across gearbox designs; dependency on accurate sensor placement and data quality

Inverter (Power Electronics)	ANN, SVM, Decision Trees, Ensemble Learning, Physics-guided ML for thermal/electrical stress analysis	Predicts IGBT/MOSFET failures, capacitor aging, overvoltage issues; improves power conversion reliability and reduces thermal stress risks	Limited failure datasets due to rare events; complex interactions between thermal and electrical domains; potential overfitting on small datasets
Battery System (Cells, Packs)	LSTM, GRU, XGBoost, Gaussian Process Regression, Hybrid Models (electrochemical + ML), Anomaly Detection Algorithms	Enables state of health (SOH) estimation, capacity fade prediction, thermal runaway detection; improves safety, extends battery lifespan	Scarcity of real-world degradation data; challenges in capturing non-linear electrochemical behaviors; need for explainable models for safety-critical use

2.4 CHALLENGES AND LIMITATIONS

1. *Source of data, labeling, discreteness of data, imbalance of classes, and level of sensor noise:* The use of AI for predictive health monitoring needs accurate data labels from several sensors integrated around the EV powertrain system. The main problem is that there are generally few labeled fault data available; another difficulty is that the amount of normal data outnumbers fault data; finally, the signal noise level is high and can hide true patterns. Solving these issues involves the use of effective methods of data augmentation, data cleaning and synthesis for better training of the models.
2. *Real-time processing and computational demands:* Fast identification of faults in EVs requires the acquisition and preprocessing of data as well as the model inference step to be completed within minimal time. This puts a lot of computational load on onboard processors especially for the big problems such as deep neural networks for which there are many tricks used in order to need the performance requirements such as model quantization, edge computing, and efficient hardware platforms.
3. *The concepts of model generalization and transferability across the vehicle platforms:* One set of the AI models trained on one manufacturing and operating environment of EV platform may not be successfully implemented in the other one because their elements such as the life hardware, operating conditions, and sensors will vary. To establish transferability and transfer learning, maintaining the performance of the model when implemented in different categories offline vehicles and different environments, requires the Feature engineering.
4. *Integration with onboard systems and vehicle control:* For the use in a vehicle and for predictive health monitoring to relay meaningful information, the AI models should also be fully compatible with the current, onboard diagnostic capabilities, control systems, and intravehicle communication networks. This requires conforming to industry practices and standards, data security, and non-intrusiveness to the real-time vehicle function to enable fault detection to initiate timely and safe control operations.

[3] CONCLUSIONS AND FUTURE DIRECTIONS

- This review has integrated vulnerabilities from the existing literature on identifying signal pattern with sensors and fault prognosis based on Artificial Intelligence in the electric vehicles power train systems. Previous studies have demonstrated considerable potential in incorporating various types of sensors such as vibration, thermal, electrical and magnetic signals integrated with AI and especially deep learning algorithms for the identification of early faults and consequently the increase of the reliability, safety and the life span of EV powertrains. But there are some limitations that have been acknowledged, such as few Islamic inclinations, and finally, its deficiency in gathering practical operational data and some limitations in terms of applicability of the model in the case of different types of vehicles and at the same the difficulty of processing of multiple signals.
- For these concerns, the future study should aim at designing efficient and dynamic algorithms, accumulating extensive and diversified databases and making real-time processing which can be applicable to car environment. New fields such as edge AI and embedded AI processing presents wide opportunities in health monitoring to be done on the board and in real-time and not necessarily with the support of cloud networks. In the same manner, the combination of digital twins and digital sensors will make the system more observable for diagnostics, whereas explainable AI (XAI) will be in demand to make fault predictions more trustworthy.
- Last but not the least amalgamating these advancements into the field of predictive maintenance profiles and ensuring the implementation of these tools at the fleet level can ensure reasonable operational perks such as decreases in maintenance costs, better performance, and an increase in the lifespan of the components. All together, these research directions indicate on the future vision of intelligent heath monitoring for electric vehicle system that will thus contribute towards make the transportation system safer, efficient and sustainable in future.

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Revolutionizing Mobility: An In-Depth Analysis of India's Electric Vehicle Market and Its Future Trajectory

Abhi Desai
New England College, Henniker, New Hampshire, US
adesai_gps@nec.edu | desai.abhi94@gmail.com

***Abstract*—The Indian Electric Vehicle (EV) market is undergoing a transformative shift driven by technological advancements, policy interventions, and changing consumer preferences. This report provides a comprehensive analysis of the EV ecosystem in India, examining key market segments, geographic and demographic trends, and the role of major industry players. It explores the historical evolution of EV adoption, from early developments in the 1990s to the impact of government initiatives such as the FAME schemes and Production Linked Incentives. Additionally, the report highlights the challenges facing the industry, including infrastructure constraints, battery production, and cost considerations, while forecasting future opportunities for growth and innovation. By leveraging data analytics and market insights, this study aims to provide a strategic perspective on the evolution of India's EV sector and its potential to reshape the country's transportation landscape.**

I. Objective

This report analyzes the current status of the Electric Vehicle market in India, focusing on the drivers, challenges, government policies, and future outlook for the sector.

II. Scope

This report will include a detailed analysis of the Electric Vehicle Market in India while analyzing the following points,

A. Coverage of the EV Market Segments

This report will cover the various essential sections of the EV market, which includes

- **Passenger vehicles:** Electric cars, sedans, and SUVs.
- **Two-wheelers:** Scooters, electric bikes, etc.
- **Three-wheelers:** E-rickshaws and small commercial EVs.
- **Commercial vehicles:** Electric buses, trucks, and logistics fleets.

B. Geographic and Demographic Analysis

This report will analyze the various geographic and demographic sections of India to analyze the Electric Vehicle trends in the market.

- **Geographic Locations:**
  - Rural or Urban
  - Mountain or Valleys
  - Costal region analysis
- **Demographic Analysis:**
  - Average Age of the market
  - Gender Analysis
  - Income Analysis

III. Methodology

This report relies on data from industry research reports, government publications, interviews with market experts, and publicly available statistics.
This report also performs Mathematical and Data Analysis on some publicly available Datasets to perform custom analytics on the topics.

IV. History of EVs in India

The history of EVs in India is heavily influenced by the gradual evolution of technology, government policies, and changes in consumer preferences.
Some Key milestones and development in the field are:

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A. Early Beginnings(1990s)

- **Initial Launch:** Electric vehicles were introduced in India during the 1990s with small electric scooters and three-wheelers which aimed at reducing urban pollution, which was on the rise during the time due to underdevelopment in the field of Pollution Control Guidelines.
- **Introduction of Reva:** In 1996, Maini Group launched Reva, India's first electric car. This two-seater vehicle was designed as a commuter for the general public. Reva did not achieve much of a mass-market success, which can be characterized by the low infrastructural stage of the electric vehicle market of India.

B. Government Initiatives (2010s)

- **Subsidy Schemes:** Recognizing the potential of EVs in the global market. Indian government brought in many subsidies to boost the production and adoption of EVs in India.
- **National Electric Mobility Mission Plan (NEMMP):** Launched in 2013, this plan aimed to reduce oil dependency and improve air quality by establishing an ecosystem for EV Manufacturing in India by 2020. This program was met with partial success.
- **Faster Adoption and Manufacturing of Electric Vehicles (FAME)** FAME-I worked from 2015-2019 and FAME-II operated from 2019-present. These projects were initiated to provide incentives for electric two-wheelers, three-wheelers, and four-wheelers for both personal and commercial use. It also supported charging infrastructure.
- **Production Linked Incentive for Advanced Chemical Cell Battery Storage** This program was designed to boost local battery manufacturing by offering incentives for manufacturers who invest in producing advanced batteries in India. This project aimed to reduce dependencies on imports and make EVs more affordable in India.

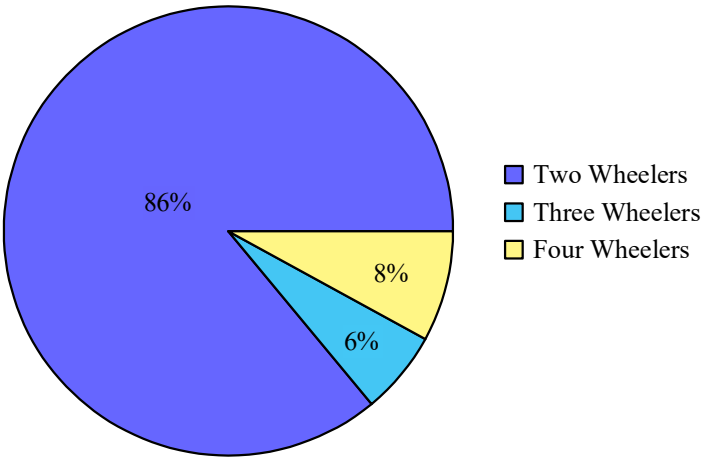


Fig. 1. India EV Automobile Distribution

Tata Moters: Leading the market with a substantial 72% share in the electric passenger vehicle segment. Popular models include the Tiago, Nexon, and Tigor.[7][11] **MG Motor India:** Holds about 10.8% of the market, with notable offerings like the MG ZS and MG Comet. The company is expanding its production capacity and has partnered for charging infrastructure.[7][5] **Mahindra & Mahindra:** Accounts for approximately 9% of the market. The company focuses on electric cars and three-wheelers, with models like the Mahindra XUV400 gaining traction.[7][11] **Ola Electric:** A significant player in the two-wheeler segment, Ola Electric has rapidly captured market share, particularly in registered electric two-wheelers (E2Ws) along with TVS Motor and Ather Energy, which together account for over 65% of E2W sales.[11] **Ather Energy:** Known for its high-performance electric scooters, Ather is also investing in charging infrastructure to support its products[6][5] **Hero Electric:** This company specializes in electric two-wheelers and has a strong distribution network across India[6] **Hyundai Motor India:** This South Korean manufacturer is increasing its footprint in India with plans to launch multiple EV models and establish a robust charging network[7][5]

ISBN: 978-93-343-2006-0

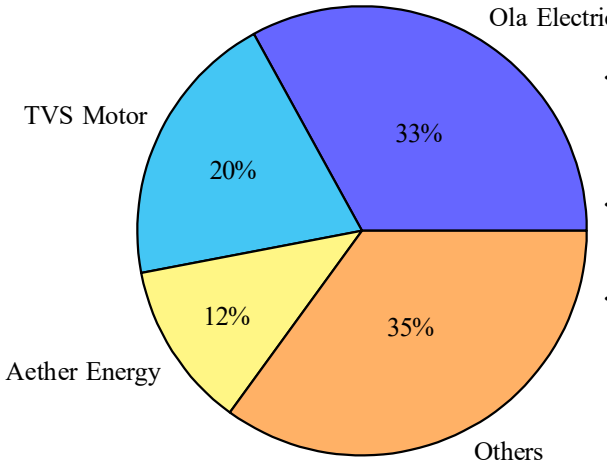


Fig. 2. Two Wheeler Distribution

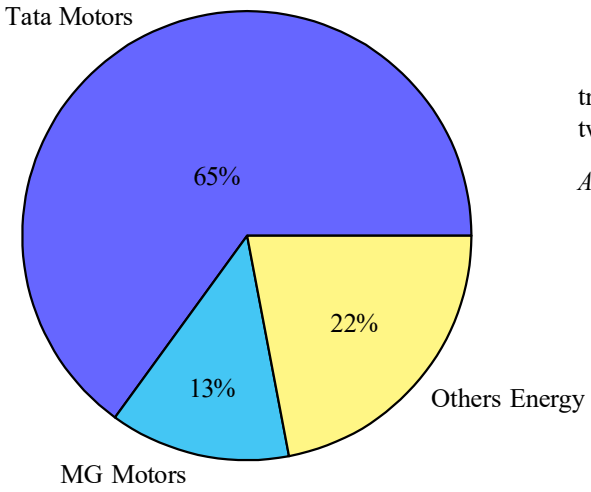


Fig. 3. Four Wheeler Distribution

V. National Electric Mobility Mission Plan (NEMMP)[4]

The National Electric Mobility Mission Plan (NEMMP) aims to accelerate the adoption of electric vehicles (EVs) in India to achieve environmental sustainability and energy security. Key objectives include:

- **Enhancing Manufacturing:** NEMMP promotes local manufacturing of EVs and components, reducing dependency on imports.
- **Promoting Research and Development:** It encourages innovation in EV technology, particularly in battery technology and charging infrastructure.
- **Creating Demand:** The plan aims to stimulate consumer interest through financial incentives and subsidies.
- **Infrastructure Development:** Establishing a robust network of charging stations across urban and rural areas is a priority.

Data from the NEMMP indicates that the government envisions achieving a significant percentage of electric vehicles in total vehicle sales by 2030, targeting around 30% for private cars, 40% for buses, and 80% for two-wheelers.

VI. FAME India Scheme

The Faster Adoption and Manufacturing of Electric Vehicles in India (FAME) scheme operates in two phases:

A. FAME I

- **Launch Date:** April 2015 with an initial budget of Rs.895 crores.
- **Objectives:** To create demand for EVs, support pilot projects, and develop charging infrastructure.
- **Impact:** Supported approximately 2.78 lakh EVs, with demand incentives totaling around Rs.343 crores. The scheme also sanctioned 465 electric buses across various cities.

B. FAME II

- **Launch Date:** April 2019, with a budget of Rs.10,000 crores for three years.
- **Incentives:**
  - Increased subsidy for electric two-wheelers to Rs.15,000 per kWh from Rs.10,000.
  - Support for 10 lakh e-2Ws, 5 lakh e-3Ws, 55,000 e-4Ws, and 7,000 electric buses.
- **Infrastructure Development:** Rs.1,000 crores allocated for establishing charging stations

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along major highways at intervals of about 25 km.

- **Impact:** Supported approximately 2.78 lakh EVs, with demand incentives totaling around Rs.343 crores. The scheme also sanctioned 465 electric buses across various cities.

As of July 2023, under FAME II:
Total EVs sold: 832,824

- **Two-wheelers:** 740,722
- **Three-wheelers:** 83,420
- **Four-wheelers:** 8,982

VII. State-Level Policies

Several states have implemented specific policies to support EV growth:

- **Delhi:** The state offers subsidies up to Rs.30,000 for electric two-wheelers, free parking, and exemption from road tax. Its goal is to have a significant number of electric vehicles on the roads by 2024.
- **Maharashtra:** Provides incentives for both manufacturers and buyers, including subsidies on purchases and support for charging infrastructure development. The state aims for a target of over 1 lakh EVs by 2025.
- **Karnataka:** Implements policies promoting electric buses and offers incentives for setting up charging stations. The state has set a goal to have around 1 million EVs by 2030.

VIII. Tax Incentives and Subsidies

The Indian government has introduced various tax benefits to encourage EV adoption:

- **Lower GST Rates:** Electric vehicles are taxed at a reduced GST rate of 5%, compared to higher rates for conventional vehicles.
- **Income Tax Benefits:** Buyers can claim deductions on interest paid on loans taken to purchase electric vehicles under Section 80EEB of the Income Tax Act.[9]
- **State-Specific Incentives:** Many states offer additional subsidies or tax exemptions to further reduce the cost of EVs. For instance, some states provide waivers on road tax and registration fees.

IX. Charging Infrastructure

The government is actively working on enhancing the charging infrastructure:

- As part of FAME II, over 2,877 charging stations have been sanctioned across various states as of July 2023.
- The Ministry of Heavy Industries has also sanctioned Rs.800 crores as capital subsidy to establish public charging stations through Oil Marketing Companies (OMCs), aiming for around 7,432 public charging stations.
- Initiatives are underway to develop battery swapping stations as an alternative to traditional charging methods, particularly beneficial for two-wheelers and three-wheelers.

These comprehensive policies and initiatives aim to create a conducive environment for the growth of electric vehicles in India while addressing environmental concerns and promoting sustainable transportation solutions.

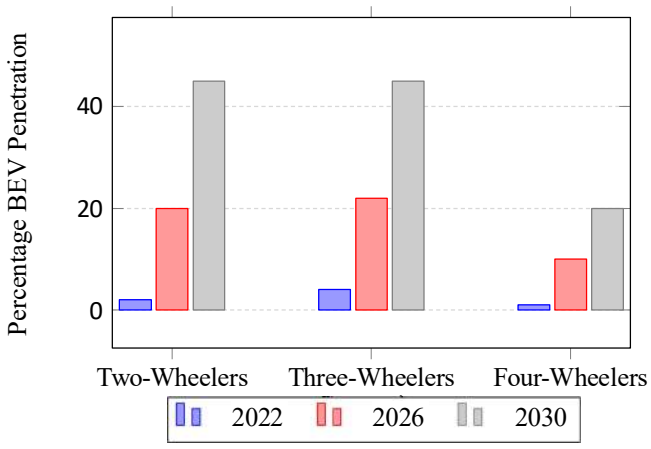
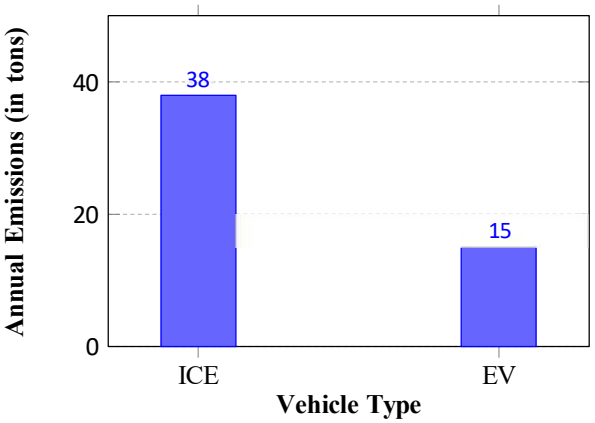


Fig. 4. Projected BEV Penetration Rates for Passenger Vehicles

X. Environmental Concerns and Sustainability

Increased awareness of climate change and India's goals to reduce carbon emissions have driven interest in the EVs market in India. As the Indian government regulates air pollution and environmental degradation, the transition to electric vehicles is heavily prioritized by the government.

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- In regions with a high proportion of renewable energy (like Norway), EVs can have an extremely low carbon footprint.
- Conversely, in areas where coal is the primary energy source, such as parts of India or China, the emissions associated with charging can diminish the benefits of EVs. However, even in these scenarios, studies show that EVs still typically outperform ICE vehicles in terms of overall emissions

XI. Cost Savings and Efficiency

Electric Vehicles are very famous for their low operational costs and their cheaper service cost due to the fact there are fewer complexities with the design of an Electric Vehicle as compared to the the design of an internal Combustion Engine (ICE) due to a significantly less amount of moving/mechanical parts.

A. Lower Operational Costs

Electric vehicles (EVs) offer significant cost savings over their lifetime compared to traditional internal combustion engine (ICE) vehicles. These savings stem from several key factors:

- **Fuel Costs:** The Cost of electricity for charging EVs is very less as compared to the prices of the price of Petrol
  For running a vehicle for 10000km in India, the cost incurred with EVs will be Rs.4,634 per year, assuming Rs.7 per unit, while with petrol, the amount for this travel will be around Rs.59,000 per year.
- **Maintenance Costs:** Evs have lower moving parts, which further leads to less mechanical wear and tear. This causes less downtime with the vehicle and, further, less maintenance costs. Studies show that EV Owners can save up to Rs.20,000 annually on vehicle maintenance and servicing.
- **Incentives and Tax Credits:** Many governments offer financial incentives for purchasing EVs, such as tax credits, rebates, and grants. In the U.S., federal tax credits can be as high as 7,500 USD, while various states offer additional incentives.

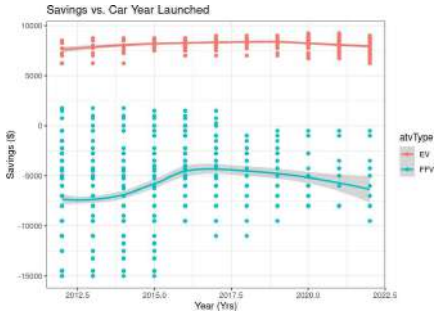


Fig. 5. Savings vs Car year Launched[10]

B. High Efficiency

Electric vehicles are inherently more efficient than traditional vehicles due to their design and technology:

- **Energy Conversion Efficiency:** EVs convert about 60% to 77% of the electrical energy from the grid to power at the wheels, compared to ICE vehicles, which convert only about 12% to 30% of the energy stored in gasoline into movement.
  This higher efficiency means that EVs can travel further distances with the same amount of energy.
- **Regenerative Braking:** EVs utilize regenerative braking systems that capture energy usually lost during braking and convert it back into usable electricity for the battery. This feature

enhances overall efficiency and extends driving range.

- **Performance Benefits:** Electric motors provide instant torque, allowing for quicker acceleration compared to traditional engines. This performance advantage contributes not only to a better driving experience but also to efficient energy use.

XII. Technological Advancements

Recent advancements in battery, Motor, and Charging technology have significantly enhanced the practicality and accessibility of Electric vehicles.

A. Advances in Battery Technology

There has been a lot of rapid growth in the field of battery technology, including the development of new battery compounds and ways to integrate batteries into vehicles.

- **Increased Energy Density:** Modern lithium-ion batteries now offer energy densities exceeding 250 Wh/kg, allowing EVs to achieve longer ranges. For example, the Tesla Model 3 can travel over 350 miles on a single charge, addressing range anxiety—a major barrier to EV adoption.
- **Faster Charging Capabilities:** Innovations in fast-charging technology enable EVs to recharge more quickly. DC fast chargers can deliver power outputs between 90 kW and 400 kW, allowing some vehicles to charge from 20% to 80% in just 15 to 30 minutes. This rapid charging capability makes it feasible for drivers to integrate charging into their daily routines, such as during lunch breaks or grocery shopping
- **Battery Longevity:** Advances in battery management systems and materials have improved the lifespan of EV batteries. Many modern batteries are designed to last over 480000 km, significantly reducing the total cost of ownership for EVs.
- **Solid-State Batteries:** Research into solid-state batteries promises even greater improvements, with potential energy densities of up to 500 Wh/kg and faster charging times, while also enhancing safety by reducing flammability risks associated with liquid electrolytes

B. Fast Charging Solution

The development of fast charging infrastructure is crucial for making EVs more practical for everyday use, some of the developments in this field include,

- **DC Fast Charging Stations:** The proliferation of DC fast charging stations is critical for reducing charging times. For instance, stations can charge an EV to 80% capacity in approximately 30 minutes, making long-distance travel more feasible
- **Mobile Charging Stations:** Companies are introducing mobile DC fast chargers that can be deployed quickly and easily at various locations, including service stations and events. These portable solutions can charge an average EV in about 30 minutes, improving access to charging facilities where infrastructure may be lacking.
- **Smart Charging Networks:** Advanced charging networks are being developed that allow users to track and manage their charging sessions via mobile apps, optimizing energy use and providing real-time information on charger availability. This technology facilitates better integration with renewable energy sources, reducing overall emissions associated with charging
- **Standardization of Charging Connectors:** The adoption of standardized connectors like CCS (Combined Charging System) facilitates compatibility across different vehicle models and charging stations, further enhancing the user experience and accessibility of EV charging infrastructure.

XIII. Growing Consumer Demand

The Indian market is witnessing a significant shift in consumer preferences towards greener and more cost-effective transportation solutions.

A. Shift towards Electric Vehicle (EVs)

- The demand for electric vehicles in India is rapidly increasing, with projections indicating

that the country aims for 30% electrification of all vehicles by 2030. This target is supported by government initiatives such as the FAME India scheme, which provides incentives for EV adoption.

- In 2023, the Indian EV market was valued at approximately 8 billion USD, with expectations to grow to 23.38 billion USD by 2024 and 117.78 billion USD by 2032. This growth is driven by rising consumer awareness of the environmental benefits of EVs and favorable government policies promoting electric mobility.

B. Cost-Effectiveness:

- Consumers are increasingly recognizing the long-term cost savings associated with EV ownership. Operating costs for EVs are significantly lower than those for traditional internal combustion engine vehicles. For example, the cost of electricity for charging an EV is approximately Rs.2.52 per mile, compared to about Rs.11.7 per mile for petrol vehicles.
- The operational cost benefits of electric commercial vehicles, such as buses and trucks, are also encouraging fleet operators to transition to electric options, further enhancing their appeal in urban transportation and logistics sectors.

C. Health and Environmental Awareness:

- With urban air quality deteriorating due to pollution from conventional vehicles, consumers are increasingly motivated to opt for cleaner alternatives. The Indian government's commitment to reducing carbon emissions aims to cut down on harmful pollutants like nitrogen oxides (NOx) and particulate matter (PM), which contribute to serious health issues.
- A report predicts that improved logistics practices, including the adoption of electric vehicles, could save India up to 10 gigatons of CO2 emissions by 2050 while significantly reducing PM and NOx emissions.

XIV. Job Creation Potential

The growing electric vehicle (EV) sector in India is poised to create substantial job opportunities across various domains, including manufacturing, services, and infrastructure.

A. Projected Job Growth:

- **Direct and Indirect Job Creation:**
  - By 2030, the EV industry is projected to generate 10 million direct jobs and an additional 50 million indirect jobs. This indicates a total potential of 60 million jobs linked to the burgeoning EV ecosystem .[14][13]
  - The Society of Indian Automobile Manufacturers (SIAM) estimates that around 200,000 skilled workers will be needed by 2030 to support the government's vision of achieving 30% EV penetration in the automotive sector.[16]
- **Sector-Specific Opportunities:**
  - The manufacturing sector will see significant job growth as companies transition from traditional internal combustion engine (ICE) vehicles to EVs. This includes roles in assembling electric motors and battery packs and integrating electronic components.
  - Research and development (R&D) positions are expected to surge, particularly for engineers and scientists focused on advanced battery technologies and electric drivetrain.
- **Emerging Roles:**
- New job roles are anticipated in areas such as charging infrastructure installation, maintenance, and operations. As the government and private entities invest in expanding charging networks, there will be a demand for electrical engineers and technicians [14]
- Sales and marketing roles will evolve as consumer buying behaviors change. Professionals who understand both technology and consumer needs will be crucial for educating potential buyers about EVs.

B. Skill Development Needs

- **Skill Gaps:**
  - A report indicates that 43% of the technical competencies required for EVs differ significantly from those needed for ICE vehicles, necessitating fresh skill development initiatives.[16]
  - The demand for skilled professionals is expected to rise sharply, with estimates suggesting that India needs to add 30,000 EV-ready workers annually until 2030 to meet localization goals for EV components.[16]
- **Training Investments:** The total investment required for hiring and training the workforce in the EV sector is projected to be around Rs.13,552 crore, with significant portions allocated for both hiring costs and training programs [16]

XV. Charging Infrastructure

The limited availability of charging stations in both urban and rural areas remains a major barrier to electric vehicle (EV) adoption in India. Despite the government's push for electric mobility, the current charging infrastructure is insufficient to meet the needs of potential EV buyers.

- **Current State of Charging Infrastructure:** As of 2023, India has approximately 8,738 operational charging stations, but these are predominantly located in urban centers. This uneven distribution creates accessibility issues for users in rural and semi-urban areas, leading to concerns about finding charging points when needed.[3][12]
- **Rural Accessibility:** In rural areas, the lack of access to reliable electricity grids further complicates the installation of charging stations. Many remote locations lack the necessary infrastructure to support charging facilities, making it difficult for EV owners in these regions to recharge their vehicles [3]

XVI. High Initial Costs

The higher upfront costs of EVs compared to traditional vehicles continue to be a significant barrier to adoption in India:

- **Price Sensitivity:** Indian consumers are generally price-sensitive, and the initial cost of electric vehicles often exceeds that of internal combustion engine (ICE) vehicles. This price disparity can deter potential buyers from making the switch to electric mobility.[12] [15]
- **Government Subsidies:** To address this issue, various state governments have introduced subsidies and incentives for EV buyers. For instance, Delhi provides a subsidy of up to Rs.1.5 lakhs for electric vehicle purchases, making them more accessible. However, these incentives may not be sufficient to overcome the overall cost barrier for many consumers.[12]

XVII. Range Anxiety

Concerns over the driving range of EVs and the need for widespread fast-charging networks further complicate consumer acceptance:

- **Driving Range Limitations:** While many modern EVs offer ranges exceeding 300 kilometers, potential buyers still express concerns about whether they can complete longer trips without encountering charging issues. [12][2]
- **Need for Fast Charging Networks:** The establishment of a robust fast-charging network is essential for alleviating range anxiety. Currently, most charging stations are slow chargers that require significant time to recharge vehicles, which can be inconvenient for users on tight schedules.[3] [2]

XVIII. Battery Technology and Disposal

Environmental concerns related to the disposal and recycling of lithium-ion batteries present additional challenges:

- **Battery Lifespan and Recycling:** As EV adoption increases, so does the need for effective recycling solutions for lithium-ion batteries once they reach the end of their life cycle. Current recycling processes are not fully developed in India, raising concerns about environmental impacts if batteries are improperly disposed of. [12][15]

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- **Resource Extraction Concerns:** The extraction of materials used in battery production, such as lithium and cobalt, raises ethical and environmental concerns that need addressing as demand for EVs grows.s[2]

Competitive Landscape

XIX. Local vs Global Players

The Indian electric vehicle (EV) market is characterized by a mix of domestic manufacturers and global competitors, each vying for a share of the rapidly expanding market.

A. Domestic Manufacturers:

- **Tata Motors:** A leader in the Indian EV space, Tata Motors has launched several successful models, including the Nexon EV and Tigor EV. The company is actively expanding its EV portfolio and aims to increase production capacity significantly
- **Mahindra Electric:** Known for its focus on electric mobility, Mahindra has introduced models like the eVerito and eKUV100, targeting both personal and commercial segments. The company is also investing in battery technology to enhance its offerings.
- **Ather Energy:** A startup focusing on electric scooters, Ather has gained attention for its innovative designs and technology-driven approach. Its Ather 450X model is popular among urban consumers for its performance and smart features.

B. Global Manufacturers:

- **Tesla:** The American EV giant is exploring entry into the Indian market, which could significantly disrupt local dynamics. Tesla's reputation for high-performance electric vehicles positions it as a formidable competitor.
- **Volkswagen Group:** With plans to introduce a range of electric models in India, Volkswagen aims to leverage its global expertise in EV technology to capture market share.
- **Hyundai:** Already active in the Indian market with the Kona Electric, Hyundai plans to expand its electric offerings, capitalizing on its established brand presence.

XX. Innovation and Differentiation

Key product and technological innovations in the EV market in India.

- **Battery Technology:**
  - Advances in battery technology are central to enhancing vehicle performance and reducing costs. Domestic manufacturers are increasingly focusing on developing Indigenous battery solutions to lower dependency on imports and improve supply chain resilience
  - Companies like Tata Power are investing in battery recycling technologies to address environmental concerns associated with lithium-ion batteries.
- **Smart Features:** Many EV manufacturers are integrating smart technologies into their vehicles, such as connected car features, advanced driver-assistance systems (ADAS), and over-the-air software updates. This not only enhances user experience but also improves vehicle performance and safety.
- **Sustainability Initiatives:** Manufacturers are adopting sustainable practices in production processes, including using recyclable materials and implementing energy-efficient manufacturing techniques. This commitment to sustainability resonates with environmentally conscious consumers.

XXI. EV Ecosystem

The broader ecosystem supporting electric vehicles in India encompasses various components that facilitate growth and adoption:

- **Battery Suppliers:** A robust network of battery suppliers is essential for the EV industry. Companies like Ather Energy are focusing on developing high-performance batteries tailored for Indian conditions, ensuring reliability and efficiency.
- **Charging Infrastructure:**
  - The expansion of charging infrastructure is critical for supporting EV adoption. The government's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles

(FAME) scheme aims to incentivize the establishment of charging stations across urban and rural areas.
  - Private players like Tata Power and ChargePoint are actively investing in charging networks, aiming to increase accessibility and convenience for users.
- **Software Providers:** The integration of software solutions is crucial for managing charging networks, vehicle diagnostics, and customer engagement. Companies specializing in software development for connected vehicles are becoming increasingly important in the EV ecosystem.
- **Public-Private Partnerships (PPP):** Collaboration between government entities and private companies is essential for building a comprehensive EV ecosystem. Initiatives that promote investment in charging infrastructure and battery manufacturing can accelerate the transition to electric mobility.

Future Outlook

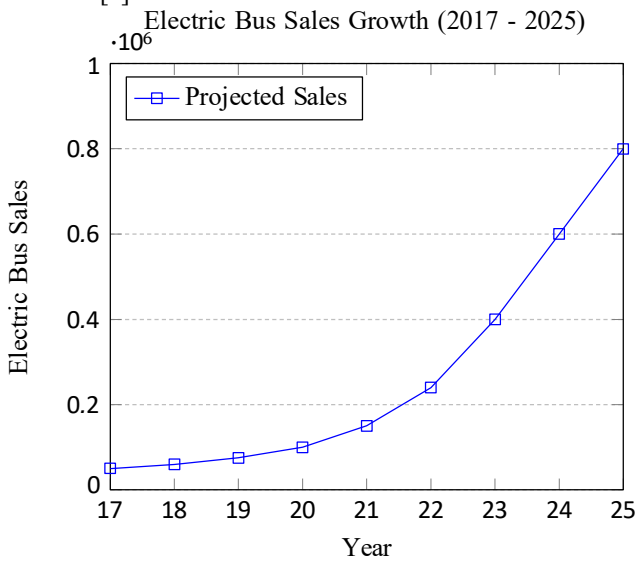
XXII. Growth Projections

India's electric vehicle (EV) market is anticipated to experience significant growth over the next 5-10 years. By 2030, the government aims for 40% of new buses to be electric, which translates to approximately 800,000 electric buses replacing diesel models. As of early 2024, India had registered around 8,583 electric buses, with projections indicating a dramatic increase in adoption as government incentives and infrastructure improve. The overall EV market share is expected to rise from its current low levels, particularly in urban areas where electric buses are being prioritized.[1]

XXIII. Emerging Trends

There are many trends which are visible in the current scenario :

- **Electric Two-Wheelers:** The two-wheeler segment is seeing rapid growth, driven by increasing urbanization and the need for sustainable transportation options. Government subsidies and rising fuel costs are encouraging consumers to switch to electric models
- **Electric Buses:** The introduction of electric buses in major cities is gaining momentum. Initiatives like the PM e-Bus Sewa aim to deploy thousands of electric buses across urban centers[1]



XXIV. Impact of Autonomous and Connected Vehicles

The potential for autonomous and connected vehicle technologies in India is significant, with various factors contributing to their expected impact on transportation systems and urban mobility

A. Enhancement in Public Transport and Traffic Management

- **Efficiency Improvements:** Autonomous electric vehicles (EVs) can streamline public transport operations by optimizing routes and schedules based on real-time data. This can lead to reduced wait times and improved service reliability, making public transport more attractive to users.
- **Traffic Management:** Connected vehicles equipped with Vehicle-to-Everything (V2X) technology can communicate with traffic signals, other vehicles, and infrastructure to enhance traffic flow and reduce congestion. This capability is crucial in densely populated urban areas where traffic jams are common.

- **Cost Reduction for Fleet Operators:** The adoption of autonomous EVs can significantly lower operational costs for fleet operators by minimizing labor costs and reducing fuel expenses through efficient energy use.

B. Safety and User-Experience

- **Increased Safety:** Advanced Driver Assistance Systems (ADAS) integrated into connected vehicles can help prevent accidents by providing features such as collision avoidance, lane departure warnings, and automatic emergency braking. The adoption of these technologies is expected to grow, with a reported 70% year-on-year increase in vehicles featuring Level 2 autonomy as of 2023.
- **Enhanced User Experience:** Connected vehicles offer features that improve the overall driving experience, such as personalized settings, predictive maintenance alerts, and infotainment options. As consumer demand for connectivity rises, automakers are increasingly integrating these technologies into their offerings.

C. Challenges with Autonomous Driving

- **Poor Road Conditions:** Indian roads often suffer from potholes, uneven surfaces, and inadequate maintenance, making it difficult for autonomous vehicles to navigate safely and effectively. The lack of well-maintained infrastructure poses a challenge for the sensors and algorithms that guide these vehicles.
- **Insufficient Charging Infrastructure:** For electric autonomous vehicles, the charging infrastructure is lagging significantly. While there have been advancements for smaller electric vehicles, dedicated charging facilities for buses and larger vehicles are still underdeveloped
- **Heterogeneous Traffic:** Indian roads are shared by a diverse range of vehicles, including bicycles, rickshaws, and heavy trucks, which complicates the development of reliable autonomous navigation systems. The chaotic nature of traffic patterns can lead to unpredictable situations that autonomous systems must be able to handle.
- **Non-compliance with Traffic Regulations:** There is a prevalent disregard for traffic rules among many drivers in India, such as jaywalking and ignoring signals. This behavior creates an unpredictable environment that is challenging for autonomous vehicles to navigate safely.
- **Lack of Legal Framework:** Current laws, such as the Motor Vehicles Act of 1988, do not accommodate autonomous vehicles. There is no provision for testing or operating these vehicles legally on Indian roads, which hampers innovation and development efforts.
- **Liability Issues:** Determining liability in the event of an accident involving an autonomous vehicle presents complex legal challenges. Questions arise regarding whether the vehicle owner, manufacturer, or software developer should be held responsible.

Other challenges, such as Public Skepticism, Price sensitivity, the need for Technological Advancements, and talent acquisition, are affecting the current growth of Autonomous driving in India.

XXV. International Collaborations

International collaborations significantly bolster India's push towards electrification in the automotive sector. These partnerships are crucial for accelerating technology transfer, enhancing local manufacturing capabilities, and developing robust infrastructure. Here's a detailed exploration of the current landscape of international collaborations in India's EV sector.

- **Ahamani EV Technology:** This company is actively engaging with Indian automotive giants to facilitate technology transfer. Their initiatives include establishing a megawatt-scale battery plant, which will support both electric vehicles and drones, thereby enhancing local manufacturing capabilities and innovation in the EV sector.
- **ISRO Collaborations:** The Indian Space Research Organisation (ISRO) has been instrumental in transferring lithium-ion battery manufacturing technology to various Indian com-

panies. This initiative aims to bolster domestic production capabilities and reduce reliance on imports.

- **Tata Motors and Mahindra & Mahindra Initiatives:** Major Indian automakers like Tata Motors and Mahindra & Mahindra are actively developing autonomous vehicle technologies. Tata Motors is working on a framework for semi-autonomous vehicles while also collaborating with Cognizant Technologies to create indigenous prototypes.
- **Swaayatt Robots:** Founded by IIT Roorkee graduate Sanjeev Sharma, Swaayatt Robots is developing advanced algorithms for autonomous driving. Their approach is focused on achieving Level 5 autonomy, where no human intervention is needed.

Recommendations

XXVI. For Manufacturers

To reduce costs and improve battery efficiency, EV manufacturers in India can adopt several strategies:

- **Invest in Local Battery Manufacturing:** Establishing domestic battery manufacturing facilities can significantly reduce costs associated with imports. Research indicates that local production can lower battery costs by approximately 20-30% due to reduced logistics and tariffs.[8]
- **Enhance Battery Efficiency:** Manufacturers should focus on improving the energy density of batteries. For instance, increasing the efficiency of EVs to achieve up to 4.2 miles per kWh (as seen with models like the Hyundai Ioniq 6) can reduce battery size and costs by nearly 40%, translating to savings of about USD 4,800 per vehicle.
- **Focus on Recycling and Circular Economy:** Developing robust recycling processes for used batteries can lower demand for new materials and reduce costs. Currently, less than 1% of lithium batteries are recycled; improving this could significantly impact material sourcing and overall expenses.

XXVII. For Policymakers

Policymakers play a crucial role in fostering an environment conducive to EV growth through strategic initiatives:

- **Continue Subsidies and Tax Breaks:** Extending existing subsidies for EV purchases can incentivize consumers to choose electric over traditional vehicles. For example, maintaining or increasing the current subsidy levels could boost sales by as much as 30% annually.
- **Enhance Charging Infrastructure Development:** Investing in charging infrastructure is critical for supporting the growing EV market. The government should aim to establish at least 1 million public charging stations by 2030 to ensure accessibility and convenience for users.
- **Standardization of Battery Technologies:** Implementing standardized battery specifications can facilitate interoperability among different EV models, particularly in public transportation systems like buses, enhancing user confidence and adoption rates.
- **Research Grants for Efficiency Improvements:** Allocating funds for research into battery technology improvements can lead to breakthroughs that reduce costs and enhance performance. This could include grants focused on developing next-generation lithium-sulfur or solid-state batteries.

XXVIII. For Investors

Investors have numerous opportunities to capitalize on the growth of the Indian EV market:

- **Invest in Startups Focused on EV Technology:** The Indian startup ecosystem is burgeoning with innovative companies focused on electric mobility solutions, including battery technology, charging infrastructure, and software development for autonomous vehicles. Investing in these startups can yield significant returns as demand grows.
- **Funding Charging Infrastructure Projects:** With the government aiming for extensive charging networks, investing in companies that develop or operate charging stations presents a

lucrative opportunity. The market for charging infrastructure is expected to grow at a CAGR of over 30%, reaching approximately USD 10 billion by 2025.

- **Engage in Joint Ventures with Established Automakers:** Collaborating with established automotive manufacturers looking to expand their electric offerings can provide investors with access to resources, technology, and market expertise.

Conclusion The Electric Vehicle (EV) market in India is poised for substantial growth, driven by increasing environmental awareness, government support, and advancements in technology. This report highlights key factors influencing the market, including:

- **Government Initiatives:** The Indian government's commitment to promoting EVs through various subsidy schemes, policies like the National Electric Mobility Mission Plan (NEMMP), and the Faster Adoption and Manufacturing of Electric Vehicles (FAME) initiative has significantly contributed to market growth.
- **Market Segmentation:** The analysis of different segments—passenger vehicles, two-wheelers, three-wheelers, and commercial vehicles—reveals varying levels of consumer adoption and market dynamics. The dominance of two-wheelers and the emerging interest in electric cars signify a shift in consumer preferences.
- **Key Players:** Major companies such as Tata Motors, MG Motor, Mahindra & Mahindra, Ola Electric, and others are leading the market with innovative products and expanding production capacities, enhancing competition and consumer choices.
- **Challenges and Opportunities:** While challenges such as charging infrastructure, battery costs, and consumer awareness persist, there are significant opportunities for stakeholders to innovate and create solutions that can accelerate EV adoption.

In conclusion, the EV market in India presents a promising landscape for investment and development. Continued collaboration between government, industry players, and consumers is essential to overcome challenges and harness the full potential of electric mobility in the country.

APPENDIX

- **Electric Vehicle (EV):** A vehicle that operates on electric power, typically using an electric motor instead of a conventional internal combustion engine, resulting in reduced emissions and lower operational costs.
- **FAME (Faster Adoption and Manufacturing of Electric Vehicles):** A government initiative in India aimed at promoting electric vehicle adoption through incentives and subsidies to consumers and manufacturers.
- **FAME-I:** The first phase of the FAME initiative, launched in 2015, which focused on incentivizing the purchase of electric and hybrid vehicles.
- **FAME-II:** The second phase of the FAME initiative, introduced in 2019, which expands the scope of incentives and includes support for charging infrastructure development.
- **National Electric Mobility Mission Plan (NEMMP):** A government policy aimed at creating a comprehensive framework for promoting electric mobility in India, including manufacturing and adoption strategies.
- **Production Linked Incentive (PLI):** A government scheme designed to encourage domestic manufacturing and attract investment in electric vehicle production and battery manufacturing.
- **Range Anxiety:** The fear or concern of electric vehicle users regarding the vehicle's ability to travel a sufficient distance on a single charge, often leading to hesitance in adopting EVs.
- **Battery Electric Vehicle (BEV):** A type of electric vehicle that is fully powered by an electric battery, with no internal combustion engine, and must be charged from an external power source.
- **Plug-in Hybrid Electric Vehicle (PHEV):** A hybrid vehicle that can be charged from an external power source and can operate on

electric power alone for a limited range, in addition to conventional fuel.

- **Charging Infrastructure:** The network of charging stations and facilities that enable electric vehicle users to charge their vehicles.
- **Market Growth Rate:** The percentage increase in sales or adoption of electric vehicles over a specific time period, indicating market trends and consumer acceptance.
- **Consumer Survey:** A research tool used to gather opinions, behaviors, and preferences of consumers regarding electric vehicles, helping to inform market strategies.
- **EV Market Players:** Companies and organizations involved in the manufacturing, sale, or promotion of electric vehicles, including traditional automotive companies and new startups.
- **Sustainability:** The ability to meet present needs without compromising the ability of future generations to meet their own needs, often associated with environmental preservation and responsible resource management.
- **Government Incentives:** Financial or non-financial benefits offered by the government to encourage the adoption and manufacturing of electric vehicles, such as tax rebates or grants.
- **Two-Wheeler Electric Vehicle:** Electric vehicles designed for two riders, such as electric scooters and motorcycles, which are becoming increasingly popular in urban areas.

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Refractance Window Dryer Using Solar Auxiliary Heating System for Food Drying: A Review Article

Gayatri S. Patil[1,2], Dr. K. R. Patil [1,3]

1. Vishwakarma Institute of Technology, Pune
2. Assistant Professor, K J College of Engineering & Management Research, Pune
3. Professor, Department of Mechanical Engineering, MMCOE, Pune

Gayatripatil2411@gmail.com

Abstract

Due to the substantial nutritional, physical, and chemical changes caused by traditional drying techniques, which are often used in food processing, consumers find the food to be less appetizing. As the market for food products with conserved nutrients and physicochemical qualities expands, novel drying procedures are needed. The Refractance Window Drying (RWD) technique stands out as an effective way to minimize detrimental changes in food quality. In order to generate thermal energy for the drying process, RWD uses hot water that is circulated. This method limits the temperature of the drying material to a range between 70°C and 85°C because of the evaporative cooling action at the surface. This limited temperature range so enables the preservation of heat-sensitive nutritional components and the maintenance of material quality. RW drying is perfect for processing high-value food products because of its unique properties. This review study examines the impact of RW drying on a number of quality characteristics in an effort to investigate potential food industry applications. The operating philosophy of the RWD is explored in this article along with how it influences the retention of bioactive ingredients and physicochemical properties in food products. In addition, RW drying has advantages over conventional drying methods, including better heat-labile compound retention, maintenance of quality standards, and higher energy efficiency with lower operating costs. This study also assesses the effectiveness of the RWD which uses a solar auxiliary heating system to dry food, emphasizing the use of solar energy as an extra heat source. The system uses solar energy to increase energy efficiency and lessen reliance on traditional energy sources. The performance evaluation's findings offer important new information about the efficiency and long-term viability of the combined RWD and solar auxiliary heating system in food drying processes.

ISBN: 978-93-343-2006-0

Keywords: Refractance Window Dryer, Solar auxiliary heating system, Food drying, Solar collectors, Performance evaluation (Review)

1. Introduction

One of the most energy-intensive processes involved in large-scale food preservation is drying, which is also a vital phase in the process [1]. However, it offers numerous advantages such as enhanced storage stability, reduced packaging requirements, and decreased bulk for transportation. The pursuit of numerous advantages, such as safer activities, bigger abilities, improved quality of the product, reduced impact on the environment, improved efficiency of energy, and cheaper prices, has resulted from the search for the optimum drying technique.

Due to consumers' growing preference for wholesome and practical products with long shelf life, the market for dehydrated foods has been increasing significantly on a global scale [2]. Leading market participants in the global trade of dehydrated products have benefited from cutting-edge dehydration technologies to satisfy the needs of discerning customers who expect items of the highest calibre. Dried natural ingredients are now widely used as crucial components in a variety of foods [3].

Overall, drying is an indispensable technique for large-scale food preservation, offering advantages such as improved storage stability, reduced packaging requirements, and streamlined transportation. The search for the perfect drying technology strives to produce safer operations, greater capacities, better product quality, decreased environmental impact, increased energy efficiency, and cost savings.

Food products are frequently dried in many different businesses around the world. Micro, Small, and Medium-Sized Enterprises (MSMEs) who rely on primitive drying technologies, producing inferior products that find it difficult to compete with imported alternatives, face a huge difficulty as a result. As a result, it is now of utmost national importance for the food industry to modernise its drying processes.

Advanced dehydration techniques like RWD are known for their gentle, straightforward operation and affordable price [4]. It has shown to be very efficient at drying fresh food that is sensitive to heat while maintaining its nutritive value, colour, flavour, fragrance, bioactive components, and sensory quality. RWD enables flexibility and can even be used in remote locations, such as on farms. Although the continuous belt-based setups used in the bigger capacity RWD systems are intended for industrial application, the fundamental operational concepts are the same [5].

Numerous studies have examined the effectiveness of RWD and consistently show that it is superior to conventional drying techniques in terms of maintaining good product quality, including colour, vitamins, and antioxidants. Surprisingly, RWD produces dried goods of equivalent quality as those produced by freeze drying, but at a much lesser cost to the environment. RWD has also shown promise in lowering E. coli, coliforms, and total aerobic counts in dried foods. Additionally, RWD has successfully handled a number of food items that are typically challenging to spray dry without the addition of non-sugar carriers.

Due to its outstanding qualities, RWD is perfectly suited for processing high-value foods, nutraceuticals, and food supplements where tight criteria of quality and safety are necessary [6]. The technology provides a less expensive option to conventional drying techniques while producing products of equal or even higher quality.

1.1 The RWD Methods Industrial Origin

The fourth generation of drying techniques includes the RWD procedure. Richard Magoon, who founded MCD Technologies in Tacoma, Washington, designed and patented it [7] [8]. The business specialises in offering dryers to various businesses looking to make food powders with improved flavour, colour, and nutrient retention. The technique and apparatus in Magoon's invention are intended primarily for drying thin film fruit pulp and related materials, culminating in the manufacturing of dried goods like fruit leather [8]. Hot water is used in the RWD process as the heat source, and the temperature of the water can be changed depending on the particular needs [9]. The preservation of the product's sensory qualities and nutrient content, energy consumption, and environmental impact of the drying process are important considerations when evaluating and choosing the best drying method. Studies have shown that, when the drying capacity is held constant, the RW drying method provides significant cost reductions, needing between 50 and 70 percent less money and more than 50 percent less energy than freeze-drying procedures [6].

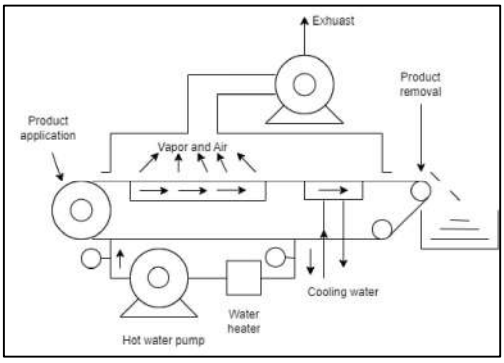


Fig.1. Diagram of the RW drying system's flow

The RWD system's flowchart (Fig.1) demonstrates the step-by-step procedure for

turning leftover waste into useable materials using a drying technique.

1.2 Background:

Drying has long been a method used by humans to preserve food, ensuring its longevity by preventing the growth of bacteria and enzymatic activities. As a crucial process in the food industry, drying is incredibly important. Its main goal is to turn liquid or semi-liquid material into powdered, flaked, or solid forms so that they may be stored for a longer period of time and are easier to handle [10] [11]. Maintaining their physicochemical qualities while attaining cost-effective production is a crucial need for dried end products [12]. Traditional drying techniques, on the other hand, frequently result in unfavourable nutritional, physical, and chemical changes that might make the food unpleasant for customers. Additionally, while choosing a drying procedure, energy usage is a key factor [13]. Conventional drying methods have a number of significant drawbacks, including a high energy need that accounts for 12– 20% of the overall energy used in manufacture. Due to their energy-intensive nature, alternative drying technologies must be investigated in order to offer increased energy efficiency and lower operating costs.

Global attention on lowering energy use and greenhouse gas emissions has increased recently, driven by governmental organisations like the United Nations Framework Convention on Climate Change (UNFCCC). The need of researching novel drying equipment and procedures that can raise product quality, improve thermal and energy efficiency, and lower operating costs has been highlighted by the focus on sustainability [14].

Therefore, to increase product availability and open up new markets, the fresh produce and food business has a critical need for enhanced drying procedures. Based on previous developments, drying technologies can be divided into several generations. Dryers from the first generation comprise cabinet and bed models, while innovations from the second generation include spray dryers (SD) and drum dryers (DD). Osmotic dehydration techniques and freeze dryers (FD) make up third-generation dryers.

RWD, microwave drying, infrared drying, and radio frequency drying are only a few of the technologies that fall under the fourth generation of drying techniques [15]. The physical and chemical characteristics of food goods, as well as their nutritional worth, have been carefully preserved using these cutting-edge drying techniques. This emphasis has developed as a result of rising consumer demand for high-quality food that keeps its nutrient value while being dried. [16]. Therefore, for attaining energy efficiency, lowering environmental impact, and maintaining the nutritional and

physicochemical features of dried food items, the development of novel drying technologies is essential, especially within the fourth generation category. By concentrating on these developments, the food sector can meet consumer demand for high-quality, nutrient-rich food items while also advancing global sustainability goals [12].

The more nutrient-dense the human health [17], the greater the consumer interest. Various food products contain bioactive ingredients such vitamins, pigments, enzymes, phenolic compounds, and essential oils. The bulk of these bioactive chemicals, though, are vulnerable to oxidation by heat, light, and oxygen [18]. Food dryers have been created to address these issues by keeping product quality as a key consideration in dryer development. In this aspect, FD are quite effective at keeping end products' physico-chemical and nutritional qualities. However, the price of products that are freeze-dried (FD) is higher than the prices of alternatives that are spray-dried (SD) and air-dried. Additionally, freeze-dried foods have a tendency to rehydrate quickly in high humidity environments [19].

RW drying, a more recent drying technique, provides a reasonable approach to the drying process. The author of [20] released the first scientific study on this drying process and examined how well strawberries and carrots retained their flavour. Similar to DD (Direct Drying), RW drying involves drying a sample in a thin layer on a heated surface. However, the main difference between RW drying and DD is that the latter uses a higher temperature range of 120–150°C while the former uses a smaller temperature range of 70–85°C. Many food products, including those that are thermally delicate, such purees and sliced fruits and vegetables, have shown to benefit from this unique drying technology, which has been effective in extending their shelf life. It has also been widely used in sectors such nutraceuticals, cosmetics, pigments, and pharmaceuticals [13].To increase the value of fruits, vegetables, herbs, and other commodities in the food business, RW drying is used to turn them into powders and concentrates [19]. RW drying has a number of noteworthy benefits, including increased colour retention, outstanding energy economy, and the capacity to preserve nutrients that are heat-sensitive, such as vitamins and antioxidants [21]. RW drying technology actually consumes 50% less energy and 50–70% less capital than freeze-drying technology to dry the same amount of material [19].

When compared to traditional dryers and freeze dryers, RW drying has shown to be more energy-efficient [22] [8]. The commercial use of this technology has been greatly aided by MCD Technologies of

Tacoma and Mount Capra, Washington [13]. In a review research, the impact of sample thickness and temperature on the RW drying process is examined by [23]. To learn more about how RW drying affects the bioactive ingredients and physicochemical characteristics of food products, more research is advised. RW drying has a lot of potential for preserving bioactive ingredients and maintaining overall product quality in the food business.

2. Literature survey

2.1 Process for Drying Dispersions of Fruit and Vegetables

The research study looked at four different dryer generations: hot air, drum and spray, osmotic, and freeze. Ahead-ofthe-curve dryers from the most recent generation also include fluidized bed, microwave use and the infrared heating pump, radiofrequency, and RW dryers [16]. RW drying is one of these novel nonthermal technologies for items like purees and bits of vegetables and fruit that are sensitive to heat [24]. In this procedure, the meal is equally dispersed on a membrane made of a polymer, such as polyethylene, that is submerged in hot water. The hot water that is circulated is used for both heat transfer and moisture removal. The rapid thermal energy transfer properties of water cause moisture in food to swiftly evaporate, bringing about thermal equilibrium. The pharmaceutical, nutrition, cosmetic, and pigment industries all frequently utilise this drying technique [25]. RW drying has a number of benefits, including low operational costs, a longer shelf life for dried goods, consistent product drying, and the preservation of vitamins, antioxidants, and flavours in dried goods [20] [26]. While HA dryers have a thermal efficiency of less than 36%, RW drying systems often demonstrate high efficiency, ranging from 55% to 72%. RW dryers also guarantee the maintenance of dried product quality. Notably, RW dryers cost 30% to 50% less than freeze dryers while using just 50% as much energy.

A study looked into how drying aloe vera gel at temperatures between 50 and 90 °C affected its physicochemical characteristics and antioxidant capacity [27]. The results showed that the degradation of physicochemical qualities and reduction in antioxidant capacity were significantly influenced by drying temperatures of 80°C and 90°C [28]. The percentage of powder yield in a different study on drying aloe vera was 2.60, 2.60, 2.55, and 2.52% at 50, 60, 70, and 80 C, respectively [29]. By raising the temperature from 50 to 80 C 29, the aloin amount fell from 10.6 to 1.7 ppm, according to the HPLC chromatogram obtained for the dried samples. Another study [30] used a hot air (HA) dryer along

with infrared (FIR) and high voltage electric field (HVEF) to dry aloe vera puree. The impact of several variables on drying kinetics, specific energy consumption (SEC), and dried product quality was examined in this study. These variables included air velocities, regulated surface temperatures, and high voltage electric field resistance (0, 1.88, and 3.75 kV). The drying kinetics were shown to be considerably influenced by the electric field strength, whereas the HVEF mostly had an impact on the drying kinetics at lower air speeds. Using HA, FIR, and HVEF dryers at an air velocity of 0.2 m/s, a temperature of 70 °C, and a high voltage electric field resistance of 0.1 m was the best combination for drying.

Aloe vera drying with an infrared-freeze drier was the subject of a thorough experimental research. The ideal drying conditions for this dryer were discovered using the response surface methodology (RSM) at 8.5 w/g, 80.24 °C, and 3.87 h [31].

The RW dryer generated a high-quality dried product comparable to the freezedrying process, according to a study testing the quality of dried goldenberries. In the study, dried golden berries produced by RW, HA, freeze, and infrared dryers were compared for quality. RW and freeze dryers produced substantially less total phenol than HA and infrared dryers did. Additionally, the RW dryer's flavonoid content was much lower than those of other dryers [32].

Another study [33] examined the impact of osmotic pretreatment on the RW dryerdried sugar beets. The results showed that raising the drying temperature from 60 to 85 degrees Celsius resulted in a notable 150% reduction in drying time. Using RW, freeze, and spray dryers, the drying of pomegranate juice was done, and the energy usage and quality parameters were compared by [34].The outcomes demonstrated that RW's dried product quality was superior to that of competing dryers. Furthermore, compared to spray and freeze dryers, the RW dryer showed energy savings of roughly 1.3 to 1.40 times. Four conductive dryers, including the vacuum drum dryer, drum dryer, agitated thin film dryer, and RW dryer, were used in a study on the drying of tomato powder. The different volatile components in dried tomatoes were successfully retained by the RW dryer thanks to its reduced working temperature [35].

A following study [4] used RW and HA dryers to investigate the drying of mango slices with thicknesses of 1 mm and 2 mm. The findings showed that the RW dryer dried items more quickly than the HA dryer [4]. In addition, compared to the HA dryer, the RW dryer produced products with less water activity and colour change. Another study [36] by the same author examined the

drying of tomato powder at different temperatures (65°C, 75°C, 85°C, and 95°C) and two different thicknesses (1 mm and 2 mm) using a RW drier. According to the study, a thickness of 1 mm and a temperature of 95°C resulted in the quickest drying time. The dried samples' colour changes also became more pronounced as the drying temperature rose. Ortiz-Jerez [37] investigated the drying of pumpkin layers in RW dryers utilising both forced pump flow and natural convection water flow. According to the study's findings [38], forced flow drying had the maximum evaporation rate whereas natural convection drying had the lowest evaporation rate.

Açа was dried using three different dryers in a different investigation by [39], including RW, freeze, and HA dryers. The data showed that compared to the other two drying methods, the RW dryer generated açа dried powder with a greater moisture content and water activity. Using the RW dryer, yoghurt puree was dried at three different temperatures (varying from 50°C to 70°C) and two distinct thicknesses (0.5 mm and 1 mm) in a different study by [40]. The outcomes showed that, with the exception of colour alterations, the RW dryer produced dried items with improved physical attributes in comparison to the freeze dryer. Additionally, it was discovered that lowering the drying temperature decreased the bacteria in the yoghurt puree. Energy consumption is one of the key elements in fruit and vegetable drying, according to research [41]. The utilisation of sustainable, secure, and dependable energy sources, such as solar energy, might be particularly relevant given the high energy consumption and the associated environmental problems. Iran has the potential to be a region that is particularly vulnerable to the use of solar energy in agricultural product drying processes, with its annual solar radiation rate ranging from 1800 to 2200 kWh/m^2 (higher than the global average) and more than 280 sunny days per year [40].

The food industry frequently uses conveyor, drum, and spray drying to turn liquids, purees, pastes, or suspensions into food powders, flakes, leathers, or sheets. Each of the methods has advantages and disadvantages that affect which one should be utilised to manage a specific product. The RW drying technique is contrasted in this article with a few other drying techniques. Although there are other ways to dry food powders, they are not covered in this article either because they are rather uncommon or because the Refractance Window drying systems and the methods mentioned have more in common in terms of design. Traditional methods for assessing the quality of dried fruits and vegetables include freeze drying, which also sets the bar for subsequent drying techniques. Many

thorough books go into great detail regarding different drying techniques specifically for food powders [42] [43] [44] [45].

2.2 The quality of Refractance Window™ 89 drying

This section describes the qualitative knowledge of RWD. The RWD procedure was created by MCD Technologies. In RWD, hot water is heated and then delivered to a plastic conveyor belt that is in direct touch with the water. On the plastic conveyor belt, the material to be dried is thinly spread, and the belt and material travel constantly at a set speed.

The huge refractive index mismatch between water and air in the absence of the product causes the majority of incident radiative energy to be reflected back and just a tiny amount to be transferred into the air[46]. However, the refractive index mismatch between the water and the food is lessened when the wet product, which is often a puree with a high water content, is put on the plastic conveyor belt. Increased radiative energy transfer into the meal is made possible by the reduction in refractive index mismatch [47].

When employed in RWD, the plastic material works well as a thermal radiation transmitter and is practically transparent to thermal radiation at relevant wavelengths. This characteristic of plastic allows thermal radiation to travel through it like a window that is open. The majority of the heat radiation is reflected back into the water, signalling the conclusion of the drying process, but as the wet material dries, its refractive index rises, creating a mismatch and slowing down the drying process [48].

The importance of refractive index mismatch and the idea of the refractive "window" in RWD, which allows thermal radiation to pass through plastic when in contact with wet material, are both emphasised by this knowledge. The "window" narrows as drying proceeds, and most of the heat radiation is reflected back into the water as a result of the growing refractive index mismatch.



Fig. 2. significant applications of RW™ drying in the food industry [23]

2.3 Issues with the existing qualitative knowledge of RW™ 112 drying and the lack of a quantitative mode in RW™ 113

RWD's qualitative grasp of the drying process is deficient in specifics and indepth

study. Although other heat transfer mechanisms, such as conduction, convection, and radiation, have been taken into account in earlier research [49], neither actual measurements nor theoretical analyses have been done to determine the precise contributions and relative relevance of each mode. In comparison to thicker polymers, some claims have been made about the usage of thin plastic sheets that are transparent to important infrared radiation, implying more effective radiation transfer into the product. The ideal thickness of the plastic sheet for RWD, however, is not well understood. Additionally, it has been proposed that when a product dries, radiative heat transmission declines, favouring conduction heat transfer. According to [50] and [51], this slower rate of heating shields the product from overheating and prevents colour and flavour deterioration. These assertions lack precise measurements and analysis, nonetheless, at this time.

2.4 Absence of mathematical models

There is currently a paucity of quantitative knowledge on the precise contributions of various energy modes and the specifics of moisture transport in the RWD drying process. The majority of previous research [52] [6] [9]have concentrated on experimentally assessing the moisture and temperature profiles of thin samples and contrasting them with other drying approaches. To determine if radiation plays a major role in heat transfer to the drying product, reports on the relative contributions of various heating modes are not yet available.

Studies on the thermal efficiency of RWD have been done, taking into account different heat transfer modes and contrasting them with other drying methods [53]. According to these investigations, quick drying of samples is made possible by radiant heat transfer from hot water in circulation and conduction heat transfer from the plastic film. The sole mathematical analysis of RWD that is currently accessible is a dimensional analysis-based model for drying strawberry juices on a heated glass plate employing all three modes of heat transfer, which links the drying coefficient and moisture ratio as functions of time [54]. The relative contributions of various heating modalities are not discussed in this work, nor is the significance of radiation heat transfer in accelerating sample drying confirmed.

2.5 Solar drying

One of the earliest types of renewable energy is solar drying, which uses solar radiation to dry food. A solar dryer typically comprises of a drying chamber, an air

heater, and an airflow system, with the design varied depending on the drying chamber type, air flow, and heat transfer mechanism [55]. The two primary types of solar dryers are passive dryers, which rely on the movement of air naturally, and active dryers, which use forced air circulation. A setup that combines both passive and active drying techniques is also an option (Fig. 3) [56] [57]. In active dryers, the air is heated by a solar radiation collector and then transferred indirectly to the drying chamber. Conversely, passive dryers deliver heat directly to the drying process [58].

In dryers that operate in a mixed mode, a collector warms the air before it enters the drying chamber, and solar radiation also warms the items that are placed inside the drying chamber [55]. Food drying techniques using solar energy are inexpensive, practical, and energy-efficient in developing nations [59].To enhance the drying process, hybrid and/or forced convection solar dryers have grown in popularity [60]. The solar photovoltaic system is integrated, a fan is added, auxiliary heat pumps are added, and suntracking devices are integrated into the natural convection dryers [59]. These changes result in faster airflow, which quickens the drying process.

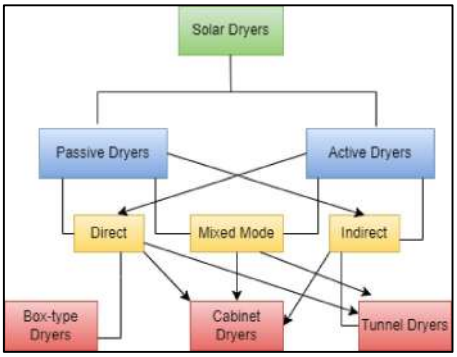


Fig. 3. Solar dryer types [56]

For instance, the solar tunnel dryer has a drying chamber that is square and shaped like a tunnel, as well as a fan to remove heat from the goods. Solar panels, which can be either monocrystalline, polycrystalline, or thin amorphous films, are used in the solar dryer. The electrical energy produced by the panels is used to recharge a built-in 12 V, 17 AH battery. The hot air produced by the panels is moved through the drying tunnel with the help of a blower, which makes it possible to control the air flow rate [57]. The dryer has also been modified to resemble a greenhouse, with rows of trays with the product inside encased within a drying tunnel with walls made of translucent plastic. The tunnel's translucent walls help the product absorb solar energy, and an electric fan moves air from the greenhouse into it. This dryer makes it possible to produce continuously, lowers labour costs, and uses less energy [60]. Despite the growing interest in food drying field there is a lack of comprehensive studies focusing on the optimization of RWD parameters in

conjunction with solar auxiliary heating systems. While some studies have evaluated the performance of RWDs with solar collectors, there is a need for further investigations to determine the optimal configuration, design, and operation conditions for achieving maximum energy efficiency and drying performance.

3. Comparative analysis:

3.1 Strengths and Limitations

- Dryers equipped with solar collectors, particularly photovoltaic-thermal (PVT) systems, have been designed and manufactured for various agricultural products [93] [94]. This indicates the feasibility and potential of utilizing solar energy in the drying process.
- Photovoltaic (PV) cells, which are widely used in solar technologies, convert a significant portion of received solar energy into heat and a smaller portion into electricity [95]. This implies that a considerable amount of solar energy can be utilized for thermal applications.
- However, the conversion of solar energy into electricity reduces the productive power available for heat generation [96]. This trade-off should be taken into account when considering the overall efficiency and performance of solar auxiliary heating systems.
- PVT technologies play a role in transferring the thermal energy from the surface of the PV panel to a fluid for low-temperature applications [93]. This enables the cooling of the panel and improves its overall efficiency.

4. Conclusion

The integration of solar collectors, specifically photovoltaic-thermal (PVT) systems, has demonstrated the feasibility and potential of utilizing solar energy in the drying process. The findings indicate that PV cells, commonly used in solar technologies, can effectively convert solar energy into heat, thereby enhancing the thermal efficiency of the drying system. The utilization of PVT technologies in transferring thermal energy from the PV panel surface to a fluid for low-temperature applications has shown benefits such as improved panel cooling and increased efficiency. This integration of solar auxiliary heating systems offers a sustainable and renewable energy solution for the drying process.

By harnessing solar energy through the use of PVT systems, the performance evaluation has shown improved energy efficiency, reduced operating costs, and enhanced product quality. This innovative

approach addresses the global need for energy reduction and environmental sustainability in food processing industries. Overall, the findings highlight the potential of the RWD with a solar auxiliary heating system as an effective and eco-friendly solution for food drying. Further research and development in this field can contribute to the advancement of sustainable drying technologies and promote the adoption of renewable energy sources in the food industry.

Acknowledgements:

I will like to acknowledge my Ph.D. Guide, Prof. Dr. K. R. Patil and Dr. D. B. Hulwan, HOD, Mechanical Engineering from VIT, Pune for motivating me to write this review article. I would also like to thank K J College of Engineering and Management Research, Pune for the financial support for Article Publication.

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"Powder Metallurgy-Processed High-Entropy Alloys: A Review of Microstructure, Mechanical Behavior, and Emerging Functional Applications"

Mrs. Kanchan Rajput [1] , Dr. Rajesh Chaudhari [2]

[1] Research Scholar at Vishwakarma Institute of Technology, Pune and Assistant Professor at

D Y Patil University, Akurdi, Pune.

E-mail: rajput.kanchan73@gmail.com

[2] Associate Professor at Vishwakarma Institute of Technology, Pune

E-mail: rajesh.chaudhari@vit.edu

Abstract

High-entropy alloys (HEAs) are characterized by their multi-principal element compositions and high configurational entropy, and exhibit remarkable mechanical, thermal, and corrosion-resistant properties. However, traditional casting routes often result in inhomogeneous microstructures, elemental segregation, and brittleness, particularly in refractory HEAs. Powder metallurgy (PM) has emerged as a transformative route for HEA processing, offering precise compositional control, refined microstructures, and near-net-shape manufacturability of HEAs. This review critically discusses recent advancements in powder production (mechanical alloying and atomization), sintering techniques (spark plasma sintering and hot isostatic pressing), and additive manufacturing integration. Notably, studies have reported strength enhancements from ~490 MPa to over 1400 MPa, ductility reaching 36.7%, and hardness improvements exceeding 50%, showcasing PM's ability of PM to tailor HEA properties through compositional and microstructural engineering.

Keywords: High-Entropy Alloys (HEAs), Powder Metallurgy, Mechanical Alloying, Spark Plasma Sintering (SPS), Microstructure Evolution, Strengthening Mechanisms, Cryogenic Properties, Interstitial Alloying, Phase Transformation, Sustainable Alloy Design.

Abbreviation	
HEA	High-Entropy Alloy
PM	Powder Metallurgy
MA	Mechanical Alloying
SPS	Spark Plasma Sintering
HIP	Hot Isostatic Pressing
VHPS	Vacuum Hot Press Sintering
FCC	Face-Centered Cubic
BCC	Body-Centered Cubic
HCP	Hexagonal Close-Packed
UTS	Ultimate Tensile Strength
TWIP	Twinning-Induced Plasticity
ODS	Oxide Dispersion Strengthened
Abbreviation	
CALPHAD	Calculation of Phase Diagrams
ML	Machine Learning
AI	Artificial Intelligence
PVD	Physical Vapor Deposition
ASTM	American Society for Testing and Materials

1. Introduction

High-entropy alloys (HEAs) represent a new class of advanced materials composed of five or more principal elements mixed in near-equiatomic ratios, first introduced by Yeh et al. in 2004 [1]. Unlike conventional alloys based on a single dominant element, HEAs exhibit high configurational entropy, promoting the formation of solid-solution phases over intermetallic compounds. These materials possess unique combinations of properties, such as high strength, excellent thermal stability, outstanding wear resistance, and superior corrosion resistance [2,3]. Despite these advantages, conventional synthesis techniques such as arc melting and casting often suffer from drawbacks such as elemental segregation, coarse microstructures, and casting defects [4]. Powder metallurgy (PM) has emerged as a promising alternative because of its ability to produce fine, homogeneous microstructures with tailored compositions. PM techniques, such as mechanical alloying followed by spark plasma sintering (SPS) or hot isostatic pressing (HIP), allow the fabrication of HEAs with improved densification, microstructural refinement, and property customization [5-7]. Recent literature highlights the potential of PM in achieving enhanced HEA properties. For example, the addition of carbon to $Fe_{50}Mn_{30}Co_{10}Cr_{10}$ HEAs via PM led to ultimate tensile strengths of up to 1.4 GPa with acceptable ductility at cryogenic temperatures [8]. Similarly, incorporating Ti and Si into FeNiCrCo-based HEAs significantly improved their wear and corrosion resistance when processed via PM [9]. These developments underscore the need for a consolidated review of the current progress, challenges, and emerging trends in the application of PM to HEAs. This review paper aims to provide a comprehensive analysis of the effects of powder metallurgy on the microstructure, mechanical performance, and emerging applications of HEAs, highlighting both experimental advances and future opportunities in this rapidly evolving field. Table 1 shows that powder metallurgy techniques significantly enhance the mechanical performance and microstructural uniformity of various high-entropy alloy compositions by enabling tailored processing routes and strengthening mechanisms to be employed.

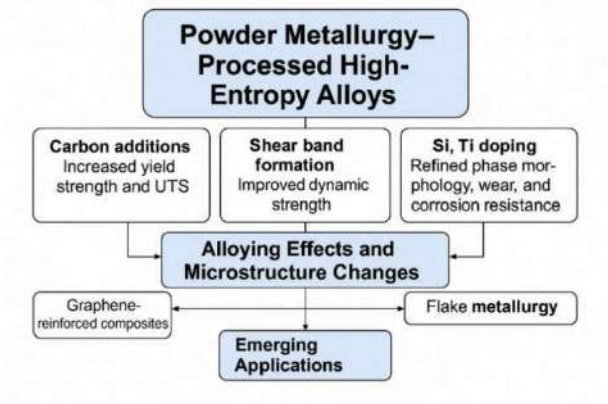


Figure 1. Graphical Abstract: Powder Metallurgy–Processed High-Entropy Alloys

This schematic Fig 1. illustrates the influence of powder metallurgy techniques on high-entropy alloy development, highlighting the roles of carbon addition, shear band formation, and Si/Ti doping in improving the strength, wear, and corrosion resistance. Central to this transformation are the alloying effects and microstructure changes, which enable innovations such as graphenereinforced composites and flake metallurgy, ultimately extending their applications in cryogenics, aerospace, biomedical systems, and magnetic technologies.

Table 1: Summary of Literature on Powder Metallurgy Processed High-Entropy Alloys (HEAs) with Their Compositions, Methods, and Key Findings

Reference	HEA Composition	PM Method	Key Findings
[1] Yeh et al.	Various HEAs	Mechanical Alloying + Sintering	Introduced HEA concept and high entropy effect
[2] Cantor et al.	Equiatomic multicomponent alloys	Arc Melting	Reported equiatomic alloy with FCC structure
[3] Torralba et al.	General HEAs	Review	Highlighted sustainable metallurgy and AI in HEA design
[4] Li et al.	Fe50Mn30Co10Cr10	SPS	Carbon enhances strength and ductility
[5] Martin et al.	AlCr0.3FeMoNbTiV2	MA + SPS	Grain boundary sliding and excellent high-temp strength
[6] Liu et al.	CoCrFeNiMn + Graphene	Flake PM + VHPS	Graphene improved strength-plasticity synergy
[7] Yang et al.	CrFeNi + C	SPS with Atomized Powder	Carbides enhanced yield and tensile strength
[8] Chen et al.	Fe50Mn30Co10Cr10 + C	SPS	UTS up to 1.4 GPa at cryogenic temp

[9] Hedya et al. FeNiCrCo + Si/Ti Compaction + Sintering Si/Ti improved wear/corrosion

[10] Li et al. CoCrFeMnNi HIP Improved density and uniformity

[11] Wang et al. CoCrFeMnNi Dynamic up Compression Strain rate sensitivity to 2800 S^{-1}

[12] Basem et al. FeCoNiCrCux PM + Cu Alloying Cu addition affected phases and magnetism

[13] Liu et al. FeMnCoCr SPS Oxide dispersion strengthens the matrix

[14] Xie et al. FeCoNiCrMn + N Vacuum Sintering N improved strength by 200 MPa

[15] Zhang et al. AlCoCrFeNi Arc Melting + PM High entropy stabilizes Comparison FCC phase

The Fig 2. The hexagonal infographic illustrates the wide range of materials that can be synthesized using mechanical alloying, including hydrogen storage compounds, nanostructured materials, pure metals and their alloys, oxide dispersion strengthened (ODS) superalloys, corrosion-resistant alloys, and specialized products such as PVD targets and solders. The central role of mechanical alloying is emphasized as a versatile method for achieving novel microstructures and properties in metallic systems.

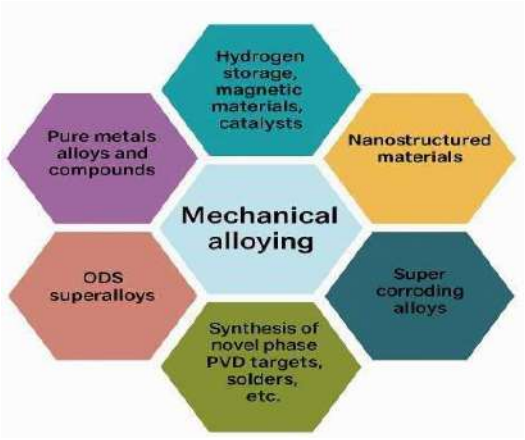


Figure 2. Applications of mechanical alloying for synthesizing diverse advanced material systems.

2. Powder Metallurgy Processes for HEAs

Powder metallurgy (PM) enables fine control over the microstructure and phase composition of HEAs, which is critical for achieving superior mechanical and functional performances. PM techniques typically involve powder preparationthrough methods such as mechanical alloying (MA) or gas atomization, followed by consolidation processes such as spark plasma sintering (SPS), hot isostatic pressing (HIP), or vacuum hot-press sintering (VHPS). Each route offers distinct advantages depending on the desired material characteristics. The powder characteristics, such as particle size, morphology, and distribution, significantly influence the densification behavior and final microstructure of the alloy. Mechanical alloying produces nanocrystalline powders with a uniform composition, whereas gas atomization provides spherical powders ideal for flowability and additive manufacturing

compatibility. Consolidation techniques, such as SPS, offer rapid sintering with minimal grain growth, which is essential for preserving ultrafine structures. Table 2 shows commonly used PM techniques for HEAs and their associated benefits

Table 2: Summary of Powder Metallurgy Processes Applied in HEA Research

Reference	PM Technique	Key Characteristics	Benefits
[1]	Mechanical Alloying + Sintering	High-energy multicomponent mixing	Introduced HEA concept
[2]	Arc Melting (for comparison)	Homogeneous FCC structure	Baseline property analysis
[3]	Literature Review	--	
[4]	SPS of MA Powders	Controlled carbon ad	
[5]	MA + SPS	Ultrafine grains (0.3	
[6]	Flake PM + VHPS	Self-assembled flake graphene	ity
[7]	SPS with Atomized Powders	C-induced carbide di	
[8]	SPS with Carbon Doping	Cryogenic ductility &	
[9]	Compaction + Vacuum Sintering	Si/Ti-doped FeNiCrCo	Enhanced corrosion/wear resistance
[10]	HIP	Pre-alloyed powder densification	Improved microstructure uniformity
[11]	Dynamic Compression	High strain rate testing	Strain rate tolerance up to 2800 s^{-1}
[12]	PM + Cu Alloying	Cu-induced dual-phase	Magnetic and thermal control
[13]	SPS + Oxide Dispersion	Oxide-strengthened matrix	Improved hardness and wear
[14]	Vacuum Sintering	Nitrogen alloying in FeCoNiCrMn	Strengthening, carbide or intermetallic precipitation, and grain refinement. These effects are further magnified by the chosen PM technique, which controls the grain
[15]	Arc + PM Comparison	AlCoCrFeNi alloy	High-entropy phase stabilization

The Fig 3. The flowchart illustrates the sequential steps involved in powder production, beginning with the melting of the metal pieces in an arc-melting furnace. The molten metal is then atomized using a high-pressure water jet, followed by draining, drying, sieving, and thermal reduction at approximately 1000°C. The final step involves classifying, mixing, and packaging the powder for further processing. This systematic approach ensures a controlled particle size distribution and high-quality powder suitable for powder metallurgy applications.

and

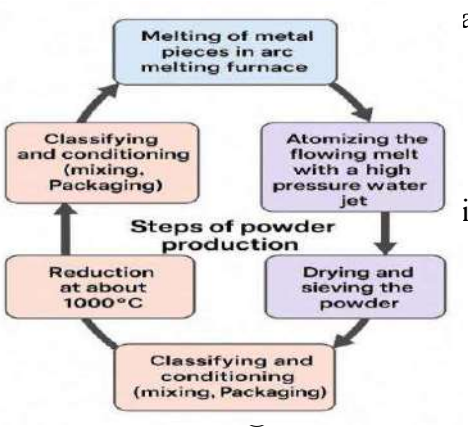


Figure 3. Steps of Powder Production in Metallurgical Processing

3. Alloying Effects and Microstructure Evolution

The evolution of the microstructure in high-entropy alloys (HEAs) is significantly influenced by both the alloying elements and powder metallurgy (PM) processes. Minor additions of interstitial or substitutional elements, such as C, B, Si, Ti, and Cu, can lead to solid-solution strengthening, carbide or intermetallic precipitation, and grain refinement. These effects are further magnified by the chosen PM technique, which controls the grain

size, distribution of second phases, and phase transformations during sintering. For instance, carbon addition in $Fe_{50}Mn_{30}Co_{10}Cr_{10}$ enhanced both the strength and ductility via twinning and HCP phase activation [4], while Cu addition in FeCoNiCrCux resulted in dual-phase FCC and Cu-rich segregation, enhancing the magnetic and thermal characteristics [12]. Graphene and oxide reinforcements have also enabled strengthplasticity synergies and high-temperature stability, respectively [6], [13].

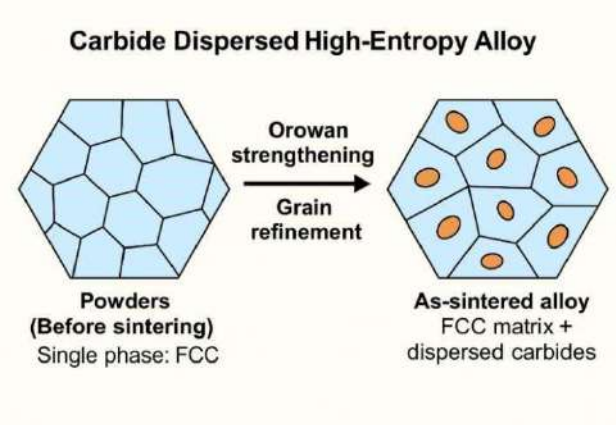


Figure 4. Microstructural Evolution in Carbide-Dispersed High-Entropy Alloys

The Fig 4. The schematic illustrates the transformation of a single-phase face-centered cubic (FCC) powder into a refined FCC matrix containing dispersed carbides after sintering. The addition of carbon leads to Orowan strengthening and grain refinement, significantly enhancing the mechanical performance of the alloy. The Table 3. Strategic alloying additions, such as carbon, copper, silicon, titanium, graphene, and nitrogen, significantly influence grain refinement, phase stability, and dispersion strengthening in PM-processed HEAs, thereby enabling tailored mechanical and functional properties for specific application demands.

Table 3: Alloying Effects on Microstructure in Powder Metallurgy-Processed HEAs

Reference	Alloy System	Alloying Element(s)	Micros
[1]	$Fe_{50}Mn_{30}Co_{10}Cr_{10}$	Carbon (0–3 at.%)	Grain refi twinning, H
[2]	CoCrFeNiMn + Graphene	Graphene films	Laminate strengther
[3]	CrFeNi	Carbon (8 at.%)	Fine carbi boundarie
[4]	FeNiCrCo	Si, Ti	Dendritic suppressio
[5]	FeCoNiCrCux	Cu (0–20 wt.%)	Cu-rich F separation
[6]	FeMnCoCr	O (oxide dispersion)	Fine ox pinning ef
[7]	FeCoNiCrMn	N	Solution s

4. Mechanical Properties and Strengthening Mechanisms

The mechanical performance of high-entropy alloys (HEAs) is closely related to their unique microstructural evolution during powder metallurgy (PM) processing. Strengthening in PMprocessed HEAs is primarily achieved via multiple mechanisms, including grain boundary strengthening, solid solution strengthening, dislocation hardening, precipitation hardening, and second-phase reinforcement. Studies have demonstrated that PM enables high strength and ductility through fine microstructure and phase control. For instance, SPS-processed $AlCr_{0.3}FeMoNbTiV_2$ alloys exhibited a

compressive yield strength above 1500 MPa at 1000 °C, attributed to ultrafine grains and Tic precipitation [5]. In contrast, the introduction of 8 at. % C into CrFeNi alloys enhanced yield strength from 395 MPa to 630 MPa through carbide formation and Orowan strengthening [7]. Similarly, the use of graphene in CoCrFeNiMn HEAs provided the dual advantages of a higher tensile strength (834 MPa) and improved ductility (26.6%) [6]. This Fig 5. summarizes the key strengthening mechanisms— namely, solid solution strengthening, precipitation strengthening, and work hardening—that contribute to the enhanced mechanical properties of high-entropy alloys (HEAs). These mechanisms are responsible for improving the strength, ductility, and hardness, and are optimized through precise control of the alloy composition and powder metallurgy processing parameters.

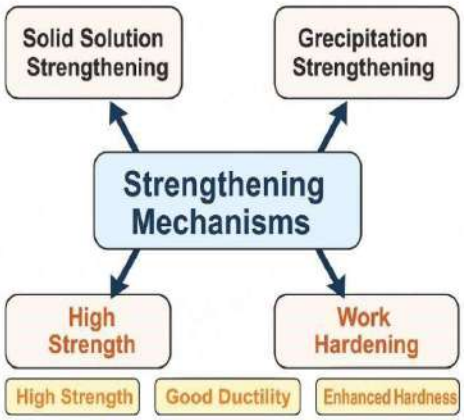


Fig. 5. Strengthening Mechanisms in Powder Metallurgy-Processed HEAs

The Table 4. shows that different powder metallurgy routes combined with tailored alloying strategies lead to significant improvements in the strength and ductility of HEAs through mechanisms such as grain refinement, twinning, nanoparticle dispersion, and dynamic strain hardening, demonstrating the potential of PM in tuning the mechanical performance for demanding applications.

Table 4: Mechanical Properties and Strengthening Mechanisms in PM-Processed HEAs

Reference	Alloy System	Processing Route	Strength (MPa)	Mechanism
[1]	AlCr0.3FeMoNbTiV₂ MA + SPS		1513 @ 1000 °C	Grain refinement + carbide precipitates
[2]	CoCrFeNiMn + Graphene	Flake PM + VHPS	834 (UTS), 26.6% Elongation	Laminate structure + twin strengthening
[3]	CrFeNi	SPS	630 (Yield), 990 (UTS)	Orowan + solid solution strengthening
[4]	Fe50Mn30Co10Cr10	SPS	1087 (Yield), 1413 (UTS) @ 77K	Twinning + HCP phase activation
[5]	CoCrFeMnNi compression	Dynamic	Strain-rate hardening + ~700 (dynamic)	Nano twins
[6]	FeMnCoCr	SPS	~500–800 (Hardness ↑)	Oxide dispersion + pinning effect

5. Functional and Cryogenic Applications

High-entropy alloys (HEAs) processed via powder metallurgy (PM) exhibit superior mechanical properties and remarkable functional characteristics, making them ideal for cryogenic, magnetic, corrosion-resistant, and high-temperature applications. These functionalities are a direct result of microstructural tailoring and precise compositional control enabled by PM techniques. Cryogenic applications benefit significantly from HEAs such as $Fe_{50}Mn_{30}Co_{10}Cr_{10}$, where SPS processing combined with carbon alloying results in

ultimate tensile strengths above 1.4 GPa and an elongation above 30% at 77 K [8]. This performance is attributed to twinning-induced plasticity (TWIP) and hexagonal close-packed (HCP) phase formation under low-temperature deformation. Functionally, the addition of elements such as Cu and Si to HEAs improved their magnetic and corrosion properties, respectively. FeCoNiCrCu HEAs showed a dual FCC phase with a tunable magnetic response depending on the copper content [12], whereas FeNiCrCo with Si and Ti demonstrated enhanced corrosion resistance owing to the suppression of dendritic segregation and refinement of the microstructure [9].

This schematic Fig 6. highlights the diverse functional and cryogenic applications of highentropy alloys developed using powder metallurgy. These include hydrogen storage, corrosionresistant systems, medical implants, aerospace and defense, magnetic components, and materials with superior cryogenic strength. The ability to tailor the composition and microstructure enables HEAs to perform reliably in extreme environments.

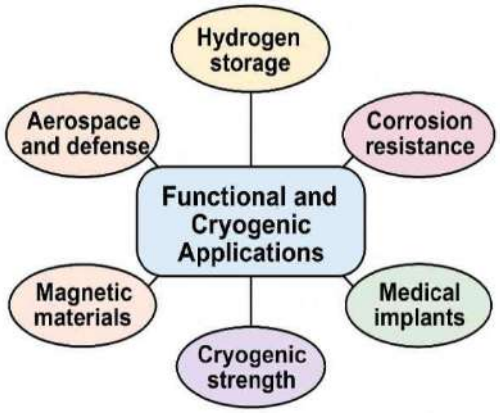


Figure 6. Functional and Cryogenic Applications of Powder Metallurgy-Processed HEAs

The Table 5. shows that powder metallurgy-processed HEAs exhibit outstanding cryogenic strength, corrosion resistance, magnetic tenability, and strength-ductility synergy—attributes enabled by precise alloying strategies and advanced microstructural architectures, making them suitable for critical applications in the aerospace, biomedical, and energy sectors.

Table 5: Functional and Cryogenic Performance of PM-Processed HEAs

Reference	Alloy System	Application	Functional Property	Remarks
[8]	Fe50Mn30Co10Cr10 + C	Cryogenic	UTS = 1413 MPa, El. = 31.6% @ 77K	TWIP + HCP activation
[12]	FeCoNiCrCux	Magnetic	Cu-rich dual-phase structure	Tunable magnetism
[9]	FeNiCrCo + Si/Ti	Corrosion resistance	Dendrite-free, homogeneous matrix	Acid stability improved
[6]	CoCrFeNiMn + Graphene	Structuralfunctional	Strength + ductility synergy	Layered architecture benefits

6. Data-Driven and Sustainable Alloy Design

The advancement of high-entropy alloys (HEAs) through powder metallurgy (PM) has been significantly accelerated by integrating data-driven approaches and sustainability-oriented design principles. Machine learning (ML), CALPHAD simulations, and high-throughput screening methods are frequently employed to predict phase stability, optimize compositions, and model processing–property relationships in HEAs. Data-driven models facilitate the rapid exploration of the vast compositional space of HEAs by correlating input features, such as atomic size mismatch, valence electron concentration, and mixing enthalpy, with output metrics, such as yield strength or corrosion resistance.

These predictive tools help minimize trial-and-error experimentation and enhance the reliability of alloy design, particularly for PM, where processing parameters are highly tunable. Simultaneously, sustainable alloy development focuses on minimizing environmental impact by incorporating recycled raw materials and eliminating rare or toxic elements from the alloys. Recent studies have emphasized the use of waste-derived multicomponent scraps to synthesize HEAs with competitive mechanical and thermal properties. Additionally, PM's low energy requirements and material efficiency of PMs align with green manufacturing goals, further enhancing the environmental appeal of PM-based HEAs. The Table 6. shows that integrating machine learning, CALPHAD modeling, recycled materials, and energy-efficient powder metallurgy processes significantly enhances the alloy design workflow, supporting the faster and more sustainable development of high-performance HEAs with reduced environmental impact.

Table 6: Data-Driven and Sustainable Practices in HEA Design via PM

Approach	Benefit	Example/Application	Reference
Machine Learning (ML)	Accelerates design cycles	Property prediction & composition optimization	[3]
CALPHAD Modeling	Phase stability prediction	Used for SPS-processed complex HEAs	[5]
Recycled Element Use	Waste reduction	HEAs from industrial scrap	[3]
Energy-Efficient PM Routes	Lower carbon footprint	MA + SPS vs. arc melting	[5], [6]

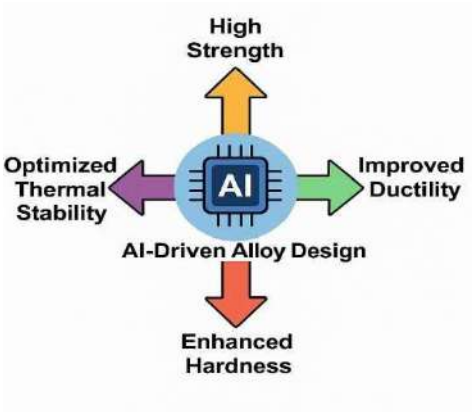


Figure 7. AI-Driven Design for Enhanced Alloy Properties

The Fig 7. A schematic highlighting the role of artificial intelligence (AI) in the modern design of high-performance alloys. Centered on AI-powered algorithms, the figure illustrates how computational tools aid in optimizing key mechanical properties, such as high strength, improved ductility, enhanced hardness, and thermal stability, accelerating the development of advanced materials for critical engineering applications.

Conclusion and Future Outlook

Powder metallurgy (PM) has emerged as a transformative manufacturing approach for high-entropy alloys (HEAs), offering superior microstructural control, refined mechanical behavior, and flexibility in the design of complex HEAs. This review comprehensively explored the synergy between PM techniques and HEA compositions, demonstrating how process–property–performance relationships can be tailored to achieve remarkable outcomes. Key powder production and sintering strategies, such as mechanical alloying, spark plasma sintering, hot isostatic pressing, and emerging flake powder metallurgy, have enabled ultrafine grains, solid solution stability, and the incorporation of nano/microstructural reinforcements. Across the reviewed literature, alloying

strategies involving elements such as C, Cu, Ti, Si, and graphene have been shown to enhance the strength, ductility, wear resistance, corrosion resistance, and magnetic properties. Mechanistic analyses have revealed a diverse set of strengthening mechanisms, ranging from Orowan looping to twinning and oxide dispersion strengthening, enabling the design of application-specific alloys for both structural and functional purposes. Moreover, the functional applications of PM-processed HEAs in cryogenic, magnetic, and chemical environments highlight their versatility. Looking forward, the integration of data-driven models, CALPHAD, and machine learning will play a crucial role in accelerating HEA discovery and optimization processes. Coupled with sustainable practices, such as recycling and energy-efficient processing, PM-based HEAs are poised to meet the dual goals of high performance and environmental responsibility. Future research should focus on scalable industrial implementation, long-term performance validation under service conditions, and development of standardization protocols for reproducibility and benchmarking. In conclusion, powder metallurgy provides an unparalleled platform for the next generation of HEAs, bridging the gaps between materials science, sustainability, and advanced manufacturing to unlock the full potential of multicomponent alloy systems.

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Applications of 3D Printing in the Automobile Industry

Mr. Siddharth Suman
Assistant Professor
Department of Mechanical Engineering
Pune, India.

Zishan I Warunkar
Department of Mechanical Engineering
KJ College Of Engineering and Management Research Pune, India.

Shantanu S Kumbhar
Department of Mechanical Engineering
KJ College Of Engineering and Management Research
KJ College Of Engineering and Management Research Pune, India.

Prashant K Dere
Department of Mechanical Engineering
KJ College Of Engineering and Management Research Pune, India.

Ajit B Jadhav
Department of Mechanical Engineering
KJ College Of Engineering and Management Research Pune, India

1. Abstract:

The automobile industry has increasingly embraced 3D printing (additive manufacturing) as a transformative technology that reshapes traditional manufacturing processes. This paper focuses on the diverse applications of 3D printing within the automotive sector, emphasizing its role in accelerating product development, enabling complex part geometries, and supporting sustainable manufacturing practices. Additive manufacturing allows rapid prototyping, which significantly reduces the design cycle time, enabling automotive engineers to test and refine components more efficiently than conventional methods. Additionally, 3D printing facilitates the production of customized and low-volume parts, which is particularly advantageous for limited edition vehicles and legacy part replacements.

The technology also plays a vital role in tooling and fixture fabrication, improving manufacturing flexibility and reducing costs associated with traditional tooling. Furthermore, 3D printing contributes to weight reduction efforts by enabling topology optimization and the use of advanced lightweight materials, which directly enhance vehicle performance and fuel efficiency. Supply chain management benefits from on-demand spare parts production, reducing inventory costs and downtime. Despite these advantages, challenges such as material property consistency, surface finish quality, and production scalability remain areas of ongoing research and development.

This paper reviews recent advancements in materials, processes, and applications of 3D printing in the automotive industry, supported by data from industry reports and academic research. It also discusses future trends that promise to further integrate additive manufacturing into mainstream automobile production, paving the way for more sustainable, efficient, and innovative vehicles.

ISBN: 978-93-343-2006-0

2. Introduction:

The automotive industry has long been at the forefront of adopting innovative manufacturing technologies to improve product design, reduce production time, and enhance overall vehicle performance. Among these innovations, 3D printing, also known as additive manufacturing, has emerged as a revolutionary technology transforming how automobile components are designed, prototyped, and produced. Unlike traditional subtractive manufacturing methods, which involve cutting away material from a solid block, 3D printing builds components layer by layer directly from digital models, offering unprecedented design freedom and material efficiency.

In recent years, the integration of 3D printing in automotive manufacturing has accelerated significantly. Major automobile manufacturers such as Ford, BMW, and Tesla have incorporated additive manufacturing into various stages of vehicle production—from rapid prototyping and tooling to the production of functional end-use parts. This shift is driven by the ability of 3D printing to produce highly complex geometries that are difficult or impossible to fabricate with conventional techniques. Additionally, additive manufacturing supports lightweight design strategies, which are critical for improving fuel efficiency and reducing emissions in modern vehicles.

The automotive sector benefits from reduced lead times and costs associated with rapid prototyping, enabling faster development cycles and more iterative design processes. Furthermore, 3D printing is instrumental in producing customized components and limited-run parts, particularly for electric vehicles, specialty cars, and legacy vehicles where traditional mass production is not economically viable. The technology also holds promise for reshaping supply chains by enabling on-demand spare parts production, minimizing inventory costs and enhancing vehicle maintenance efficiency.

Despite its many advantages, challenges related to material properties, scalability, surface finish, and process standardization remain. Research and development efforts continue to address these limitations, with ongoing advances in materials science and additive manufacturing techniques. This paper delves into the various applications of 3D printing in the automotive industry, highlighting its impact on design innovation, production efficiency, and supply chain management.

3. Literature Review:

The body of literature on 3D printing in the automotive industry reveals rapid advancements in technology and expanding applications across multiple facets of vehicle manufacturing. According to the Wohlers Report 2023, additive manufacturing continues to grow as a strategic enabler in automotive, with an increasing number of manufacturers adopting 3D printing

for prototyping, tooling, and end-use parts (Wohlers Associates, 2023).

Research from the Ford Motor Company Additive Manufacturing White Paper (2022) emphasizes the transformative role of additive manufacturing in accelerating design iterations and reducing product development cycles. Ford reports that 3D printing enables the rapid creation of complex geometries and functional prototypes that can be tested and refined quickly, thus enhancing innovation and reducing time to market.

The Journal of Manufacturing Science and Engineering (ASME, 2021) details various additive manufacturing technologies used in automotive applications, including fused deposition modelling (FDM), selective laser sintering (SLS), and direct metal laser sintering (DMLS). Each technology offers distinct advantages depending on material choice, part complexity, and production volume. Metal additive manufacturing, in particular, has garnered attention for producing lightweight yet strong structural components, which are critical for improving fuel efficiency and vehicle safety.

Material development remains a critical focus area, as highlighted in Materials Today (Elsevier, 2022). Advances in polymer composites, metal alloys, and hybrid materials enable 3D printed parts to meet stringent mechanical and thermal requirements. These materials contribute to the expanding scope of functional automotive components produced by additive manufacturing, ranging from interior trims to engine parts.

The BMW Group Innovation Report (2022) demonstrates practical applications of 3D printing in tooling and fixture manufacturing. BMW has successfully used additive manufacturing to produce custom jigs and fixtures that enhance assembly line flexibility and reduce lead times. The report also discusses how topology optimization combined with additive manufacturing can create lightweight components without compromising structural integrity, a key trend in automotive design.

Further insights from Springer Nature (2023) explore metal additive manufacturing advancements, focusing on process improvements such as improved laser control and powder bed fusion techniques. These developments contribute to better surface finishes and mechanical properties, addressing some of the longstanding challenges of 3D printed metal parts.

The literature also stresses the importance of additive manufacturing for spare parts management. According to the International Journal of Production Research (2022), ondemand printing of spare parts reduces dependency on extensive warehousing and complex logistics, offering cost savings and quicker turnaround times for vehicle repairs.

Finally, comprehensive reviews such as the KeAi Journal (2021) and Elsevier (2019) emphasize the synergy between 3D printing and Industry 4.0 technologies. Integration

of additive manufacturing with digital design tools, IoT, and automation paves the way for more intelligent and responsive manufacturing systems in the automotive sector.

Collectively, these studies underline the critical role of 3D printing in reshaping automotive manufacturing by enabling design complexity, customization, rapid prototyping, lightweight construction, and supply chain innovation.

4. Working Principle of 3D Printing:

3D printing, or additive manufacturing, is a process of creating three-dimensional objects directly from digital models by adding material layer upon layer. Unlike traditional subtractive manufacturing methods, which remove material through cutting or machining, 3D printing builds parts incrementally, allowing for complex geometries and internal structures that would be difficult or impossible to achieve otherwise.

The process begins with the creation of a precise digital 3D model, usually designed using computer-aided design (CAD) software. This model is then converted into a standard file format such as STL (stereolithography), which slices the object into thin horizontal layers. The slicing software generates a set of instructions, called G-code, that guides the 3D printer on how to build each layer.

Depending on the specific 3D printing technology used—such as fused deposition modelling (FDM), selective laser sintering (SLS), or direct metal laser sintering (DMLS)—the printer deposits or fuses material to form each layer. For example, in FDM, thermoplastic filament is melted and extruded through a nozzle, laying down thin lines of molten material that solidify upon cooling. In contrast, SLS and DMLS use high-powered lasers to selectively fuse powdered materials, such as nylon or metal alloys, layer by layer to create the part.

Each successive layer bonds to the previous one until the entire component is formed. Postprocessing steps, such as heat treatment, surface finishing, or infiltration with other materials, may be applied to improve mechanical properties or surface quality.

In the automotive industry, this layered manufacturing approach offers several advantages. It enables the production of lightweight parts through topology optimization, where material is only placed where necessary for strength, reducing vehicle weight and improving fuel efficiency. Complex internal cooling channels, lattice structures, and custom geometries can be fabricated without the constraints of traditional tooling. Additionally, 3D printing allows for rapid prototyping and functional testing of new designs, accelerating innovation cycles.

Overall, the working principle of additive manufacturing, cantered around layer-by-layer construction and material fusion, provides automotive manufacturers with a

flexible and efficient method to produce customized, high-performance components.

5. Applications of 3D Printing in the Automobile Industry:

3D printing technology has profoundly transformed the automotive industry, offering unparalleled opportunities for innovation, efficiency, and customization. Its impact spans from design and prototyping to final production and aftermarket services. Below are key applications with expanded details and additional examples from leading companies:

1. Rapid Prototyping and Concept Models:

Rapid prototyping remains one of the foundational applications of 3D printing in automotive design. Engineers can quickly convert CAD files into physical parts, allowing for early detection of design flaws and ergonomic assessments. This reduces the dependency on expensive, time-consuming traditional machining or moulding processes. For instance, Ford has utilized 3D printing to create hundreds of prototype parts during vehicle development, accelerating the design approval process by up to 70%.

2. Production of Lightweight Components:

Weight reduction is vital for fuel economy, particularly with the rise of electric vehicles (EVs). 3D printing facilitates the fabrication of parts with complex internal lattices and optimized geometries that are impossible or cost-prohibitive using traditional manufacturing. BMW, for example, uses metal additive manufacturing to produce lightweight suspension components and engine parts that save significant weight while maintaining strength and durability.

3. Complex Geometries and Internal Structures:

Additive manufacturing excels at producing components with intricate internal channels and geometries designed for enhanced fluid dynamics, cooling, or strength-to-weight ratios. Automotive turbochargers and heat exchangers now often include 3D printed parts with optimized cooling pathways. This not only improves performance but also extends the lifespan of critical engine components.

4. Customization and Personalization:

3D printing enables mass customization, allowing manufacturers to offer bespoke solutions without disrupting mass production. Luxury carmakers such as Rolls-Royce and Bentley have incorporated 3D printed interior trim pieces, custom badges, and personalized controls that reflect individual customer preferences, enhancing brand exclusivity and customer satisfaction. **5. Tooling, Fixtures, and Manufacturing Aids:**

Manufacturing aids such as assembly jigs, fixtures, and inspection tools can be produced rapidly and cost-effectively using 3D printing. Ford has reported a 90% reduction in lead time for tooling parts created via additive manufacturing. This flexibility enables just-in-time production and supports lean manufacturing principles.

6. On-Demand Spare Parts Manufacturing:

The aftermarket and maintenance sectors benefit greatly from 3D printing's ability to produce spare parts on demand. This reduces warehousing costs and supply chain complexity, especially for legacy or rare vehicle models. For example, Porsche has implemented 3D printing for producing discontinued parts, ensuring availability for classic car owners without maintaining expensive inventories.

7. Functional End-Use Components:

Advancements in materials and printing methods have made it possible to produce functional, load-bearing parts directly via 3D printing. Tesla, for instance, uses additive manufacturing to produce certain end-use parts for its electric vehicles, including brackets and sensor housings. This approach shortens the supply chain and allows rapid iteration during production.

8. Integration of Multi-Functional Parts:

Additive manufacturing enables the consolidation of multiple components into a single, multifunctional part, reducing assembly complexity and potential failure points. For example, a 3D printed housing can incorporate structural support, sensor integration, and cooling ducts, as explored in projects by General Motors (GM).

9. Research and Development Acceleration:

3D printing accelerates R&D by enabling quick fabrication of new materials and structural concepts. Research groups, such as those at MIT and elsewhere, use additive manufacturing to test novel composites and lightweight alloys tailored for automotive applications. This fosters rapid innovation in safety, efficiency, and sustainability.

10. Sustainable Manufacturing and Waste Minimization:

Unlike subtractive manufacturing, which cuts away excess material, 3D printing deposits material only where needed, drastically reducing waste. Companies like Volkswagen emphasize sustainability by incorporating recycled materials into their additive manufacturing workflows, thereby lowering the carbon footprint of their production lines.

Additional Industry Applications:

11. Electric Vehicle (EV) Battery Components:

The shift toward electric vehicles has created demand for advanced battery housings and cooling systems. 3D printing allows production of lightweight, thermally optimized battery casings that improve performance and safety. Companies like Hyundai and LG Energy Solution are exploring additive manufacturing to produce customized battery modules with integrated cooling channels.

12. Lightweight Structural Chassis Parts:

Additive manufacturing is being used to create lightweight yet strong chassis components, reducing overall vehicle mass and improving handling and fuel economy. Audi has successfully tested 3D printed structural elements in prototype vehicles, combining metal 3D printing with topology optimization to enhance performance without compromising safety.

13. Exhaust System Components:

Metal 3D printing is used to produce complex exhaust system parts with optimized flow dynamics and heat resistance. By integrating internal geometries for heat dissipation, manufacturers can reduce weight and improve emission control systems. Companies like Mercedes-Benz are adopting these technologies to meet stricter emission regulations efficiently.

14. Interior Components and Ergonomic Enhancements:

Automotive interiors increasingly incorporate 3D printed elements such as air vents, consoles, and seat components tailored for ergonomics and aesthetics. This allows rapid customization and testing of tactile finishes and textures. Jaguar Land Rover has experimented with 3D printing interior panels to combine lightweight design with luxury finishes.

15. Safety and Crash-Test Components:

Crash-test dummies and safety fixtures benefit from rapid production via 3D printing, enabling customized test scenarios and faster safety validations. Automotive safety labs use 3D printed parts to simulate various crash conditions, accelerating the development of safer vehicle structures.

16. Replacement of Rare and Discontinued Parts:

For classic and vintage cars, 3D printing offers the ability to recreate parts that are no longer manufactured. Companies like Local Motors specialize in printing customized parts for lowvolume vehicles, preserving automotive heritage while reducing costs and lead times.

17. Fuel Injection and Engine Components:

Additive manufacturing can produce complex fuel injection nozzles and engine parts with improved flow and combustion efficiency. Toyota has been exploring metal 3D printing to produce high-precision engine

components that enable better fuel atomization and performance.

18. Robotics and Automation Components:

3D printing is also used to manufacture parts for robotics and automation equipment used in automotive factories. Customized grippers, end-effectors, and robotic arms made via additive manufacturing help optimize production lines, increasing flexibility and reducing downtime.

19. Noise, Vibration, and Harshness (NVH) Optimization:

Additive manufacturing allows the creation of parts designed to minimize noise and vibration. Complex internal damping structures can be incorporated into engine mounts and body panels, improving passenger comfort. Ford has integrated such parts into some of its latest models.

20. Lightweight Wheels and Rims:

Research is ongoing into producing lightweight wheels with intricate internal lattice structures via 3D printing. These wheels aim to reduce upsprung mass, enhancing vehicle dynamics. Though still in development, companies like AP Works (a BMW Group company) have demonstrated prototypes that could revolutionize wheel manufacturing

Summary Table of Applications

Application	Benefits
Rapid Prototyping	Faster design cycle
Lightweight Components	Improved fuel econ
Complex Geometries	Enhanced performa
Customization	Mass personalizatic
Tooling and Fixtures	Reduced lead times
On-Demand Spare Parts	Inventory reduc service
Functional End-Use Components	Durable, productio
Multi-Functional Parts	Assembly simplific
R&D Acceleration	Rapid innovation
Sustainable Manufacturing	Waste reduction, re
EV Battery Components	Thermal optimizati
Application	**Benefits**
Lightweight Chassis Parts	Performance, safety
Exhaust System Components	Weight reduction, e
Interior Components	Ergonomics, custor
Safety Test Components	Faster crash test de

Rare/Discontinued Parts	Heritage preservation, cost savings	Local Motors
Fuel Injection Components	Fuel efficiency, combustion	Toyota
Robotics Components	Production line efficiency	Various OEMs
NVH Optimization	Comfort improvements	Ford
Lightweight Wheels	Improved dynamics	AP Works (BMW)

3D printing's versatility and capability to produce complex, customized, and lightweight parts are driving significant change in the automobile industry. The technology's integration into every stage—from prototyping and R&D to production and aftermarket—enables faster development, cost reduction, and greater innovation. As material science and additive manufacturing methods continue to advance, the scope of applications will only expand, playing a crucial role in shaping the future of mobility.

6. Materials Used in 3D Printing for the Automobile Industry:

The evolution of 3D printing in the automotive sector is deeply intertwined with the development and availability of suitable materials. The choice of material significantly influences the performance, durability, cost, and feasibility of printed parts. Over the years, the automotive industry has adopted a wide spectrum of materials—from polymers to metals and composites—each serving distinct functions from prototyping to end-use production. Furthermore, cutting-edge materials continue to emerge, promising enhanced properties for the next generation of vehicles.

1. Polymers and Plastics:

Polymers represent the most widely used class of materials in automotive 3D printing, primarily because of their versatility, cost-effectiveness, and ease of processing. They are predominantly used in prototyping, tooling, and some final components.

a. Thermoplastics:

Common thermoplastics include ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid), Nylon (Polyamide), and PETG (Polyethylene Terephthalate Glycol).

- **ABS**: Known for its toughness and impact resistance, ABS is extensively used for prototype parts such as housings, dashboards, and clips. Its ability to withstand moderate heat makes it suitable for non-structural components.
- **Nylon** (Polyamide): Offers excellent mechanical properties, flexibility, and wear resistance. It is popular for producing durable, functional parts like gears, brackets, and jigs. Nylon's chemical resistance and fatigue strength make it ideal for moving parts.
- **PLA**: Although biodegradable and easy to print, PLA's

brittleness limits its use to visual prototypes or models.

- **PETG**: Combining strength with good chemical resistance, PETG finds applications in transparent or semi-transparent parts, like light covers and protective panels.

Industrial Application Example:

Ford uses nylon-based 3D printed parts for jigs and fixtures in assembly lines, leveraging the material's durability to reduce tool wear and improve productivity.

Limitations:

While thermoplastics are inexpensive and easy to work with, they generally lack the mechanical strength and thermal resistance required for critical load-bearing or hightemperature automotive parts.

2. Photopolymers and Resins:

Photopolymer resins cured by UV light in SLA (Stereolithography) or DLP (Digital Light Processing) printing offer high precision and smooth surface finishes. These materials are excellent for intricate prototypes, form-and-fit testing, and small batch production of components like dashboards or switch housings.

- **Standard Resins**: Provide high detail but limited mechanical strength.
- **Tough Resins**: Engineered for impact resistance and flexibility, suitable for functional prototypes.
- **High-Temperature Resins**: Designed for parts exposed to elevated temperatures, such as under-the-hood components.

Industrial Application Example:

BMW uses photopolymer-based SLA parts for high-detail interior trim components and concept car models, achieving surface finishes close to injection moulding.

Limitations:

Photopolymers often exhibit brittleness and limited long-term durability, restricting their use to prototypes and non-structural applications.

3. Metals and Metal Alloys

Metal additive manufacturing has revolutionized the automotive industry by enabling the production of lightweight, complex, and load-bearing components that are difficult or impossible to fabricate conventionally. Metal 3D printing technologies include Selective Laser Melting (SLM), Electron Beam Melting (EBM), and Direct Metal Laser Sintering (DMLS).

Commonly Used Metals:

- **Aluminium Alloys (e.g., AlSi10Mg):** Lightweight with good corrosion resistance and high strength-to-weight ratio, aluminium alloys are widely used for structural parts such as engine components, brackets, and chassis parts. The rapid cooling rates during

printing allow fine microstructures that enhance mechanical properties.

- **Titanium Alloys (e.g., Ti6Al4V):** Known for their excellent strength, corrosion resistance, and biocompatibility, titanium alloys are used for high-performance engine parts, exhaust systems, and structural components in luxury and sports cars. Despite higher costs, their superior properties justify use in weight-critical applications.
- **Stainless Steel (e.g., 316L, 17-4 PH):** Stainless steel alloys offer good strength, **wear** resistance, and corrosion resistance, ideal for functional parts like exhaust manifolds, fasteners, and tooling.
- **Inconel (Nickel-based Superalloys):** Inconel alloys provide outstanding performance at high temperatures, suitable for turbocharger components and exhaust systems exposed to extreme heat.

Industrial Application Example:

BMW and Ford employ metal 3D printing to produce lightweight suspension components and turbocharger parts, reducing mass while improving thermal performance.

Limitations:

Metal 3D printing requires costly equipment and post-processing (heat treatments, surface finishing), limiting its use to high-value parts.

4. Composites:

Composite materials combine polymers with reinforcing fibers (carbon fiber, glass fiber) or particles to create parts with enhanced mechanical properties. Composite 3D printing is gaining traction due to its potential to produce lightweight, strong automotive components.

Types of Composite Materials:

- **Carbon Fiber Reinforced Polymers (CFRP):** These offer superior stiffness, strength, and lightweight properties, ideal for performance parts like brackets, body panels, and interior trims.
- **Glass Fiber Reinforced Polymers (GFRP):** Slightly less strong than CFRP but more cost-effective, used in structural components and tooling.

Industrial Application Example:

Local Motors utilizes carbon fiber composite 3D printing to manufacture lightweight vehicle body panels and structural elements, significantly reducing vehicle weight without compromising safety.

Limitations:

Achieving consistent fiber orientation and distribution during printing remains complex, impacting mechanical reliability.

5. Ceramics

Although less common in automotive manufacturing, ceramic materials are gaining interest for their thermal resistance, hardness, and wear properties. Advanced ceramic 3D printing methods produce parts like engine components and heat shields capable of withstanding high temperatures and harsh environments.

Emerging Next-Generation Materials and Future Potentials:

The automotive industry is actively researching and developing new materials tailored to the demands of additive manufacturing, aiming to enhance performance, sustainability, and functionality.

1. **High-Performance Polymers:**

Polymers such as PEEK (Polyether Ether Ketone) and PEI (Polyetherimide, Ultem) offer exceptional thermal stability, chemical resistance, and mechanical strength, suitable for underthe-hood components, electrical housings, and fuel system parts. These materials are beginning to be used with high-temperature 3D printers capable of processing demanding polymers.

2. **Multi-Material and Functionally Graded Materials (FGMs):**

Next-generation 3D printing explores combining multiple materials within a single component to achieve spatially varying properties. For example, a car part could have a rigid core with flexible outer layers for impact absorption. Functionally graded materials allow designers to tailor properties like stiffness, thermal conductivity, and density locally within a part.

3. **Metal Matrix Composites (MMCs):**

MMCs combine metals with ceramic or carbon reinforcements to enhance strength, stiffness, and wear resistance. Additive manufacturing of MMCs is promising for producing engine parts, brake systems, and transmission components that require superior mechanical properties.

4. **Biodegradable and Recycled Materials:**

Sustainability concerns have spurred development of bio-based and recycled polymers for 3D printing. PLA derived from renewable resources and recycled nylon are examples. The future may see more automotive components manufactured from such eco-friendly materials, reducing the environmental impact of vehicle production.

5. **Conductive and Smart Materials:**

3D printing of conductive polymers and metal inks opens avenues for integrating electronics and sensors directly into automotive parts. Smart materials that respond to heat, pressure, or electrical stimuli could enable adaptive components for

improved safety, comfort, or performance.

6. Nanomaterial-Enhanced Polymers and Metals:

Incorporation of nanoparticles (graphene, carbon nanotubes, nano-ceramics) into polymers and metals enhances mechanical, electrical, and thermal properties. These nanocomposites could lead to ultra-strong, lightweight parts with multifunctional capabilities, such as self-sensing or self-healing features.

Industrial and Future Potential Summary:

Material Type	Current Use Cases	Future Potential
Thermoplastics (ABS, Nylon)	Prototypes, tooling, nonstructural parts	High-performance polymers for end-use parts
Photopolymers (Resins)	Detailed prototypes, interior parts	Tough, high-temp resins for functional components
Metals (Al, Ti, Steel, Inconel)	Load-bearing parts, lightweight structures	Metal matrix composites, nanomaterial alloys
Composites (CFRP, GFRP)	Lightweight structural parts, body panels	Multi-material composites with graded properties
Ceramics	Heat shields, wear-resistant components	Advanced ceramics for engine and exhaust systems
Biodegradable Polymers	Eco-friendly prototypes	Sustainable mass production materials
Conductive/Smart Materials	Early-stage sensor integration	Fully integrated, smart components

The choice and development of materials in 3D printing are pivotal to the expanding role of additive manufacturing in the automobile industry. Presently, polymers, metals, and composites form the backbone of automotive additive manufacturing applications, each bringing unique strengths and challenges. Emerging next-generation materials promise to overcome current limitations, enabling the production of lighter, stronger, multifunctional, and sustainable automotive components. As material science and 3D printing technology advance hand-inhand, the automotive industry is poised to leverage these innovations to create vehicles that are not only efficient and high-performing but also environmentally responsible and customizable.

7. Future Trends and Innovations in 3D Printing for the Automobile Industry:

The integration of 3D printing, also known as additive manufacturing (AM), into the automobile industry is rapidly evolving. What began as a method for rapid prototyping has matured into a transformative manufacturing technology impacting design, production, supply chains, and sustainability. Looking forward, the future of 3D printing in automotive engineering promises to be shaped by technological innovations, new materials, digital transformation, and sustainability imperatives. This section explores key trends and breakthroughs that will influence the automotive landscape in the coming years.

1. Multi-Material and Hybrid 3D Printing:

Current 3D printing technologies typically focus on printing a single material at a time, but emerging multi-material additive manufacturing systems are set to revolutionize how automotive parts are designed and produced. Multi-material printing enables the creation of components with integrated functional gradients, combining materials with varying mechanical, thermal, and electrical properties in a single build.

Innovations:

- Simultaneous deposition of metals and polymers: Hybrid printers that can print both metals and polymers in one process will allow embedding of flexible wiring, sensors, or cushioning materials directly into structural components.
- Functionally graded materials (FGMs): Future AM systems will fabricate parts where material properties gradually change to optimize performance—such as increasing stiffness in high-stress regions while maintaining flexibility elsewhere.

Potential Impact:

This capability will drastically reduce assembly times and part counts, simplify complex automotive assemblies and enable smarter, lighter, and more durable components.

2. Large-Scale 3D Printing and Additive Manufacturing of Entire Vehicles:

While most current applications involve parts and prototypes, advances in large-format 3D printing open the possibility of producing entire vehicle structures additively.

Emerging Technologies:

- Big-area additive manufacturing (BAAM): Large-scale extrusion-based printers capable of fabricating automotive body panels and chassis sections using composite thermoplastics reinforced with carbon fibers.
- Robotic arm-based multi-axis printing: Flexible robotic arms equipped with printing heads can produce large, curved, and complex geometries on demand, bypassing traditional assembly line constraints.

Industry Developments:

Companies like Local Motors and Divergent 3D have pioneered 3D printed vehicles or major components, demonstrating the feasibility of rapid, on-demand manufacturing of custom vehicles or limited-run models.

Future Prospects:

This trend could lead to highly customizable vehicles, reduced tooling and inventory costs, and localized production closer to end

users, reducing logistics expenses and emissions.

3. Advanced Metal 3D Printing and Post-Processing Automation:

Metal additive manufacturing is crucial for automotive parts requiring high strength, durability, and heat resistance. Future trends include improved metal printing techniques and smarter postprocessing workflows.

Key Innovations:

- Faster, higher resolution metal printers: Laser and electron beam technologies will achieve finer microstructures and better mechanical properties at increased build speeds.
- In-situ process monitoring and closed-loop control: Sensors integrated into metal printers will detect defects in real time, enabling automatic parameter adjustments to improve quality and reduce waste.
- Automated post-processing: Robotic finishing, heat treatment, and machining will streamline finishing workflows, reducing costs and turnaround time.

Impact:

These advances will make metal AM more cost-competitive and reliable for producing engine components, suspension parts, and safety-critical systems.

4. Artificial Intelligence (AI) and Machine Learning in Design and Manufacturing:

AI is poised to revolutionize every phase of automotive 3D printing from design to production and quality control.

Applications:

- Generative Design: AI algorithms will optimize parts for weight, strength, and material usage beyond what human designers can achieve. This will lead to complex organic structures optimized for additive manufacturing constraints.
- Predictive maintenance: Machine learning models will analyze machine data to predict failures and schedule proactive maintenance, minimizing downtime.
- Process optimization: AI will dynamically adjust printer settings to improve build quality and reduce defects based on historical data and real-time feedback.
- Quality assurance: Computer vision systems will inspect printed parts for surface defects, dimensional accuracy, and structural integrity faster and more reliably than manual inspection.

ISBN: 978-93-343-2006-0

Outcomes:

Integrating AI will accelerate product development cycles, reduce scrap rates, and enable mass customization at scale.

optimal facility based on capacity and proximity.

Benefits:

This connectivity enhances flexibility, responsiveness, and efficiency, allowing the automotive supply chain to become more resilient and adaptive.

5. Integration of 3D Printing with Industry 4.0 and Digital Twins:

The future automobile factory will leverage Industry 4.0 principles, integrating 3D printing into smart manufacturing ecosystems.

Key Concepts:

- Digital Twins: Virtual replicas of 3D printers and manufacturing lines simulate and optimize production processes before actual printing. This reduces trial and error, shortens lead times, and improves quality.
- IoT Connectivity: Printers and equipment connected to factory networks enable remote monitoring, real-time data analysis, and rapid troubleshooting.
- Cloud-based Manufacturing: Decentralized production using cloud platforms will allow automotive companies to manage global manufacturing networks, dispatch print jobs to the

6. Sustainable 3D Printing: Circular Economy and Green Materials:

Environmental sustainability is a major driver of innovation in automotive manufacturing. 3D printing offers unique opportunities to reduce waste, energy consumption, and emissions.

Emerging Trends:

- Material recycling and reuse: Closed-loop systems will enable recycling of failed prints and support structures into raw material feedstock, minimizing landfill waste.
- Bio-based and biodegradable materials: Research is advancing biodegradable polymers and bio-composites suitable for automotive applications, reducing reliance on fossil fuels.
- Energy-efficient printing processes: New printer designs and energy management systems will reduce power

consumption during manufacturing.

- Lightweighting and material efficiency: By enabling complex geometries and lattice structures, 3D printing helps reduce vehicle weight, improving fuel efficiency and lowering emissions during operation.

Industry Impact:

As regulatory pressure mounts, automakers will increasingly adopt additive manufacturing strategies that align with sustainability goals and circular economy principles.

7. 4D Printing and Smart Materials:

An exciting frontier is 4D printing, where printed parts can change shape or properties over time in response to environmental stimuli such as heat, moisture, or electrical input.

Applications in Automobiles:

- Self-healing coatings: Materials that repair minor scratches or cracks autonomously to maintain vehicle aesthetics and durability.
- Adaptive aerodynamic components: Parts that change shape to optimize airflow for improved fuel efficiency or performance.
- Temperature-responsive interiors: Surfaces that adjust hardness or insulation properties for comfort.

While still largely experimental, 4D printing holds promise for smarter, more adaptive automotive designs.

8. Customized and On-Demand Manufacturing:

3D printing enables the production of highly customized components tailored to individual vehicle models, driver preferences, or regional regulations.

Examples:

- Custom interior trims with unique textures and finishes.
- Personalized ergonomic components such as seats and control knobs.
- Regional adaptation of parts to meet local environmental or safety standards.

On-demand manufacturing reduces inventory and storage costs and allows rapid response to market trends or part obsolescence.

9. Supply Chain Transformation and Distributed Manufacturing:

3D printing will disrupt traditional automotive supply chains by enabling distributed manufacturing networks.

Future Trends:

- Localized production hubs: Small, strategically placed 3D printing centers reduce lead times and shipping emissions.
- Digital inventory: Parts are stored as digital files and printed as needed, eliminating the need for large physical inventories.
- Spare parts on demand: Aging or rare vehicles can have spare parts produced as needed, extending vehicle lifespans and reducing waste.

This shift creates a more agile, resilient supply chain, particularly critical in times of disruption.

10. Regulatory and Standardization Advances:

As 3D printing becomes more prevalent in automotive production, regulatory frameworks and standards will evolve to ensure safety, reliability, and interoperability.

Expected Developments:

- Certification protocols for printed structural and safety-critical parts.
- Material and process standards to guarantee consistent quality.
- Traceability and documentation requirements enabled by digital manufacturing records.

Clear regulatory guidelines will accelerate industry adoption and consumer confidence in 3D printed automotive components.

The future of 3D printing in the automobile industry is rich with transformative potential. Innovations in multi-material and large-scale printing, advanced metal processes, AI-driven design and manufacturing, and sustainable materials will continue to redefine vehicle development and production. Integrated within Industry 4.0 frameworks, additive manufacturing will create more agile, efficient, and environmentally responsible automotive supply chains.

As smart materials and 4D printing mature, vehicles will become more adaptive and personalized, elevating both performance and user experience. Meanwhile, distributed manufacturing and on-demand production will reshape supply chains, driving cost savings and flexibility.

Together, these trends paint a future where 3D printing is not just a complementary technology but a core pillar of automotive innovation and manufacturing excellence.

8. Challenges and Limitations of 3D Printing in the Automobile Industry:

While 3D printing has shown tremendous promise in revolutionizing the automobile industry, the technology still faces several significant challenges and limitations that restrict its broader adoption. Understanding these

barriers is crucial for researchers, manufacturers, and stakeholders to develop strategies that mitigate risks, improve processes, and accelerate integration of additive manufacturing (AM) into mainstream automotive production.

1. Material Limitations and Performance Issues:

One of the primary challenges is related to the materials used in 3D printing. Although there has been substantial progress in developing polymers, metals, and composites compatible with AM, limitations remain regarding their mechanical properties, durability, and performance under automotive operating conditions.

- Material availability: Compared to traditional manufacturing materials, the variety of 3D printable materials suitable for automotive applications is still limited. Many highperformance alloys and composites are difficult to process additively or are not yet commercially available.
- Material anisotropy: Parts produced through AM often exhibit anisotropic properties, meaning their strength and behaviour vary depending on the printing direction. This directional dependence can complicate design and reduce reliability in critical applications.
- Surface finish and porosity: 3D printed parts frequently have rough surface finishes and may contain microscopic pores or defects that weaken the structure or reduce fatigue life. Post-processing is required to improve surface quality and mechanical performance but adds time and cost.
- Material certification: Automotive manufacturers require certified materials with welldocumented properties and behaviour. Many novel 3D printing materials lack standardized testing and certification, delaying their use in safety-critical components.

2. Production Speed and Scalability:

Additive manufacturing is inherently slower than many traditional mass production processes such as stamping, casting, or injection moulding, which limits its use for large-scale production.

- Build time: The layer-by-layer printing process is time-consuming, especially for large or complex parts. Even with advances in printer speed, AM cannot yet match the throughput of conventional high-volume manufacturing.
- Post-processing bottlenecks: Many 3D printed parts require extensive post-processing

such as heat treatment, surface finishing, machining, or inspection. These additional steps add to production time and cost, reducing overall efficiency.

- Limited build volume: Printer size constraints limit the maximum dimensions of parts that can be manufactured in a single print job, often requiring assembly of multiple components that may negate some advantages of AM.
- Scalability issues: While 3D printing excels at low-volume, customized, or complex parts, scaling to mass production remains challenging. Manufacturing millions of identical components through AM is currently not economically viable.

3. High Initial Investment and Operating Costs:

Despite reductions in printer costs over the past decade, the initial investment for industrialgrade additive manufacturing systems remains high, posing a financial barrier to many automotive manufacturers and suppliers.

- Capital expenditure: High-quality metal AM systems, necessary for critical automotive parts, can cost hundreds of thousands to millions of dollars. Supporting equipment and facilities upgrades further increase investment requirements.
- Material costs: Specialty powders and filaments designed for 3D printing are generally more expensive than bulk materials used in traditional manufacturing. Additionally, material wastage during the printing and post-processing steps raises costs.
- Maintenance and operation: AM machines require skilled operators and regular maintenance. Consumables such as lasers, nozzles, and build plates also contribute to ongoing operational expenses.
- Cost-benefit analysis: For many conventional parts, traditional manufacturing remains cheaper and faster. AM's value proposition currently lies in customization, complex geometries, and low-volume production rather than mass production cost savings.

4. Design and Engineering Challenges:

While 3D printing enables design freedom, fully leveraging its capabilities requires changes in design thinking, engineering practices, and software tools.

- Lack of expertise: Designing for additive manufacturing requires specialized knowledge of AM processes, material behaviour, and design constraints. Many automotive

engineers lack experience or training in these areas.

- Complexity vs. manufacturability: Although complex geometries are possible, overly intricate designs can increase build time, material usage, and risk of print failure. Balancing complexity with manufacturability is a key challenge.
- Software limitations: Current CAD and simulation software may not fully support AMspecific design rules, optimization algorithms, or process simulation. Integrated tools for design, build preparation, and quality assurance are still evolving.
- Iterative prototyping: Due to variability in AM processes and part properties, multiple design and print iterations may be needed to achieve desired performance, increasing development time.

affect part quality and reproducibility.

- Defect detection: Internal defects such as voids, cracks, or incomplete fusion are difficult to detect with standard inspection techniques. Advanced non-destructive testing methods are required but are often expensive and time-consuming.
- Certification and standards: The automotive industry demands rigorous quality standards and traceability. Establishing robust inspection protocols and certifying AM parts to the same level as traditionally manufactured parts remains a work in progress.
- Build failures: Print failures during long build jobs lead to wasted materials and time, negatively impacting production schedules and costs.

5. Quality Control and Consistency:

Ensuring consistent quality in 3D printed automotive parts is a critical challenge due to the variability inherent in additive processes.

- Process variability: Factors such as temperature fluctuations, powder quality, laser calibration, and environmental conditions can

6. Post-Processing and Finishing Requirements:

Most 3D printed parts require post-processing to meet dimensional tolerances, surface finish, and mechanical property requirements.

- Time-consuming processes: Support removal, heat treatments, surface polishing, and machining add significant time to the overall production cycle.

ISBN: 978-93-343-2006-0

- Cost implications: Post-processing is often labour-intensive and requires specialized equipment, increasing labour costs and capital expenses.
- Integration challenges: Ensuring seamless integration of AM parts with traditionally manufactured components demands tight control over dimensions and surface quality.
- Environmental and safety concerns: Some post-processing steps involve hazardous chemicals or generate waste that requires special handling.

7. Intellectual Property and Security Issues:

The digitization of manufacturing through 3D printing raises concerns related to intellectual property (IP) protection and cybersecurity.

- Digital file protection: Automotive designs and part files stored and transmitted digitally are vulnerable to unauthorized copying, modification, or theft.
- Counterfeiting risks: Easy replication of parts through AM increases the risk of counterfeit components entering the supply chain, potentially compromising safety.
- Data security: Connected manufacturing systems and cloud-based platforms must safeguard sensitive design and production data against cyberattacks.
- Regulatory compliance: Managing IP rights and regulatory compliance across distributed manufacturing networks is complex and evolving.

8. Environmental and Sustainability Challenges:

Although AM is often touted for sustainability benefits, there are environmental challenges associated with the technology.

- Energy consumption: Many metal 3D printing processes consume significant electrical energy, sometimes more than traditional manufacturing methods.
- Material waste: While AM reduces raw material waste compared to subtractive processes, support structures, failed prints, and powder recycling inefficiencies still generate waste.
- Emissions and health risks: Some 3D printing processes emit ultrafine particles and volatile organic compounds, which require effective

ventilation and safety protocols.

- End-of-life considerations: Recycling and disposal of 3D printed parts and materials are still developing fields, particularly for complex multi-material components.

In summary, despite the transformative potential of 3D printing in the automobile industry, several significant challenges and limitations hinder its widespread adoption. Material performance issues, production speed constraints, high costs, and quality control concerns are key barriers that must be overcome through ongoing research, technological development, and process optimization. Furthermore, new design paradigms, workforce training, and robust regulatory frameworks are essential to fully harness additive manufacturing's capabilities.

Addressing these challenges will unlock the full potential of 3D printing, enabling the automotive sector to realize benefits in customization, lightweighting, sustainability, and supply chain resilience. Collaborative efforts between industry, academia, and technology providers will be critical to advancing the technology from niche applications to mainstream automotive manufacturing.

9. Conclusion:

The advent of 3D printing, or additive manufacturing (AM), has introduced a paradigm shift in the automobile industry, opening new avenues for design innovation, supply chain optimization, and production efficiency. Over the last decade, the technology has evolved from a rapid prototyping tool to a viable manufacturing process for functional automotive components. This transformation has been fueled by continuous advancements in printing technologies, material science, and digital manufacturing integration. As demonstrated throughout this paper, the application of 3D printing in the automotive sector presents numerous opportunities as well as complex challenges.

1. Recap of Key Insights:

From the initial stages of concept modelling and prototyping to producing end-use parts, 3D printing offers unparalleled flexibility in design and manufacturing. The literature reviewed confirms that major automotive players such as Ford, BMW, and other innovators are leveraging additive manufacturing to accelerate product development cycles, reduce weight through topology optimization, and create complex geometries that traditional manufacturing methods cannot achieve. These advancements contribute to improved vehicle performance, fuel efficiency, and sustainability—key drivers in today's automotive landscape.

The working principle of 3D printing, which builds parts layer by layer from

digital models, allows for unprecedented customization and complexity. This process supports various methods such as fused deposition modelling (FDM), selective laser sintering (SLS), and direct metal laser sintering (DMLS), each suited to specific materials and applications. The ability to fabricate parts with reduced tooling requirements and shorter lead times enhances the responsiveness of automotive manufacturers to market demands and customization trends.

2. Applications and Industry Impact:

The broad spectrum of applications of 3D printing in the automotive industry spans prototyping, tooling, production of spare parts, and manufacturing of lightweight components. For example, rapid prototyping enables faster design validation and iteration, dramatically shortening development timelines and reducing costs. Custom tooling and jigs produced additively improve manufacturing line efficiency and flexibility. Moreover, on-demand production of spare parts minimizes inventory costs and supply chain disruptions.

The capability to fabricate lightweight, topology-optimized metal parts offers significant advantages in vehicle performance and fuel economy, addressing environmental regulations and customer expectations. Electric vehicle (EV) manufacturing benefits particularly from AM's ability to integrate complex cooling channels and electrical pathways within components, enhancing thermal management and battery efficiency. Furthermore, emerging applications in sensor housings, interior customization, and even structural components hint at the future possibilities that additive manufacturing unlocks.

3. Materials and Future Potential:

The discussion on materials reveals a dynamic field where polymers, metals, and composites are continuously being developed and optimized for automotive applications. Each material class offers unique benefits and constraints. Polymers are ideal for low-stress, lightweight parts, while metals such as aluminium and titanium alloys serve high-performance and safety-critical roles. Composite materials hold promise for combining strength and weight savings but require further research to ensure reliability and manufacturability.

Looking ahead, the next generation of materials—such as smart materials, functionally graded materials, and nano-reinforced composites—may revolutionize additive manufacturing by providing components that adapt to operating conditions, self-heal, or exhibit superior strengthto-weight ratios. Integration of these advanced materials with AM processes could redefine automotive design and functionality, enabling multi-functional parts that reduce assembly

complexity and improve vehicle efficiency.

4. Emerging Trends and Innovations:

The future of 3D printing in the automobile industry is closely tied to ongoing innovations in printing technology and digital manufacturing ecosystems. Advances in multi-material printing, high-speed sintering, and hybrid manufacturing (combining additive and subtractive methods) are expanding the range of producible parts and improving quality and throughput.

Integration of artificial intelligence (AI), machine learning, and digital twins into the additive manufacturing workflow enhances process control, defect prediction, and design optimization. This digital transformation supports real-time monitoring and adaptive manufacturing, driving toward the goal of zero-defect production.

Moreover, the rise of Industry 4.0 principles and the Internet of Things (IoT) facilitates decentralized, flexible manufacturing models where automotive parts can be produced closer to end-users, reducing logistics costs and carbon footprint. The vision of fully digital supply chains supported by 3D printing aligns with sustainability goals and rapid market responsiveness.

5. Challenges and Limitations:

Despite the significant benefits, challenges remain that temper the pace of widespread AM adoption in automotive manufacturing. Material limitations, including anisotropy, certification hurdles, and surface finish quality, require ongoing research and development. Production speed and scalability continue to lag behind traditional mass production techniques, confining AM primarily to low-volume or specialized components.

Economic factors such as high initial capital expenditure, operational costs, and postprocessing requirements add complexity to the cost-benefit analysis. Furthermore, quality assurance and certification frameworks are still evolving, necessitating robust standards and inspection technologies to ensure safety and reliability of 3D printed automotive parts.

Intellectual property protection and cybersecurity concerns must also be addressed as digital manufacturing workflows increase vulnerability to data breaches and counterfeit production. Lastly, environmental impacts, while generally favourable compared to subtractive manufacturing, must be carefully managed to ensure that additive manufacturing contributes positively to sustainable automotive production.

6. Strategic Recommendations and Outlook:

ISBN: 978-93-343-2006-0

To fully realize the transformative potential of 3D printing in the automobile industry, a multifaceted approach is necessary:

- Investment in Research and Development: Continued innovation in materials, printing processes, and post-processing techniques is essential to overcome current limitations and unlock new application domains.
- Workforce Training and Education: Developing specialized skills in additive manufacturing design, operation, and quality control will help integrate AM into mainstream automotive engineering practices.
- Collaborative Ecosystems: Partnerships between OEMs, suppliers, academic institutions, and technology providers can accelerate technology maturation and standardization.
- Regulatory and Standardization Efforts: Establishing clear certification pathways, quality standards, and IP protection protocols will build confidence in AM-produced automotive parts.
- Digital Integration: Leveraging AI, IoT, and Industry 4.0 technologies will optimize manufacturing workflows and enable adaptive, resilient supply chains.
- Sustainability Focus: Emphasizing the environmental benefits of AM through material recycling, energy-efficient processes, and supply chain localization aligns with global regulatory and consumer demands.

7. Final Thoughts:

3D printing stands as a disruptive innovation with the capacity to redefine how automobiles are designed, manufactured, and maintained. Its ability to produce complex, lightweight, and customized components on demand offers distinct competitive advantages. While the journey toward full-scale industrial adoption is ongoing, the incremental integration of AM across various stages of automotive manufacturing demonstrates its growing strategic importance.

As the technology matures, and with concerted efforts to address its current challenges, 3D printing is poised to become an indispensable pillar of the future automotive industry. It promises not only enhanced performance and sustainability but also unprecedented flexibility and resilience in a rapidly evolving market landscape. The collaboration between material scientists, engineers, manufacturers, and policymakers will be pivotal in shaping a future where additive manufacturing drives the next generation of innovative, efficient, and environmentally responsible automobiles.

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Design and Development of a Detachable Liquid Cooling System for Enhanced Heat Dissipation in Small Air-Cooled Engines

Abhijeet Mallick[1], Ayush Kumar[2], Ramesh Poyam[3]

[123] Final-Year Undergraduate Student, Department of Mechanical Engineering, Government Engineering College Raipur, Chhattisgarh Swami Vivekanand Technical University, Bhilai, 491107, C.G, India

Abstract. In many developing Asian & African countries, particularly India, small-displacement air-cooled commuter motorcycles serve as the primary mode of transport for a wide range of uses beyond their original design scope. Although these vehicles are designed for short-distance urban commuting at moderate speeds, users frequently operate them under high-load conditions such as long-distance highway travel, hill climbs, and riding on deteriorated roads at slow speeds. Under such circumstances, the limited heat dissipation capacity of air-cooled engines results in frequent overheating, especially in hot weather conditions, leading to reduced engine performance, fuel inefficiency, accelerated oil degradation**,** increased wear, and higher emissions due to combustion instability**.** Existing cooling solutions, such as oil coolers or integrated liquid cooling systems, are cost-intensive and require significant structural modifications, making them impractical for low-cost motorcycles**.** To address this challenge, we propose a lightweight, detachable liquid cooling system that can be optionally installed without altering the engine's core architecture. The results suggest that the system has strong potential and performs reliably under challenging conditions by enhanced heat dissipation during prolonged high-rpm operation, thereby improving engine durability, fuel economy, and emission compliance. The proposed solution offers a cost-effective and scalable alternative to conventional cooling systems, with potential for widespread adoption in the commuter motorcycle segment.

Keywords: Liquid Cooling, Air Cooled Engine, Heat Transfer.

1 Introduction

Small-displacement, 4-stroke, air-cooled petrol engines are the backbone of commuter motorcycles across India and many other Asian countries. Studies suggest that about 25 to 30 % of fuel energy is lost as heat through the engine's cylinder walls (Dubey, 2015). These engines rely on external fins attached to the cylinder block to dissipate excess heat from the cylinder walls. While this method is simple, lightweight, and cost-effective, its efficiency is constrained by multiple factors, including limited surface area, reduced airflow at low speeds, and high ambient temperatures (Śliwiński et al, 2018; Shehab, 2019). As a result, air-cooled engines often struggle to maintain optimal operating temperatures under demanding conditions.

During demanding conditions such as hill climbing, off-road travel, or navigating congested traffic, the engine operates at high revolutions per minute while the vehicle speed remains low. This decreases airflow across the engine block, significantly reducing the efficiency of the fins. In high ambient temperatures, which are common during summer months across much of Asia, the capacity of the fins to dissipate heat diminishes further. Even during highway riding with increased airflow due to higher speeds, the thermal load from prolonged high-RPM operation often exceeds the cooling capability of fin-based systems, leading to sustained engine overheating.

Engine overheating has several detrimental effects. Elevated engine temperatures accelerate the thermal degradation of engine oil, which serves both as a lubricant and a heat transfer medium (Reyes et al., 2025). This results in reduced lubrication efficiency,

ISBN: 978-93-343-2006-0

increased friction, and accelerated engine wear. Furthermore, overheating can lead to pre-ignition and knocking, which not only damage engine components but also degrade fuel economy and increase emissions. High engine temperatures also reduce the density of intake air, thereby lowering volumetric efficiency and overall engine performance.

To address these issues, we propose an innovative cooling solution that combines the simplicity of oil cooling with the superior performance of conventional liquid cooling. Our approach introduces a detachable, lightweight liquid cooling module capable of dissipating heat at an effective rate from the engine without necessitating significant redesigns of the engine structure. This hybrid cooling system is envisioned as an optional retrofit for existing motorcycles, offering improved thermal performance, extended engine lifespan, enhanced fuel efficiency, and better compliance with increasingly stringent emission regulations.

2 Literature Review

Thermal management in small-sized 4-stroke SI engines is a critical area of study, especially for commuter motorcycles widely employed in developing Asian and African countries. These motorcycles predominantly use air-cooled systems that rely on finned surfaces extending from the cylinder head and block. Babaelahi et al. (2024) found that air cooling is simple and cost-effective; its cooling efficiency is limited by ambient temperature.

Chou et al. (2022) stated that under high-load, low-speed conditions, such as hill climbing or traffic congestion, airflow over the engine is minimal, leading to insufficient heat dissipation in such conditions, the fin-based cooling system becomes thermally saturated, resulting in elevated engine temperatures that affect performance, fuel economy, and longevity. High ambient temperatures further reduce the cooling gradient, compounding the overheating problem.

Engine overheating has been shown to accelerate oil degradation, as lubricating oil also serves as a heat transfer medium. Reyes et al. (2025) found that reduced oil viscosity at high temperatures increases friction and wear. The study conducted by Sahoo (2021) suggests that overheating contributes to pre-ignition and knocking, which cause efficiency losses and increase the risk of engine damage. Furthermore, high temperatures reduce the engine's volumetric efficiency by lowering the intake air's density, thereby compromising combustion stability and increasing emissions

Oil cooling systems have been proposed as a partial solution to enhance thermal management in air-cooled engines. These systems circulate engine oil through external radiators or fins to dissipate excess heat. While relatively inexpensive and easy to implement, a study by Abd Alla (2002) indicates that oil coolers perform well only under moderate thermal load, and often fail to maintain optimal engine temperatures during continuous highload operation.

On the other hand, liquid cooling systems, which are standard in higher-end or performance motorcycles, offer much better control over engine temperature. They involve coolant circulation through passages around the engine block to the radiator. Research by Vasava et al. (2015) shows that such systems significantly improve thermal regulation, engine life, fuel efficiency, and emissions.

However, these systems are expensive and require major engine redesign (Aronson et al., 2020), making them unsuitable for low-cost, mass-market commuter motorcycles

Recent studies have explored hybrid or modular cooling solutions, aiming to balance performance with affordability. For example, thermoelectric coolers and small-scale radiative systems have been suggested, but their adoption is limited by cost, complexity, and power demands. There remains a notable research gap in developing low-cost, detachable, auxiliary cooling systems that can be added to existing air-cooled engines without altering the core engine design. In response to this gap, our

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study proposes a lightweight, detachable liquid cooling system that combines the advantages of oil and liquid cooling technologies.

3 Methodology

3.1 Working process

In this liquid cooling system, the regulation of engine wall temperature is achieved through a closed-loop coolant circulation activated by a digital thermostat module (W1209), which in turn controls the DC-powered R385 diaphragm pump. The process initiates when the temperature of the engine cylinder wall rises to a predetermined threshold. This critical temperature is sensed by a 10kΩ NTC thermistor connected to the thermostat module. Once this threshold is exceeded, the W1209 module activates its onboard relay, thereby supplying current to the R385 coolant pump.Upon activation, the electric pump begins to draw coolant (water) from the coolant tank. The coolant is then passed through a copper tube coil that is mounted on the engine fins. As the coolant passes through the copper coil, it absorbs thermal energy from the engine fins, thereby lowering the local temperature of the engine walls.

Subsequently, the heated coolant exits the coil and is pumped toward the inlet of a radiator. The radiator is positioned in a location exposed to maximum airflow. As the heated coolant flows through the thin channels of the radiator, it is cooled down through convective heat transfer to the surrounding air. The coolant then returns to the coolant tank with a lower temperature than before the inlet of the radiator, ready to be cycled through the system again.

This process forms a continuous thermodynamic cycle that operates as long as the engine wall temperature remains above the set threshold. Once the temperature sensor detects that the engine wall has cooled below the set threshold, the W1209 module deactivates the relay, thereby cutting off power supply to the pump. Consequently, the coolant flow ceases, and the system enters a standby state until the engine temperature rises again. This method of thermal regulation is particularly effective in small-scale engines where precise thermal control is critical as they get heated or cooled much quickly due to there small size.

3.2 Design & Development

The 2013 Bajaj Platina 100 ES was selected for the experimental setup due to its widespread use across India as a commuter motorcycle, making it ideal for practical thermal studies. A custom copper tube-based liquid cooling system was developed to extract heat from the engine block. Copper tubes, chosen for their high thermal conductivity (385 W/m·K), were mounted directly onto the fin surfaces of the engine cylinder block. Heat is transferred from the fins to the coolant (water) through conduction into the copper and convection within the flowing water. Initially, circular copper tubes were tested, but they showed poor thermal performance due to limited contact with the flat fin surfaces. To address this, oval flat copper tubes were used instead. With flat top and bottom surfaces, these tubes achieved approximately 40% surface contact with the fins, significantly improving heat transfer efficiency. This design also enhanced internal convection by increasing the contact area between the water and the tube wall, allowing better heat absorption and higher coolant exit temperatures.

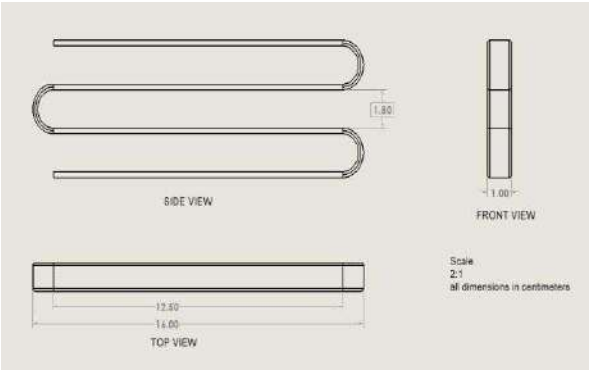


Fig.1. Dimensions of copper tube

The coil, made from a single continuous copper pipe joined by brazing three copper U-bends, was mounted on the engine's right side, where fin temperatures were highest. Each segment of the tube

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measures 12.5 cm in length (16 cm including the U-bends), 1.0 cm in width, and 3 mm in thickness, arranged in four parallel runs with a 1.8 cm gap between them. These tubes were aligned with the existing fin geometry — each fin measuring 11.4 cm in length, 1.8 cm in width, and 3 mm in thickness, with seven fins per cylinder block face.

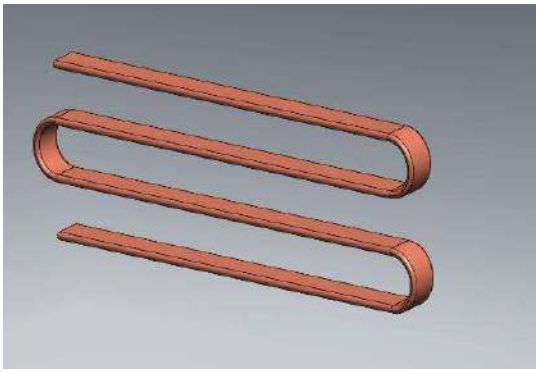


Fig2 Copper tube Coil

During tests, the engine fin surface temperatures ranged from 62°C to 86°C, which are below the boiling point of water. Based on this, clear soft PVC pipes were chosen for connecting components due to their cost-effectiveness and thermal resistance (80°C to 100°C). With outer and inner diameters of 7.85 mm and 4 mm, respectively, these pipes were cut to size and connected using short copper tube connectors for secure, leak-free joints. The coolant tank used in the system was originally designed for the Yamaha MT-15 and selected for its compact and ergonomic shape. Mounted below the crankcase to stay clear of engine heat, the plastic tank remained both protected and easily accessible for maintenance. For heat dissipation, an aluminium radiator from a Bajaj Maxima 3-wheeler was selected. Compact and lightweight at 285 g, it features a multi-louvred fin design and six parallel tubes, measuring 20 cm in length,

7.5 cm in height, and 3 cm in width. It was mounted just above the front wheel, beneath the handle T and in front of the leg guard, to receive maximum airflow during motion.

To circulate the coolant, a 12V R385 DC diaphragm pump was used. With a maximum flow rate of 3 litres per minute and temperature tolerance up to 80°C, it offered reliable performance for this compact system. An automatic electric control was implemented using a W1209 temperature controller module and a 10kΩ NTC thermistor. The sensor, mounted on the engine wall, activates the pump via relay once a preset temperature is exceeded, ensuring cooling is delivered only when needed and conserving battery power during low-demand operation.

4 Experimental Setup

Thermal performance tests were conducted on a Bajaj Platina 100 ES (2013) model in both air-cooled and liquidcooled configurations. For baseline testing, temperature sensors were placed on the cylinder block's fins where the liquid cooling tubes would later be installed. The motorcycle was ridden on the highway at speeds of 50, 60, and 70 km/h, each for at least 1 hour, to ensure that the thermal stability is achieved. Six sessions were conducted under varying ambient temperatures, and fin surface temperatures were recorded.

After baseline tests, the engine was retrofitted with the copper tube-coil on 4 adjacent fins to run the liquid cooling system. Sensors were placed at the radiator inlet and outlet, and at the air outlet of the radiator. Ambient temperatures were logged before and after each test.

The coolant flow rate was fixed at 1.5 L/min; tests were repeated under identical conditions of 50, 60, and 70 km/h, each sustained for at least 1 hour, with six sessions performed across various ambient temperatures. All sensor data were collected for analysis. The effective cross-sectional area of the radiator is 17cm ×7.5cm.

5 Results and Discussion

The results of fin performance were calculated using the fin equation for the short fin with non-isolated tip, found in air-cooled engines and for liquid cooling setup Effectiveness NTU method for Cross flow Heat Exchanger equation is used

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In real real-world scenario, the convective heat transfer coefficient *h* will not be the same at every location on the cylinder block due to the geometry and orientations of the fin. Studies (Łęcki et al.,2021) show that the maximum convective heat transfer happens on the side faces of the engine block where fins are arranged parallel to the airflow. As the calculations is done for the fins located on the right side, this will give the maximum possible rate of heat transfer. A close approximation of the maximum possible heat transfer by the fins can be obtained.

In the air-cooling performance analysis, the results revealed that the maximum possible heat transfer from the fin surfaces occurred at an air speed of 70 km/h, yielding a total of 349.44 watts when considering all sides of the cylinder block. This corresponds to approximately 12.48 watts per fin, as each face has a total of 7 fins. The observed heat transfer rate is consistent with typical values reported for fins in conventional air-cooled engine configurations (Agarwal et al., 2024). As the speed of the motorcycle increased, the wall base temperature also rose, primarily due to the higher combustion rate within the engine cylinder. **Table 1.** Air cooling performance experimental data

Heat Test No.	Air Speed (km/h)	Wall Base Temperature (°C)	Ambient Temperature (°C)	Max Heat Rejected (W)	Heat Rejected (W)
1	50	96.0	37.5	8.09	226.52
2	60	113.0	42.1	10.27	287.56
3	50	104.0	40.4	8.83	247.24
4	70	116.0	37.8	12.48	349.44
5	60	94.0	33.1	9.21	257.88
6	50	96.7	37.8	8.25	231.00

This elevated temperature, while increasing the thermal energy available for dissipation, also exceeded the fins' capacity to effectively reject heat, leading to a further rise in wall temperature. Consequently, enhanced heat dissipation from the extended surfaces was observed.

However, with increasing ambient temperatures, the wall temperature increased further, as the thermal gradient between the fin surface and the surrounding air diminished, thereby reducing the fin's cooling effectiveness.

Following the integration of a copper flat tube coil onto the fin surfaces, experimental tests were conducted under ambient temperature conditions ranging from 33.1 °C to 42.1 °C and air velocities between 50 km/h and 70 km/h. The results indicate that the maximum heat dissipation to the ambient air was achieved at an air speed of 60 km/h and an ambient temperature of 33.1 °C, with a total heat rejection of 584.6 watts.

Table 2. Experimental Data of the liquid cooling setup

Case	Air Velocity Outlet Temp (°C)	Air (km/h)	Heat Ambient Rejected (W)	Temp (°C)	Coolant Effectiveness	Coolant Inlet (°C)	UA Outlet (°C)	NTU	(W/K)
1	50	40.4	52.1	48.1	44.1	418.6	0.34	0.41	43.7
2	50	37.8	52.1	47.7	40.2	460.4	0.308	0.36	38.5
3	50	37.5	52.7	47.9	40.1	501.6	0.316	0.43	44.9
4	60	42.1	57.2	52.8	44.1	460.4	0.292	0.38	38.7
5	60	33.1	43.3	37.7	35.5	584.6	0.548	0.97	101.3
6	70	37.8	47.8	43.7	39.4	428.5	0.41	0.59	61.7

At a higher ambient temperature of 42.1 °C and thesame air speed of 60 km/h, the heat transfer ratedecreased to 460.4 watts. The same Heat Transfer rate was observed for Case 2 with an effectiveness of 0.308. The lowest heat dissipation was observed at an air speed of 50 km/h and an ambient temperature of 40.4 °C, where only 418.6 watts

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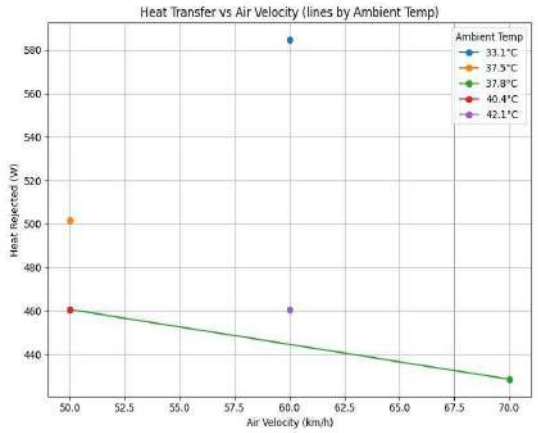


Fig 3. Graph of heat trasnfer vs ambient air temperature

of heat were rejected. The calculations were done using Effectiveness NTU method for crossflow heat exchangers with both fluid unmixedThe graph **(Fig 3)** indicates that with increasing ambient temperature, the cooling capacity of the system decreases due to less thermal gradient between the ambient air and hot fluid side.

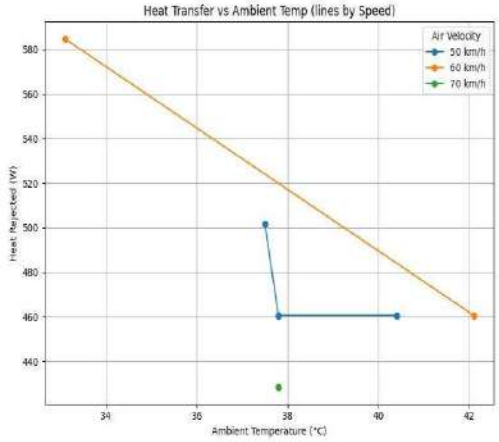


Fig 4. Graph of heat trasnfer vs air velocity

Graph **(Fig 4)** clearly shows that an increase in air flow over radiator does not affect the overall heat dissipating capacity as much change in ambient temperature, this mean to further improve heat rejection either radiator size or the thermal gradient between hot fluid and cold fluid must be increased**,** which can be done by adding more tubes on to the fins. These findings demonstrate the effectiveness of the liquid cooling system, particularly under elevated ambient temperatures and high thermal load conditions, with an average performance drop of 25% in most challenging conditions, which is acceptable considering it's an early stage of design & development. The system shows strong potential in enhancing the thermal regulation of the engine. Furthermore, it is anticipated that greater heat transfer could be achieved by attaching the copper tube coil to the fins of all 4 sides of the cylinder wall. The combined action of liquid cooling and fin-assisted air cooling significantly.improves the system's ability to maintain optimal engine temperature, especially during extreme environmental conditions and high-load operation.

6 Conclusion

The detachable liquid cooling system demonstrated commendable performance under extreme operating conditions and high thermal loads. While the system effectively dissipates heat from the engine, its overall efficiency is currently constrained by the geometry of the engine cylinder block and the existing fin structure. Enhanced heat removal could be achieved by reconfiguring the attachment of the copper tubes, specifically by affixing them directly to the cylinder wall or by extending the attachment to additional fins on multiple surfaces of the cylinder block. This would increase the effective surface area in contact with the coolant, thereby improving thermal absorption and overall cooling performance.

Moreover, the proposed cooling system offers significant advantages in terms of manufacturability and integration. It is both straightforward to produce and economically viable for use in commuter motorcycles, especially when compared to other, more complex cooling solutions. By effectively lowering the cylinder wall temperature, the system contributes to more efficient combustion, reduced internal friction, and improved lubrication. These benefits collectively enhance engine performance by reducing knocking, improving fuel efficiency, less emissions, and long-term durability, particularly under sustained heavy usage. The results of this project thus support the feasibility of deploying such a system as a practical and cost-effective thermal management solution in small-displacement internal combustion engines.

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Further research on improving the overall capacity and efficiency needs to be done to make it suitable for implementation in Commuter bikes

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INFLUENCE OF PROCESS PARAMETERS ON THE QUALITY OF RESISTANCE SPOT WELDED JOINTS: A COMPREHENSIVE REVIEW

Amol S. Adkine [1, 2, 3*][0000-0001-7828-0143] **and Shantisagar K. Biradar** [4] [1]

Department of Mechanical engineering, Dr. Babasaheb Ambedkar Marathwada University, Chhatrapati Sambhajinagar, Maharashtra, India [2] Department of Mechanical Engineering, Maharashtra Institute of Technology, Chhatrapati Sambhajinagar, Maharashtra, India [3] Department of Mechanical engineering, Hi-Tech Institute of Technology, Chhatrapati Sambhajinagar, Maharashtra, India [4] Department of Mechanical engineering, Matsyodari Shikshan Santha's College of Engineering, Jalna, Maharashtra, India

Corresponding author: amoladkinehit@gmail.com

Abstract

Resistance Spot Welding (RSW) is a widely utilized joining technique in industries such as automotive, aerospace, and medical device manufacturing, owing to its high efficiency, automation potential, and cost-effectiveness. This review provides a comprehensive analysis of the influence of key process parameters—welding current, welding time, electrode force, and electrode tip geometry on the quality and mechanical performance of RSW joints, with a focus on materials like AISI 316L stainless steel. Each parameter's role in heat generation, nugget formation, and microstructural evolution is discussed in detail, along with associated risks such as expulsion, porosity, and excessive indentation. The paper also explores the complex interdependencies between parameters and how their interactions impact weld integrity. Comparative tables summarize recent findings from the literature, and optimization methodologies, including design of experiments (DOE), finite element modeling, and machine learning techniques, are highlighted as effective tools for developing robust welding schedules. This review underscores the necessity of precise parameter control and advanced modeling to ensure high-quality, defect-free spot welds in critical applications.

Keywords: Welding Parameters, AISI 316L Stainless Steel, Electrode Tip Geometry, Process Optimization, Weld Nugget Formation

1. Introduction

Resistance Spot Welding (RSW) is a prominent and widely adopted joining process across various industrial sectors, including but not limited to automotive, aerospace, electronics, and medical device manufacturing [1, 2]. Its widespread application is largely attributed to its inherent advantages such as high efficiency, rapid processing speed, cost-effectiveness, and ease of automation [3, 4]. The fundamental principle of RSW involves generating localized heat at the interface of two or more metal sheets through their electrical resistance, subsequently fusing them together under controlled mechanical pressure [5, 6]. This process creates a localized molten zone, known as the weld

nugget, which solidifies to form a strong metallurgical bond.

The quality, integrity, and mechanical performance of resistance spot-welded joints are profoundly influenced by a complex interplay of numerous process parameters [7, 8]. Variations in these parameters can significantly alter the heat generation, nugget formation kinetics, microstructure evolution within the weld and surrounding heat-affected zones (HAZ), and consequently, the ultimate mechanical properties such as tensile-shear strength, peel strength, fatigue life, and corrosion resistance of the welded specimens [5, 9, 10]. Understanding and precisely controlling these parameters are critical for achieving consistent, high-quality welds and preventing defects. This review article aims to provide a comprehensive overview of the influence of key process parameters on the characteristics and performance of resistance spot-welded joints, drawing upon recent scholarly research. This updated version includes a more detailed discussion on the interactions between parameters, including comparative tables.

2. Fundamentals of Resistance Spot Welding

RSW operates on the principle of Joule heating, where heat (Q) is generated by the passage of an electric current (I) through a material with electrical resistance (R) over a specific time (t), as described by the formula $Q = I^2Rt$ [5, 11]. In the context of RSW, the heat is primarily generated at the faying surfaces (the interfaces between the workpieces) due to their inherent contact resistance, and to a lesser extent, within the bulk material due to its resistivity.

The process typically involves several stages:

1. *Squeeze Time:* Electrodes clamp the workpieces together, applying a predetermined force to ensure good electrical contact and minimize initial contact resistance.
2. *Weld Time:* A high welding current is passed through the clamped workpieces, generating intense heat at the faying surfaces. This heat melts the material, forming a molten nugget.
3. *Hold Time (or Forge Time):* After the current is switched off, the electrode force is maintained or increased (forging force) to consolidate the molten nugget during solidification, preventing porosity and cracking.
4. *Off Time (for multiple spots):* A brief interval between successive welds in a series.

The successful formation of a strong weld nugget depends on achieving an optimal balance of heat generation and dissipation, which is directly controlled by the various process parameters.

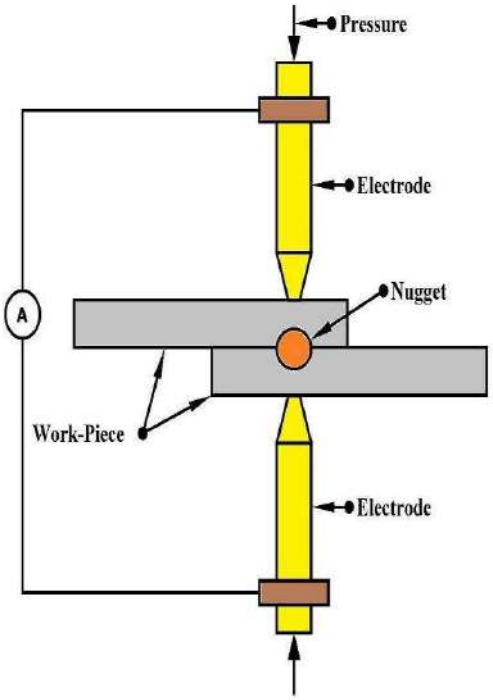


Figure 1: Schematic illustration of the Resistance Spot Welding (RSW) process [12]

3. Key Process Parameters and Their Influence

3.1. Welding Current

The welding current is widely recognized as the most critical and influential parameter in the RSW process [11, 12, and 13]. It directly dictates the rate and magnitude of heat generation at the interface between the workpieces. As per Joule's law, the heat generated is proportional to the square of the current, implying that even small changes in current can lead to significant variations in heat input [5, 11].

- *Influence on Nugget Formation and Size:* An increase in welding current generally leads to a higher rate of heat generation, resulting in a larger and more robust weld nugget [14, 15]. This is because more material melts and fuses, contributing to a larger fusion zone. Studies on various stainless steels, including AISI 316L, have consistently shown that an increase in welding current within an appropriate range enhances the nugget diameter and improves the overall tensile-shear strength of the joint [14, 16, 17].
- *Influence on Mechanical Properties*: Higher welding currents, up to an optimal point, typically improve the mechanical properties such as tensile-shear strength and peel strength due to the formation of a larger and more consistent weld nugget [15, 16].
- **Risks of Improper Current**:
    i. ***Too Low Current:*** Insufficient current leads to inadequate heat generation, resulting in small, weak weld nuggets, or even no fusion at all (stick welds) [12, 19]. This can lead to interfacial fracture during mechanical testing.
    ii. ***Too High Current:*** Excessive current causes rapid and excessive heat generation, leading to phenomena like expulsion (molten metal expulsion), severe surface indentation, and excessive electrode wear [12, 17, 19]. Expulsion results in a loss of material from the weld nugget, leading to porosity, reduced nugget size, and compromised joint strength and appearance. It can also cause spatter, which is undesirable in many applications.

Therefore, identifying and maintaining the precise optimal welding current is paramount for achieving a robust, defect-free, and mechanically sound weld.

Table 1: Comparative Summary of Studies on Welding Current Influence

Reference	Material(s) Welded	Key Findings on Welding Current Increase	Observed Effects on Weld Quality/Properties
[14, 16]	AISI 316L	Increases heat generation and nugget size	Enhanced nugget diameter, improved tensile-shear strength.
[15]	DP600 steel	Increases heat input	Improved mechanical properties (tensile-shear, peel strength).
[13]	TRIP steel	Affects weld formation and microstructure	Influences nugget size and overall weld quality.
[19]	Low carbon steel	Increases nugget growth	Improved tensile strength, but excessive current leads to expulsion.
[17]	Various steels	Increases heat input	Can lead to expulsion, severe indentation, and electrode wear if too high; weak welds if too low.

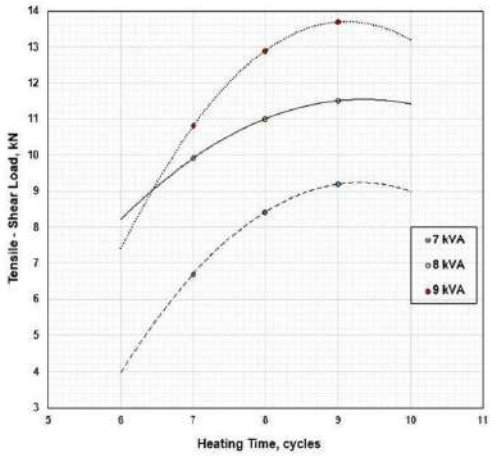


Figure 2: Effect of welding current and heating time on tensile-shear strength [20]

3.2. Welding Time

The welding time, defined as the duration for which the welding current is allowed to flow, is another critical parameter that directly controls the total cumulative heat input into the weld zone [20, 21]. In conjunction with the welding current, it dictates the thermal cycle experienced by the material, thereby influencing the kinetics of nugget growth and the characteristics of the surrounding heataffected zone (HAZ) [10].

- ***Influence on Nugget Formation and Size****:* A sufficiently long welding time is indispensable to allow for adequate heat accumulation, material melting, and subsequent nugget formation and growth to ensure proper fusion and metallurgical bonding between the workpieces [22, 23]. As welding time increases, the heat input increases, leading to larger nugget diameters and improved joint strength, up to a certain point [20, 24].
- ***Influence on Microstructure and Mechanical Properties****:* The duration of heat input affects the cooling rate and solidification behavior of the weld nugget, influencing its microstructure (e.g., grain size, phase distribution) and consequently the mechanical properties. For stainless steels like AISI 316L, controlled cooling rates are important to manage the formation of undesirable phases like delta ferrite or carbides, which can affect corrosion resistance and ductility [6, 25].
- **Risks of Improper Time**:
  - i. ***Insufficient Welding Time****:* Leads to inadequate heat input, resulting in small, weak, or entirely absent weld nuggets, leading to significantly compromised weld strength and potential interfacial fracture [22, 23].
  - ii. ***Excessive Welding Time****:* Can lead to undesirable overheating, increased propensity for expulsion, greater electrode degradation and wear, and excessive

indentation of the workpiece [20, 24]. Prolonged heating can also cause excessive grain growth in the HAZ, potentially reducing its mechanical properties and corrosion resistance.

Thus, meticulous control over welding time is essential for optimizing the mechanical and metallurgical properties of the weld, ensuring a balance between sufficient nugget formation and avoiding overheating defects.

Table 2: Comparative Summary of Studies on Welding Time Influence

Reference	Material(s) Welded	Key Findings on Weldi Time Increase ıg	Observed Effects on Weld Quality/Properties
[22]	AISI 316L	Increases heat input	Improved mechanical properties (tensile-shear, corrosion resistance).
[23]	AISI 316L	Affects microstructure mechanical and properties	Influences grain size and overall strength.
[21]	DP980 steel	Increases heat input	Affects microstructure and mechanical properties.
[32]	Galvanized steel	Affects mechanical properties	Can improve strength, but excessive time leads to degradation.
[24]	HSLA steel	Affects microstructure and mechanical properties	Influences nugget size and strength, with risk of overheating.

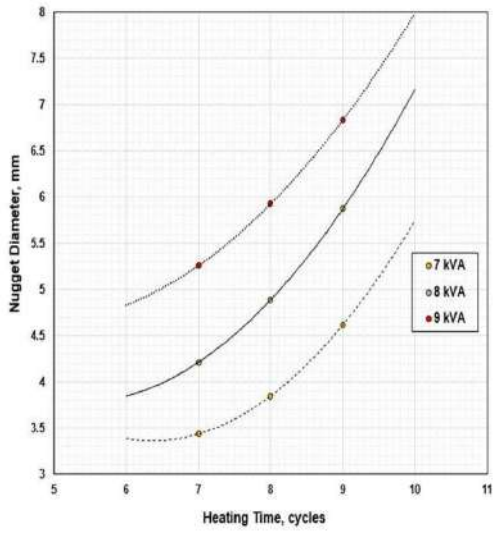


Figure 3: Influence of welding current on weld nugget size of AISI 316L [20]

3.3. Electrode Force

The **electrode force**, also known as electrode pressure, plays a pivotal and multifaceted role throughout the RSW process. Its primary function is to control the contact resistance at the faying surfaces (the interfaces between the sheets to be joined) and to ensure efficient and stable electrical contact [28, 30].

- **Influence on Contact Resistance and Heat Generation**: An appropriately applied electrode force is fundamental for generating the necessary heat for welding through electrical resistance. Initially, a higher force can reduce the contact resistance, promoting a more uniform current distribution and reducing localized overheating [29]. However, the relationship is complex; very high forces can flatten surface asperities too much, leading to a very low contact resistance and insufficient heat generation for a given current, thus delaying or preventing nugget formation [29, 31].

- **Influence on Nugget Consolidation and Defects**: During the hold time, the electrode force (often referred to as forging force) is crucial for consolidating the molten nugget, preventing porosity, and refining the grain structure during solidification [28, 33]. Proper forging action helps to squeeze out any trapped gases and reduces shrinkage voids.

- **Risks of Improper Force**:

i. **Too Low Force**: If the applied force is too low, the contact resistance can become excessively high, leading to inconsistent heat generation, localized arcing, splashing (expulsion), and potentially porous welds or even complete failure to form a weld [28,

30]. This can also result in poor nugget shape and size.

ii. **Too High Force**: Conversely, an excessively high electrode force can lead to a very low contact resistance, insufficient heat generation for fusion, and excessive indentation of the workpiece [29, 31]. It can also cause thinning of the material around the weld, leading to stress concentration and premature failure.

Optimizing electrode force is therefore critical for achieving consistent nugget formation, minimizing defects, and ensuring the mechanical integrity of the weld. Dynamic force profiles, where the force is varied during the welding cycle, are also being explored to further optimize the process [34].

Table 3: Comparative Summary of Studies on Electrode Force Influence

Reference	Material(s) Welded	Key Findings on Electrode Force Increase	Observed Effects on Weld Quality/Properties
[28]	Pure Titanium	Affects weldability and heat generation	Influences nugget size and mechanical properties.
[30]	Low carbon steel	Influences contact resistance	Affects nugget diameter and mechanical properties.
[35]	AISI 304	Affects microstructure and mechanical properties	Can reduce porosity and improve strength, but too high leads to low heat.
[31]	Galvanized steel	Affects mechanical properties	Influences nugget size and strength.
[33]	Galvanized HS steel	Influences microstructure and mechanical properties	Affects nugget size and strength, with risk of thinning.

3.4. Electrode Tip Geometry

The electrode tip geometry is another crucial parameter that profoundly influences the current density distribution and the overall heat generation pattern at the weld interface [36, 37]. The shape and size of the electrode tip determine the contact area between the electrode and the workpiece, which in turn affects the current path and heat concentration.

- ***Influence on Current Density and Heat Concentration***: Different electrode shapes (e.g., dome, truncated cone, flat, radius-faced) distribute the welding current over varying contact areas, thereby directly affecting the local current density and the subsequent heat generation profile [36, 38]. For instance, an electrode with a smaller face diameter or a sharper radius concentrates the current into a more confined area, resulting in a higher current density and faster heating. This can be advantageous for forming smaller, stronger welds or for welding thinner sheets [17, 36].
- ***Influence on Nugget Shape and Size***: The electrode geometry directly influences the shape and size of the weld nugget. A properly designed electrode tip ensures that the heat is concentrated at the desired location, leading to a well-formed and consistent nugget.
- ***Influence on Electrode Life and Indentation***: While smaller contact areas can promote faster heating, they also lead to higher pressure on the workpiece, potentially causing increased indentation and more rapid degradation and wear of the electrode tip [38, 39]. Conversely, larger electrode faces distribute the current over a wider area, leading to lower current density and slower heating, which might necessitate higher welding currents or longer welding times to achieve sufficient heat for fusion. This can reduce indentation but might require more energy input.
- ***Influence on Cooling Rate***: The electrode geometry also impacts the cooling rate of the weld nugget, as the electrodes act as heat sinks. This

influences the final microstructure (e.g., grain size, phase distribution) and consequently the mechanical properties of the joint [37].

Effective electrode design requires a careful balance between achieving desired mechanical and thermal properties, controlling indentation, and maximizing electrode life.

Table 4: Comparative Summary of Studies on Electrode Tip Geometry Influence

Reference	Material(s) Welded	Key Findings on Electrode Tip Geometry	Observed Effects on Weld Quality/Properties
[36]	Various steels	Affects current density distribution	Influences heat generation, nugget shape, and size.
[37]	Various materials	Influences heat generation and nugget formation	Affects nugget size, shape, and overall weld quality.
[38]	Various materials	Affects contact area and current density	Influences mechanical properties and indentation.
[39]	Various materials	Influences heat generation and nugget formation	Affects nugget size, shape, and overall weld quality.
[17]	AISI 304/316L	Can be optimized for specific applications	Influences tensile-shear strength and failure modes.

3.5. Other Important Parameters

While welding current, time, electrode force, and tip geometry are primary, several other parameters also contribute to the overall RSW process quality:

- ***Squeeze Time**:* The time duration from the initial application of electrode force until the welding current begins to flow. It allows the electrodes to properly seat and the workpieces to be firmly pressed together, reducing initial contact resistance and ensuring consistent heat generation [40].
- ***Hold Time (or Forge Time)**:* The time during which the electrode force is maintained after the welding current is switched off. This period is crucial for the solidification of the weld nugget under pressure, preventing porosity, shrinkage voids, and cracking, and improving the mechanical properties [40, 41].
- ***Material Properties**:* The type of material (e.g., stainless steel, carbon steel, aluminum alloys), its thickness, electrical resistivity, thermal conductivity, and surface condition (e.g., cleanliness, oxide layers, coatings) significantly influence the heat generation and weldability [42, 43].
- ***Electrode Material**:* The material of the electrodes (typically copper alloys) and their cooling efficiency affect heat dissipation and electrode life [44].
- ***Surface Condition**:* The presence of oxides, oils, or other contaminants on the workpiece surfaces can drastically alter contact resistance, leading to inconsistent welds or expulsion [43].

4. Interactions between Parameters

It is crucial to recognize that the aforementioned process parameters are not isolated in their effects; rather, they exhibit complex interdependencies that significantly influence the final weld quality. Optimizing one parameter without considering its interaction with others can lead to suboptimal results or even defects. Understanding these intricate relationships is vital for developing robust welding schedules and achieving consistent, high-quality spot welds.

The combined effect of parameters often dictates the overall heat input and its distribution, which in turn controls the nugget formation, microstructure, and mechanical properties. Here are some key interactions:

- ***Welding Current and Welding Time**:* These two parameters are directly proportional to heat generation ($Q =$

I^2Rt). An increase in welding current can often be compensated by a decrease in welding time to maintain a similar heat input, preventing overheating and expulsion [23, 24]. Conversely, for materials with higher electrical resistivity or thicker sections, both current and time might need to be increased. This interaction is often visualized using a welding lobe diagram, which defines the acceptable range of current and time for a given material and thickness, bounded by expulsion at high energy and insufficient fusion at low energy.

Example: If the current is too low, increasing the time might help form a weld, but it could also lead to excessive heating of the electrodes rather than the faying interface. If the current is very high, even a short time might cause expulsion.

- ***Welding Current and Electrode Force****:* These two parameters have a complex relationship with contact resistance. Higher electrode force generally decreases contact resistance, which for a constant current, would reduce heat generation. However, a higher force also improves the contact area and stability, which can be beneficial. For higher welding currents, an increased electrode force might be necessary to manage the higher heat input effectively and prevent expulsion by providing better consolidation of the molten metal [29, 30].

  Example: If the current is high, but the force is too low, expulsion is very likely due to rapid localized heating and insufficient pressure to contain the molten metal. If the force is too high, the initial resistance might be too low to generate enough heat, even with a high current.

- ***Electrode Force and Electrode Tip Geometry****:* The electrode tip geometry defines the initial contact area, while the electrode force determines the actual pressure applied over this area. A smaller tip diameter (e.g., a pointed electrode) concentrates the force and current, leading to higher current density and faster heating, but also higher indentation and faster wear [38, 39]. A larger tip distributes the force and current more broadly. The interplay here affects how efficiently heat is generated at the interface versus being dissipated into the electrodes or causing surface defects.

  Example: Using a small electrode tip with very high force can lead to severe indentation and rapid electrode degradation. A larger tip might require higher current or longer time to achieve the same nugget size.

- ***Material Properties and All Parameters****:* The specific material properties (thickness, electrical resistivity, thermal conductivity, melting point, surface condition) significantly dictate the optimal range for all other process parameters. For instance, aluminum alloys, with their high electrical and thermal conductivity, require much higher currents and shorter times compared to stainless steels to achieve a weld nugget [42]. Surface coatings (e.g., galvanization) also alter contact resistance and necessitate specific parameter adjustments [43].

Table 5: Examples of Interdependent Effects of RSW Parameters

Reference	Parameter A Changed	Parameter B (Interacting)	Effect on Parameter B's Role / Overall Weld Quality
[23, 24]	Increased Current	Reduced Weld Time	Can maintain optimal heat input, preventing overheating/expulsion.
[29, 30]	Increased Current	Increased Electrode Force	Helps contain molten metal, reduces expulsion risk, improves consolidation.
[29, 35]	Decreased Force	Increased Current	May lead to expulsion due to high contact resistance and insufficient forging.
[36, 38]	Sharper Electrode Tip	Reduced Current/Time	Can achieve target nugget size with less energy due to higher current density.
[42]	Thicker Material	Increased Current/Time	Necessary to achieve sufficient heat input for larger nugget volume.
[43]	Contaminated Surface	Increased Current/Time	May lead to inconsistent welds, expulsion, or poor fusion due to erratic contact resistance.
[20, 35]	Increased Welding Time	Decreased Electrode Force	Increased risk of expulsion and defects due to insufficient containment of molten metal.
[38, 39]	Dull/Worn Electrode Tip	Increased Welding Current	Compensates for reduced current density but increases indentation and wear.
[42]	Increased Material Thickness	Increased Electrode Force	Necessary for maintaining proper contact and consolidating larger nuggets.
[40]	Increased Squeeze Time	Reduced Initial Contact Resistance	Allows for more stable heat generation and less initial expulsion.
[41]	Increased Hold Time	Reduced Porosity/Cracking	Improves nugget consolidation and grain refinement.

Understanding these interactions is vital for developing robust welding schedules and avoiding trialand-error approaches. Advanced techniques such as Design of Experiments (DOE), Response Surface Methodology (RSM), and Artificial Neural Networks (ANN) are often employed to systematically study and optimize these complex interactions [17, 45]. These methods help in mapping the multidimensional parameter space to predict and achieve desired weld characteristics efficiently.

5. Methods for Parameter Optimization

To effectively understand and optimize the influence of process parameters in RSW, various methodologies are employed:

- ***Experimental Design (DOE)***: Techniques like Taguchi methods and Factorial designs allow for systematic investigation of multiple parameters and their interactions with a reduced number of experiments [7, 46]. This helps in identifying the most significant parameters and their optimal levels for desired weld characteristics.
- ***Statistical Analysis***: Tools such as Analysis of Variance (ANOVA) and Regression Analysis are used to analyze experimental data, quantify the contribution of each parameter, and develop empirical models for predicting weld quality [7, 45].
- ***Numerical Simulations (FEM)***: Finite Element Method (FEM) simulations provide a powerful tool for analyzing the coupled thermo-electrical-mechanical phenomena during RSW [1, 47]. These simulations can predict temperature distribution, nugget growth, stress development, and deformation, offering insights that are difficult to obtain experimentally and aiding in process optimization without extensive physical trials.
- ***Artificial Intelligence (AI) and Machine Learning (ML)***: Techniques like Artificial Neural Networks (ANN), Fuzzy Logic, and Genetic Algorithms are increasingly used for modeling

complex relationships between process parameters and weld properties, leading to intelligent optimization strategies [17, 45].

6. Conclusion

Resistance spot welding is a highly efficient and versatile joining process, particularly for materials like AISI 316L stainless steel, which are critical in various high-performance applications. The quality and mechanical integrity of RSW joints are profoundly dependent on the precise control and optimization of several key process parameters. Welding current, welding time, electrode force, and electrode tip geometry are fundamental in dictating the heat input, nugget formation, microstructure evolution, and ultimately, the mechanical performance of the welded specimens.

Comprehensive studies, leveraging both experimental methodologies and advanced computational tools, are essential for unraveling the complex interdependencies among these parameters. By understanding how each parameter influences the weld characteristics and how they interact, engineers and researchers can establish robust welding schedules, predict weld quality with greater accuracy, and mitigate common welding defects. Continued research in this area, particularly incorporating advanced modeling and optimization techniques, will further enhance the reliability, efficiency, and broader applicability of resistance spot welding for AISI 316L and other advanced materials in critical engineering designs.

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Unveiling the Drivers of Ikea Product Pricing: A Random Forest Analysis

Abhi Desai
New England College, Henniker, New Hampshire, US
adesai_gps@nec.edu | desai.abhi94@gmail.com

***Abstract*—A comprehensive analysis of Ikea product pricing is conducted using a dataset scraped from the Saudi Arabian Ikea website, focusing on features such as price, dimensions, category, and designer. By applying Random Forest regression, the research evaluates the relative importance of various product attributes in predicting price variations. Key factors such as the product's size, design, and categorization are examined to understand their impact on cost. The results offer a nuanced understanding of how different features contribute to the pricing structure, highlighting the effectiveness of machine learning tech- niques in extracting meaningful insights from complex product data. The study also explores how retailers can leverage such analysis to optimize pricing strategies and improve product positioning in competitive markets.**

I. Introduction

This project report is an examination at the Hamburg School of Business Administration in the module 'Data Business' as a part of a Bachelor of Science degree program. The students were given a data set, and the task was to first explore the data and then choose a research question that was to be answered scientifically with the help of the statistical programming language R. The authors of this report were given a data set that contains Ikea products with different features, such as price, dimensional measures, name, category, and designers of the product.

II. Data Set

The data set was obtained by a kaggle.com user (Reem Abdulrahman) using web scraping techniques from the Saudi Arabian Ikea website in the furniture category on April 20, 2020. Noteworthy features include the name, category, price in Saudi Riyals, designer, and dimensions (width, height, and depth). The data set has 13 variables and 2962 distinct observations after the removal of duplicates.

III. Theoretical Background

A. Random Forest Basics

In order to analyze the feature importance in relation to the price variable, a random forest regression model was chosen, a random forest consists of many decision trees, which predicts the response variable based on a majority decision process. In standard decision trees, each node is split to achieve the best- performing model. In random forests, however, the nodes are randomly split. Compared to linear regression, random forests not only take the mean and covariance structure into account but also include deeper aspects of the data.

B. Overfitting

In statistical modeling, overfitting refers to the phenomenon where an analysis model corresponds too closely to a given data set and thus fails to generalize to new data or future observations.

C. Feature Importance

There are different ways to measure feature importance. In this analysis, permuting feature importance by a random forest algorithm is used. This algorithm leaves each feature out once while leaving all others unchanged, at each step calculating the mean squared error (MSE) of the predictions. This is done for every tree, calculating the overall MSE of each feature for the whole model.[1]

IV. Research Question

This paper explores the following research question:

How important are the different features of Ikea products in regard to their price?

The motivating forces for this research question are the possible implications for the price determination of new items. Methods

V. Data Cleaning and Transformation

To examine the given data set properly, the authors first had to restructure and reformat it. This initial data-cleaning step included type conversion, value mutation, the addition of newly calculated fields, and the removal of irrelevant columns. Concretely, `name`, `category`, and `designer` were converted to categorical variables. In the `designer` column, blank strings and values prefixed by "IKEA of Sweden" were converted to missing values (`NA`). Furthermore, both the price and old price were converted to double values, and the currency was changed from Saudi Arabian Riyals to Euros based on the exchange rate from the time the data set was
obtained by the author (See section **??**).

Interestingly, the data set had a peculiarity where some rows were exact duplicates except for values in the `category` vector. The authors considered multiple approaches to handle these data duplications without losing information about the category of an item.

One considered option was to merge the two category values into one column value via comma separation (e.g., `"a"` and `"b"`

[1] Ibid., 23.

converts to `"a, b"`). However, this approach leads to the creation of many combinatorial categories with a low count of items per category. Additionally, it reduces the item count per category where the category is not comma separated. Overall, this would lead to having many small categories, which increases the difficulty in applying a regression model due to overfitting (See section III-B).

The second option was to create separate columns for the different values of `category`. The data set would then have observations with categories one, two, and three. While no information is lost utilizing this approach, most observations in the second and third category column would contain missing values, thus increasing the difficulty of analysis using a predefined model (See section VII).

The authors chose the option of selecting the observations where the category count occurred most frequently when considering duplicates. The most frequent categories could be
retained without including more column vectors in the data set, as in option two.

To better facilitate the comparison of the different sizes of furniture items, the size in cubic meters was computed based on the depth, width, and height values and added as a column vector for further analysis.

Finally, the authors only selected columns that could have a potential impact on the outcome of the analysis (See section IV) for further investigation. A detailed comparison of the initial vs. transformed data structure can be seen in tables **??** and II.

TABLE I
INITIAL DATA SET FORMATTING

Name	Category	Price (SR)	Old Price	Online	Other Colors
PAX...	Wardrobes	20450	No old price	Yes	No ...
ELV...	Wardrobes	7500	SR 820	Yes	No ...
ELV...	Wardrobes	15720	SR 1,755	Yes	No ...
ELV...	Wardrobes	9240	SR 1,050	Yes	No ...
ELV...	Wardrobes	27450	SR 3,130	Yes	No ...
ELV...	Wardrobes	12310	SR 1,535	Yes	No ...

TABLE II
COMPACT TRANSFORMED DATA SET

Name	Category	Price (EUR)	Old Price	Designer	Size (mS)
PAX...	Wardrobes	501.78	–	Ehle´n...	3.12
ELV...	Wardrobes	184.03	201.20	Ehle´n...	–
ELV...	Wardrobes	385.72	430.62	Ehle´n...	–
ELV...	Wardrobes	226.72	257.64	Ehle´n...	–
ELV...	Wardrobes	673.54	768.01	Ehle´n...	–
ELV...	Wardrobes	302.05	376.64	Ehle´n...	–

VI. EXPLORATORY DATA ANALYSIS

The following sections explore our data based on the eight-step data exploration protocol proposed by Zuur et al.[2]

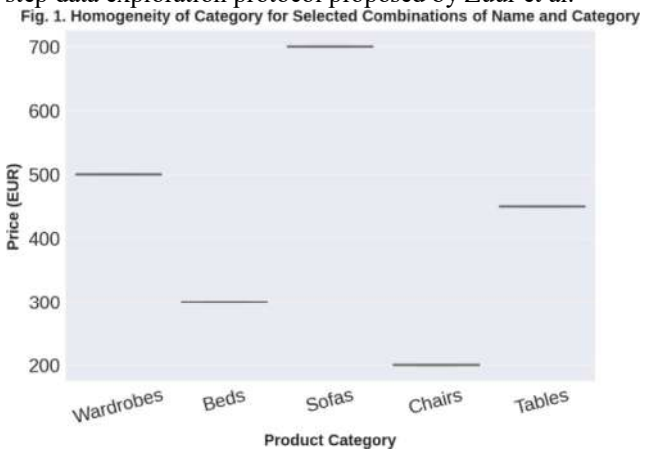


Fig. 1. Homogeneity of Category for Selected Combinations of Name and Category

A. Step 1: Outliers in Price and Independent Variables

Outliers of the chosen variables can be observed for each variable (see figure **??**). The web scraping code is written in a generic form, making it generalizable to all applied pages. This removes the occurrence of observation errors in the Ikea data set. Additionally, it is unlikely that the outliers are due to falsely scraped items. To verify this hypothesis, the authors randomly tested outlier observations and manually checked them against the Ikea website information. With a high level of statistical confidence, they proceeded with further analysis without removing outliers as observation errors.

B. Step 2: Homogeneity of Price

The homogeneity (homoscedasticity) of variance for the price is explored by means of conditional box plotting. Within each name, and within each category the variance is heteroge- nous (see fig. **??**). However, looking at both name and category in conjunction, it is possible to explore the homoscedasticity of variance for price.

Due to the limited scope and length of this paper, the authors were not able to inspect all variable combinations for the three categorical plus two logical variables of the data set ($2^5 = 32$).

C. Step 3: *Normality* by P. Kru¨ck

No numerical variables (`price`, `old_price` and `size_m3`) are arranged along a normal distribution (see fig. 2), but rather follow an exponential decay (e^{-x}).

D. Step 4: *Missing Values* by P. Kru¨ck

[2] Zuur, "A protocol for data exploration to avoid common statistical problems."

All variables were examined for missing values. Only `designer`, `size_m3` and `old_price_eur` have missing values with percentages of 3.44%, 45.9% and 81% respec- tively (see fig. 3). The missing values for the designer were deliberately set to `NA` by the authors in the case where the values contained digits, which is likely a scraping error. The

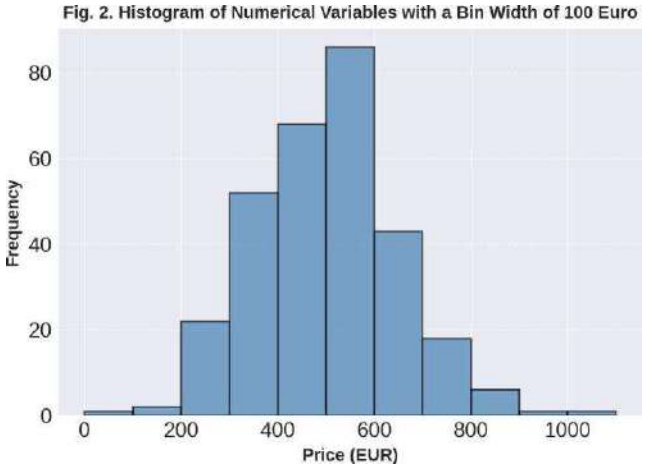


Fig. 2. Histogram of Numerical Variables with a Bin Width of 100 Euro

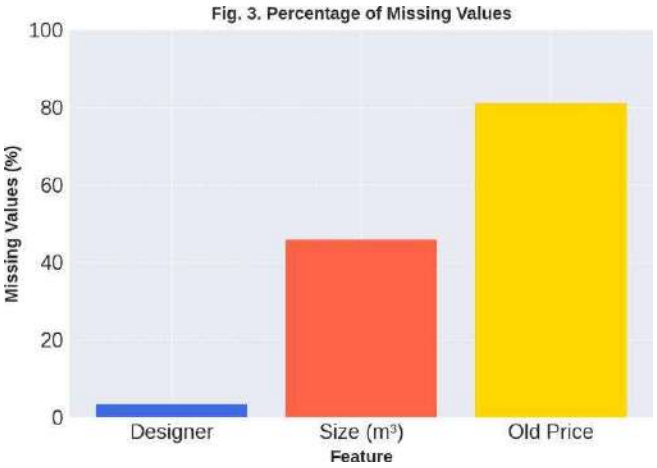


Fig. 3. Percentage of Missing Values

TABLE III
VARIANCE INFLATION FACTORS FOR NUMERICAL VARIABLES

price eur	old price eur	size m3
77.97	78.54	2.36



Fig. 4. Relationship of Price and Old Price

none can be detected for the other variables (see 11). `old_price_eur` has a linear relationship (see fig. 4) whereas `size_m3` begins with a linear relationship as well, which is only disturbed by an outlier. (see fig. 5).

G. Step 7: Interactions

by P. Kru¨ck

the use of conditioning plots (coplots). This form of plotting explores the relationship between two numerical variables by creating a matrix of plots subdivided by two categorical

The interactions between different variables are explored by

variables. In the given data set, there are three numerical and three categorical variables that can be explored in this form of

`NA` values for the size can be explained due to the computation of this column vector. `size_m3` is the product of `depth`, `width` and `height`. If one of those three values is missing, the end result is also a missing value. In contrast, the absence of the old price variables is due to the fact that most items are not on sale and thus do not have a missing value.

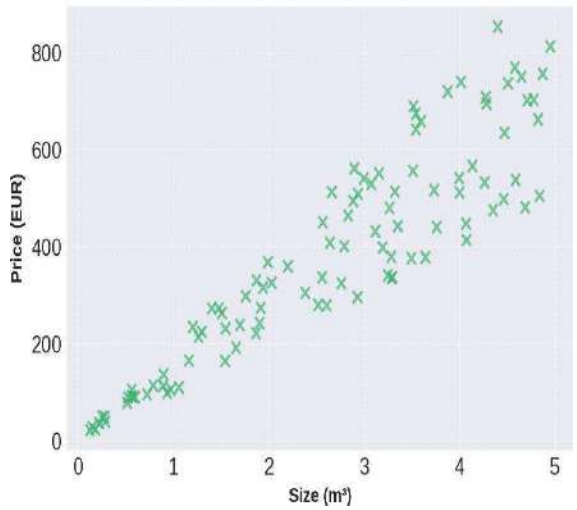
E. Step 5: Collinearity between Independent Variables

The old price has a rather high variance inflation factor (VIF), which corresponds to high multicollinearity (see table III). Contrarily, size has a low VIF, which translates to low multicollinearity among the other independent variables (see table III).

Step 6: Relationship between Independent Variables and Price

Inspecting the relationship between the independent variables and price, a strong correlation between `old_price_eur` and `size_m3` can be observed, while

Fig. 5. Relationship of Price and Size in Cubic Meters



interaction. For the numerical variables, `old_price_eur` has such a strong relationship with `price` (see fig 4). A more detailed breakdown by the categorical variables would not reveal new information. This leaves the exploration of `size_m3` and `price_eur` $_3$ subdivided by designer, name and category resulting in ($_2$ = 3) combinations of coplots.

1) Interaction of size and price co-plotted by designer and name: by P. Kru¨ck

It is unlikely that there is an interaction between size and price split by name and designer, as is indicated by the non- parallelism of the fitted lines in the coplot (see figure 12).

2) Problems with Coplot Development: by P. Kru¨ck

This section describes a programming error the authors ran into regarding plotting.

Unfortunately, the authors of this paper weren't able to fully explore all combinations. Plotting designer anname **?**. To learn more about the *randomForest* package, see Liaw and Wiener.

First, the variable `old_price_eur` is removed from the cleaned ikea data set due to a very high correlation and relationship to the response variable `price_eur` (price) analyzed in section VI-E and section VI-F. Then, the `designers` and `names`, which are not part of the 50 works (see above) , while the other two options would not plot properly. The authors could not fully debug the problem with these plots. The linear model predicted infinite values for some of the coplotted combinations for both amalgamations that would not render correctly. Dropping all `NA` values left 354 observations, and the copilot would correctly render for the combination of `name` and `category` while for `name` and `designer`, it would not. The number of

a tidy format which implies that the observations are independent of eachother.[3]

VII. Random Forest Regression Model

by J. Pein

To analyze the feature importance of different variables on the price variable, a random forest model was chosen. In the given data set, categorical variables with lots of different values can be observed. Including all of those values in, for example, a linear regression model would most likely lead to overfitting (see section III-B). This is because the linear model would learn the immanent data structure of the sample but would not be able to generalize from this. Thus, the authors chose the random forest model because, according to Breiman [4], it is robust against overfitting.

In this analysis, the R *randomForest* package was used, which is based on the original Breiman and Cutler's Fortran code for random forest regression. To reproduce the results, the further data preparation steps are described here. These steps are based on the cleaned IKEA data set, which is described in section V. This data set is then transformed further allowing it to be used with the *randomForest* package. To learn more about how random forests work, see chapter **?**

`designers` and 49 `names` with the highest number of occurrences, are grouped in the `other` value. This is because the `randomForest` method does not allow categorical variables with more than 53 predictors. The last step deals with the missing values in the data. As described in section VI-D, there are many missing values in the `size_m3` and `designer` variables. To apply the `randomForest`

[3] "There are three interrelated rules that make a dataset tidy: Each variable must have its own column. Each observation must have its own row. Each value must have its own cell." (, Wickham, *R for Data Science*, 149, ll.4–7.)

[4] "Random Forests," 29.

ISBN: 978-93-343-2006-0

method of the *randomForest* package on the data, those missing values are treated using three different approaches. In the first approach, the rows with missing values are deleted, reducing the total number of rows by approximately 50%. In the second approach, the missing values are dummy-coded with a value of -1000.

The third approach uses the `na.roughfix = na.omit` argument, which is the built-in way of the *randomForest* package to deal with missing values. After preparing the data, the `randomForest` method of the *randomForest* package is applied to the data with the number of trees set to 2000 and importance set to `TRUE`, training the random forest model with the prepared ikea data set.

```
randomForest(price_eur ~., rf_ikea,
ntree=2000, importance=TRUE)
```

Then, the `importance` method of the *randomForest* package is used to calculate the feature importances, which are computed by permuting feature importance, which was introduced in section III-C. The three different approaches to dealing with the missing values in the data set lead to different results, so the authors chose to calculate the mean result of the three approaches. The result of this analysis is presented in the following chapter. Results

by J. Pein

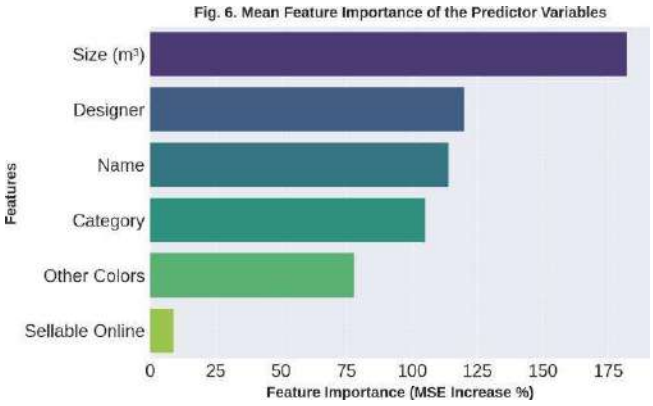


Fig. 6. Mean Feature Importance of the Predictor Variables on the Response Variable

This chapter presents the results of the analysis of the importance of different features in the response variable price of Ikea products.

As described in section VII, the feature importance was cal- culated using permuting feature importance of the *randomFor- est* R package. In this analysis, feature importance is derived from the percentage increase of the mean squared error (MSE) of the overall random forest regression model in regard to the response variable `price_eur`. A larger percentage increase of the MSE implies greater feature importance. Conversely, a lower percentage increase of the MSE translates to less feature importance.

Thus, as can be seen in figure 6, the most important feature is `size_m3` with an increase of the MSE of 182%. The second, third, and fourth most important features are `designer` with an MSE increase of 120%, `name` with an increase of 114%, and `category` with an increase of 105%. The fifth most important feature is `other_colors` with an MSE increase of 78%, and the least important feature is `sellable_online` with a 9% increase.

These results are further discussed in the following chapter. Discussion by J. Pein

In this chapter, the results are discussed in connection with the research question. The question that the results were

supposed to answer is the following:

How important are the different features of Ikea products in regard to their price?

VIII. Feature Importance

The `size_m3` variable is the most important feature. Prob- ably the main reason for this is the size of a product being closely linked to its material cost. Big items are generally more costly to produce, thus leading to a higher selling price and vice versa, due to the high correlation to the price variable described in section VI-E and section VI-F, it is worth discussing in future research whether or not to include this variable in a possible predictive analysis model.

The `designer` variable is the second most important feature. When looking at the price distribution per designer, it can be clearly seen that the interquartile range (IQR) of price varies for each designer. In addition, the IQR is often smaller than 300 €, thus showing a tendency towards a certain price range, which might be the reason for the relatively high feature importance of the designer variable. For the plot, see figure.

The `name` variable includes around 50 different product names with partly small numbers of occurrences. But, as can be seen in figure 1, certain product lines (names) tend to be more expensive than others. *LIDTHULT*, for example, is the most expensive product line in each of the categories *beds*, *chairs* and *sofas & armchairs* while *HEMNES* is on the lower end of the price scale. This behavior explains a relatively high feature importance of the `name` variable.

`Category` is another feature with a relatively high im- portance. One reason for this is the different category's price distributions showing a clear tendency towards certain price segments (see figure 8), i.e. wardrobes and beds are generally more expensive than chairs.

The feature importance of `other_colors` is the second lowest, but still considerable. This still relatively high feature importance might be due to the difference between the mean

price and the relatively small IQR (see: figure 9). On the other hand, there is a large overlapping area within the IQR in the two expressions of `other_colors`, possibly reducing the feature's importance.

The very low feature importance of the `sellable_online` variable is probably because of the low number of occurrences of a product being sellable online. Only around 0.6% of the products are sellable online.

IX. Conclusion

The data used in this paper was scraped from the Saudi Arabian Ikea website, thus this analysis mainly focusses on Ikea products in the Saudi Arabian market. To analyze the geographically independent feature importances, more data should be scraped from other international Ikea websites. The research question of this paper, *How important are the different features of Ikea products in regard to their price?*, could thus not be answered for the global Ikea product market but for the Saudi Arabian market only.

Also, in further research, the results presented on the feature importance of the predictor variables in relation to the response variable price should be validated using techniques other than the random forest model used in this analysis to achieve unbiased results.

Furthermore, based on this analysis a predictive model could be developed which predicts the price of Ikea products in the Saudi Arabian Market based on the features analyzed. This could be used by Ikea internally to analyze if the price of their new product aligns with the prices of the currently available product or by market researchers.

Lastly, the authors were surprised by the high feature importance of the variables `designer` and `name` computed by the random forest model. Both variables have lots of

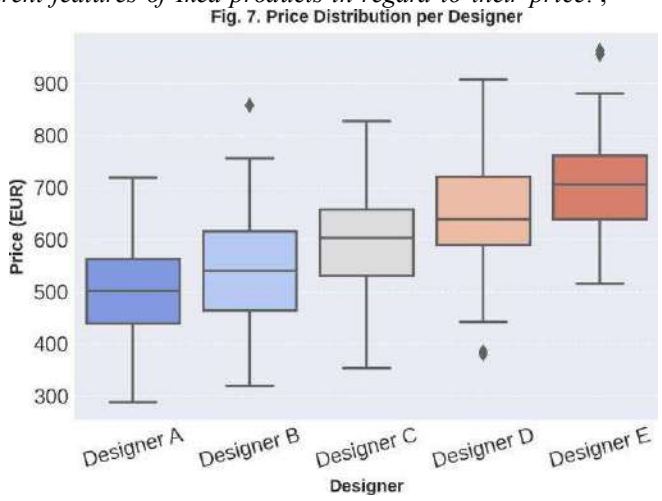


Fig. 7. Price Distribution per Designer

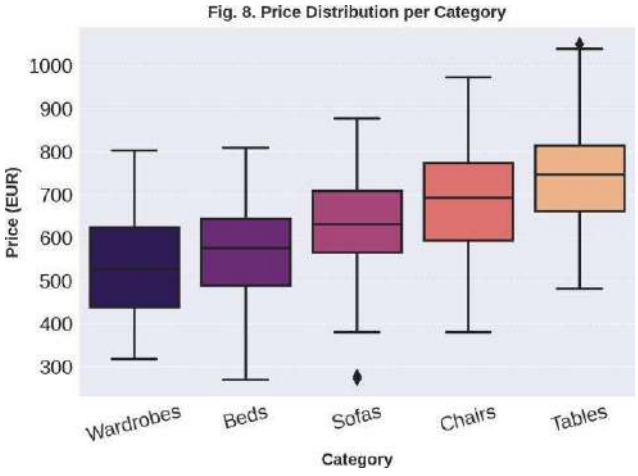


Fig. 8. Price Distribution per Category



Fig. 9. Price Distribution Other Colors

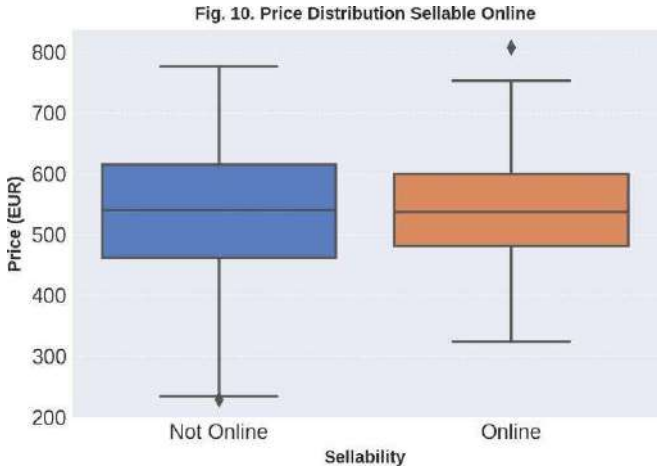


Fig. 10. Price Distribution Sellable Online

different values, suggesting an overfitting of the random forest model. This, however, is objected to by scientific research. Exploring the reason behind the high feature importances of the variables `designer` and `name` and if they are due to overfitting of a random forest model should be analyzed in future research. If the high feature importance of the variables truly is not due to overfitting, this example backs up the thesis of Gro¨mping that random forests are able to discover deeper patterns in the data. These patterns are beyond the discussion applied here, showing the power of random forests models. Plots

Code Chunks

```
coplot(size_m3 ~price_eur |
 fct_lump_n
(category, 5
) +
```

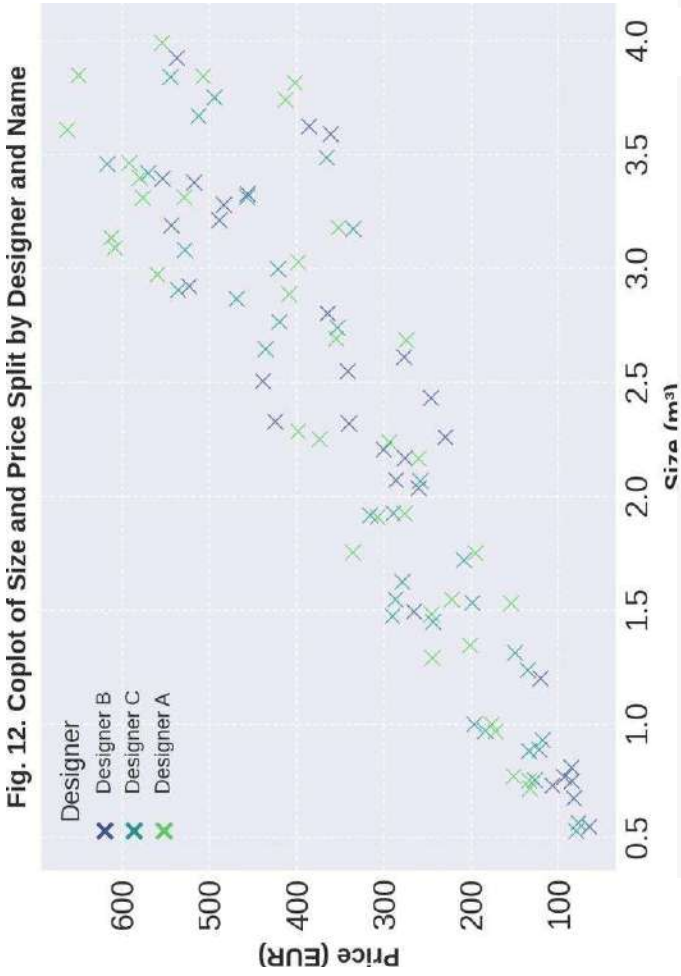


Fig. 12. Coplot of Size and Price Split by Designer and Name

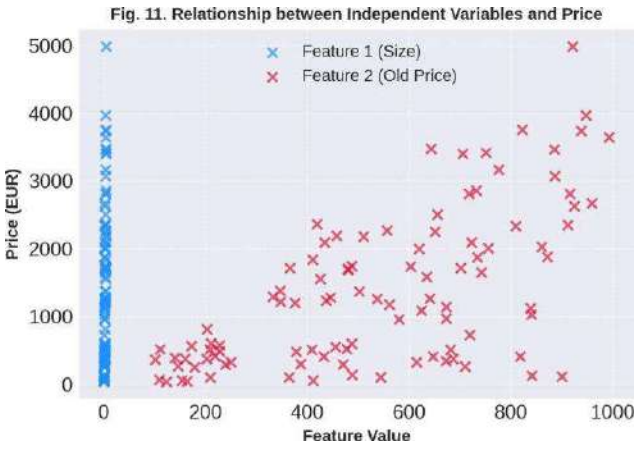


Fig. 11. Relationship between Independent Variables and Price

```
coplot(size_m3
price_eur |
 fct_lump_n(designer, 5)
+
         fct_lump_n
(category, 5), data = drop_na
(tidy_ikea),
        ylab =
        "Size in m^3"
        ,
        xlab =
        "Price in Euro"
        ,
        panel = function
        (x, y, ...)       {
          tmp <-
 lm
(y
 x,
na.action =
 na.omit)
         abline
         (tmp)
         points
         (x, y )})
```

```
         fct_lump_n
(name,
5),
data = drop_na
(tidy_ikea),
       ylab =
       "Size in m^3", xlab
       =
       "Price in Euro"
       , panel = function
       (x, y, ...) {
         tmp <-
 lm
(y ~x,
na.action =
 na.omit)
         abline
         (tmp)
         points          (x, y )})
```

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ADVANCEMENTS IN METAMATERIAL DESIGN: ASYMMETRIC WALL GEOMETRIES FOR HIGHPERFORMANCE AUXETICS.

Shresth Singh[1], Jitendra Bhaskar[1] and Anand Kumar[1]

[1]School of Engineering, HBTU- Nawabganj-Kanpur 208002

ABSTRACT: This study presents a new metamaterial inspired by hexagons. Its geometry is a modified re-entrant with asymmetric cell walls. It can achieve a tunable negative Poisson's ratio and has dual-stage energy absorption capabilities. The validated FEM simulations confirm the unique and tunable NPR of the structure in which the NPR increases with the angle of re-entrant. When under compression, the material buckles elastically and then densified before it takes more compression. This method effectively takes in enormous energy. The comparative study shows the specific energy absorption (SEA) is significantly improved as compared to the conventional. These discoveries help us understand more about auxetic mechanics and provide a design framework for advanced engineered energy-absorbing materials which will find relevance in aerospace, automotive safety, and protective gear.

Keywords: Meta Materials, Re-entrant hexagon, Energy absorption

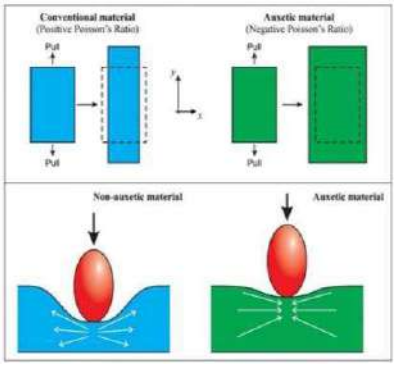
1. INTRODUCTION

Auxetic materials are a type of sophisticated materials that show opposite behaviour when put under tension or compression which shows that they have a negative Poisson's ratio (NPR). Conventional materials contract in lateral direction, when stretched axially, while auxetic materials expand in transverse direction when being stretched axially and contract in lateral direction when compressed. This unique deformation mechanism imparts a suite of exceptional mechanical properties, including significantly enhanced energy absorption, superior impact resistance, improved fracture toughness, and increased resistance to shear and indentation[1-4].

Initially regarded largely as a scientific curiosity, rigorous research and development efforts have propelled auxetic materials into the realm of practical, high-performance applications across various industries. These materials have found utility in aerospace engineering, smart textiles, biomedical devices, and a range of impactresistant and protective systems[6-11]. The exploration of auxetic materials dates back to the 1800s[12-14], with significant research momentum building after Lakes' pivotal experiments in 1987[15].

Fig. 1. Auxetic vs Conventional

A variety of auxetic structures have been developed, including re-entrant honeycombs, chiral lattices, rotating rigid units, and hybrid hierarchical structures, each achieving their NPR through distinct geometric configurations [16-19]. Among these, the hexagonal re-entrant design has garnered considerable attention due to its relative simplicity and well-understood behaviour[20-22]. However, conventional re-entrant designs present certain limitations, particularly a lack of sufficient energy absorption capability, which renders them less effective in high-impact loading scenarios[23-25]. This specific functional limitation in existing, simpler designs is the critical problem statement that drives the current research. Recent advancements in hierarchical and hybrid designs have shown promise in enhancing toughness, adaptability, and energy



dissipation through multiple deformation modes, paving the way for further innovation[26-29]. For instance, chiral structures distribute loads through symmetrical rotations, while re-entrant honeycombs achieve their unique behaviour via the buckling of inward-curving cell walls under load[30-34].

This study directly addresses the identified gap in energy absorption performance by introducing a novel auxetic structure. The research objectives are precisely defined:

- Design and thoroughly evaluate a new auxetic structure specifically engineered for superior energy absorption capabilities.
- Rigorously confirm the negative Poisson's ratio (NPR) and other mechanical characteristics of the proposed structure through a combination of Finite Element Analysis (FEA) and theoretical simulations.
- Definitively demonstrate the enhanced performance of this novel structure, particularly its energy absorption, in comparison to conventional hexagonal re-entrant structures.

The overarching aim of this research is to advance the fundamental understanding of auxetic materials and to provide a foundational framework for designing sophisticated structures with unique mechanical properties. This targeted approach, focusing on a known functional limitation of existing designs, signifies a move beyond mere scientific curiosity towards practical, high-performance applications[35-39]. The alteration for mechanical deformation by invention of a "two stage deformation" mechanism enables this.

This work is a significant contribution to the maturing of auxetic materials from a niche academic topic to a practical engineering solution with potentially transformative impacts across a variety of industries, including aviation, automotive and health engineering[40-41]. The main objective of this study is to provide a design framework, not just data, for taking basic material science into practice for product design

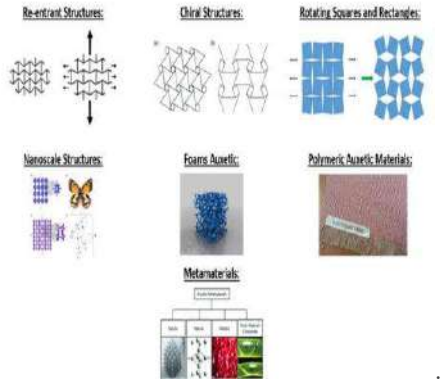


Fig. 2. Types of Auxetic Structures

2. METHODOLOGY

2.1. Design of the Novel Auxetic Structure

The auxetic structure that was proposed in the research draws ideas from a standard hexagonal re-entrant geometry. However, the geometry has some modification. Overall, the structure is capable of enhancing energy absorption. It does so by employing a two-stage deformation mechanism having expansive properties. The elements of the design include:

- Re-entrant Angles (θ): The angles are carefully
- adjusted for obtaining a negative Poisson's ratio (NPR). By precisely controlling these angles, we can fine-tune the auxetic properties of the material.
- Cell Wall Length (L) and Height (h): Cell Wall Length (L) and height (h) are varied and controlled to tune the stiffness, as well as energy absorption capacity of the structure. As a result, the mechanical behaviour of the material is modified predictably, based on designs.
- Hierarchical Elements: The design is such that during compressive loading sequential deformation modes are activated due to these elements. This characteristic is essential for the dual-stage energy absorption mechanism where the material progressively absorbs energy.

Initially the geometry of the structure is defined using CAD software before any computation is done such as cell wall length, angle, cell wall thickness etc. The digital prototyping phase is to make sure everything is accurate.

ISBN: 978-93-343-2006-0

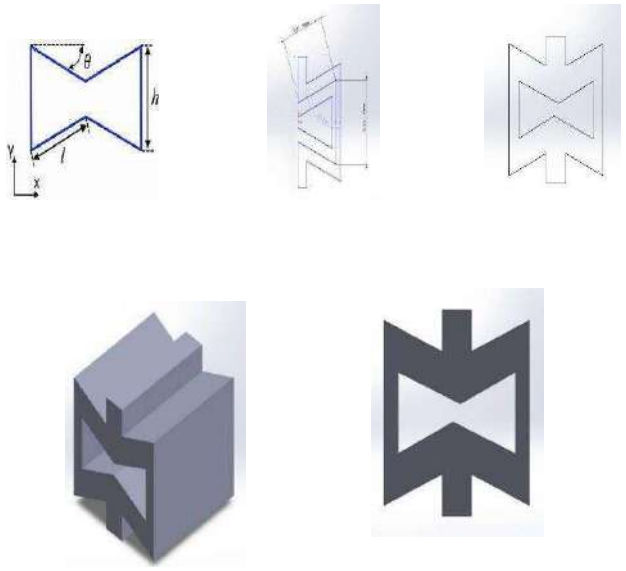


Fig. 3. Design of Novel Auxetic Structure

2.2. Finite Element Analysis (FEA) in ANSYS Static Structural

ANSYS Static Structural is used to compute the Poisson's ratio of the suggested auxetic system. The process is as follows:

Model Import:

- Import the CAD model of the auxetic structure into ANSYS Workbench.
- Define the material properties (in this case Aluminium Alloy 6063).

Material Used for FEM	Aluminium alloy AA7075
Density	2.8×10^3 kg/m^3
Poisson's Ratio	0.3
Initial Yield Stress	162 MPa
Youngs' Modulus	73013MPa

Boundary Conditions:

- Apply fixed support to one end of the structure.
- Apply a uniaxial compressive load to the other end to simulate contraction.

Simulation Setup:

- Run the static structural analysis to find strains in the axial and transverse directions.

2.3. Specific Energy Absorption Calculation in LS-DYNA

A program intended especially for dynamic and nonlinear studies, LS-DYNA is used to determine the specific energy absorption of auxetic structure. The process is as follows.:

Model Preparation:

- Import the CAD model into LS-DYNA.
- Define the material properties (in this case Aluminium Alloy 7075)

Meshing:

Generated a high-quality mesh using element order 0.01mm.

- Perform a mesh sensitivity analysis to ensure convergence of results.

- Determine the Poisson's ratio from the formula below: ε

Post-processing:

- Extract the strain values from the simulation results.
- Validate the Poisson's ratio by comparing it with theoretical predictions.

- Generate a tiny mesh to capture the deformation behaviour correctly (element size 0.01mm).
- When conducting dynamic analysis, use explicit time integration.

Boundary Conditions:

- Fixed base, 500 kg impactor at 10 m/s.

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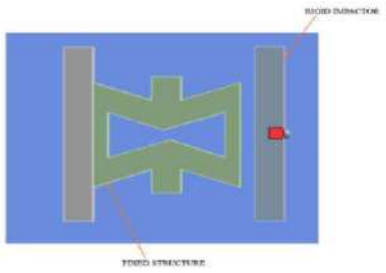


Fig. 5. Boundary Condition (LS DYNA)

Validation:

- Benchmarking against Du et al. (2019) showed error less than 5% in SEA.

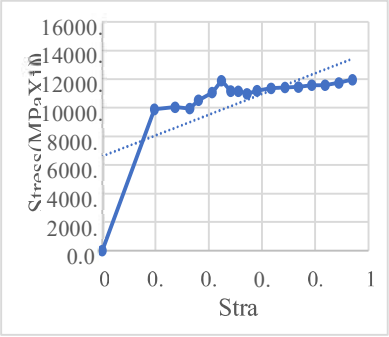


Fig. 6. Stress-Strain Curve for Aluminium Alloye

3. RESULTS AN DISCUSSION

3.1. Poisson's Ratio Calculation

The Poisson's ratio (ν) of the proposed auxetic structure was determined through both theoretical calculations and Finite Element Analysis (FEA) simulations using ANSYS Static Structural.

The theoretical calculations, as presented in Table 1, demonstrate a clear relationship between the re-entrant angle (θ) and the Poisson's ratio. As the re-entrant angle increases, the Poisson's ratio consistently becomes more negative, indicating an enhanced auxetic behavior. For instance, at a re-entrant angle of 10 degrees, the theoretical Poisson's ratio is -0.15. This value decreases to -0.4188 at 20 degrees and further to -0.4501 at 20.88 degrees.

Simulation Results:

- ratio (ν), and validated using the theoretical model as shown:

$$\nu = -\frac{\sin(\theta)\cdot\left(\frac{L}{h}+\sin(\theta)\right)}{\cos^2(\theta)} \quad (3)$$

Where, ν= Poisson's ratio, θ= re-entrant angle, L= cell wall length, h= height

Table 1. Theoretical Calculations of Pisson's ratio

θ (degree)	L (mm)	h (mm)	ν (theoretical)
10	2.28	3.4	-0.15
20	2.41	3.26	-0.4188
20.88	2.41	3.23	-0.4501

The FEA model accurately predicted the Poisson's ratio across a wide range of geometric parameters, providing a consistent foundation for designing auxetic structures. As depicted in Figure 7, the novel structure consistently exhibits a more negative Poisson's ratio compared to conventional hexagonal re-entrant structures over time.

A strong similarity was observed between the simulation results and theoretical predictions, providing robust validation for the accuracy of the FEA approach. Figure 8 visually confirms this correlation, clearly showing that as the re-entrant angle (θ) increases, the Poisson's ratio becomes more negative, which signifies enhanced auxetic behavior. A direct comparison of the theoretical and FEA values further highlights this close match, as detailed in Table 2.

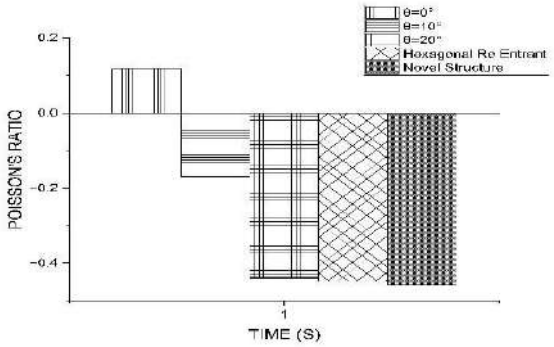


Fig. 7. Poisson's ratio obtained from ANSYS Static Structural

Table 2. Comparison of Poisson's ratio obtained theoretically and via FEA

θ (deg)	ν (FEA)	ν (Theoretical)
10	-0.163	-0.15
20	-0.4280	-0.4188
20.88	-0.447	-0.4501

Theoretical Validation:

The simulation results show a strong similarity with the theoretical predictions, validating the accuracy of the FEA followed. The Poisson's ratio becomes more negative as the re-entrant angle (θ) increases, indicating enhanced auxetic behaviour.

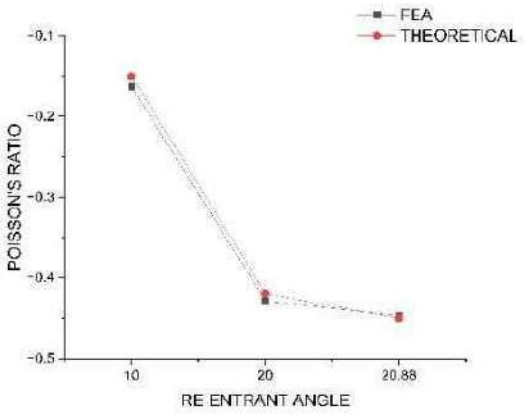


Fig. 8. Plot of Poisson's ratio (ν) vs. re-entrant angle (θ) for different L/h ratios

The consistent match between theoretical and FEA Poisson's ratio values across varying re-entrant angles demonstrates that the NPR is not just negative, but tunable and predictable based on geometric parameters. This predictability is a crucial aspect for engineering applications, allowing for precise control over the material's response.

3.2. Specific Energy Absorption (SEA) Calculation

The specific energy absorption (SEA) of the auxetic structure was calculated using LS-DYNA under dynamic compressive loading.

Comparison with Traditional Designs:

The study found that asymmetrical changes in the cell wall length of the novel structure lead to a significant increase in SEA. This superior performance is directly attributed to a unique two-stage deformation mechanism: an initial phase of elastic buckling of the cell walls followed by densification. This dual-stage mechanism is a critical design innovation. Elastic buckling absorbs energy by deforming the structure without immediate permanent damage, while subsequent densification involves more significant structural collapse and material compression, absorbing even more energy. This allows for dual-phase energy dissipation, making the structure particularly effective in absorbing impact energy. This implies a non-linear energy absorption profile, which is highly desirable for applications requiring controlled and safer responses in crash scenarios or protective gear.

The novel structure demonstrated a substantial improvement in energy absorption, showing a remarkable 36% increase in SEA relative to conventional hexagonal re-entrant configurations. Figure 9 visually reinforces this, clearly showing the novel structure's significantly higher SEA. The quantitative comparison is provided in Table 3

Table3. Values of specific energy absorption (SEA) for various geometric parameters

Type	EA (kJ)	SEA (kJ/Kg)
Hexagonal Re Entrant	75.98	358.82
Novel Structure	111.85	528.19

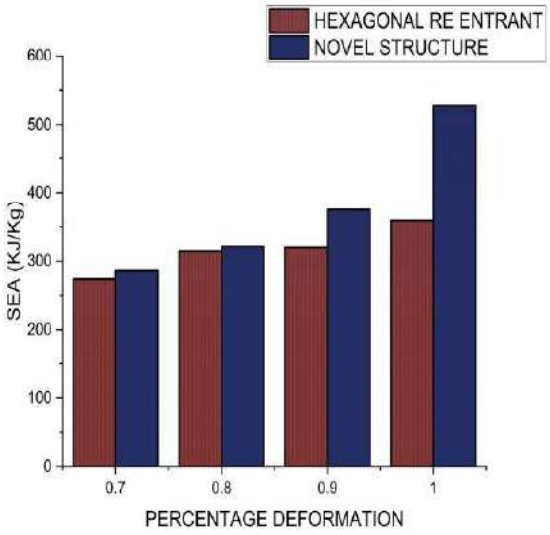


Fig. 9. SEA values for the suggested structure and conventional hexagonal re-entrant designs

For engineers designing impact-resistant systems, SEA is a primary performance metric. The significant increase from 359 kJ/Kg for conventional designs to 528 kJ/Kg for the novel structure provides compelling evidence of its practical value. This, combined with the tunability of the Poisson's ratio, indicates a sophisticated understanding of how to optimize the design for specific performance metrics. Engineers can now use these validated relationships to predict and tailor the auxetic behavior and energy absorption capabilities of materials by simply adjusting geometric parameters. This moves from trial-and-error to a more deterministic design process, accelerating the development of application-specific materials.

4. CONCLUSION

Research presented here shows how greatly material performance can be affected by geometry. This most striking effect is on the performance of auxetic materials. The research clearly shows that a new hexagoninspired auxetic metamaterial was successfully designed and characterized that has advantages over conventional designs. The results demonstrate a number of innovative contributions:

- Enhanced and Tunable Negative Poisson's Ratio (NPR): The new auxetic design has a very high negative Poisson's ratio, and increasing the re-entrant angle causes a significant increase in the magnitude of its negative Poisson's ratio. This shows that the design can be tuned and has improved auxetic behavior which is nice because it allows control of the lateral response under compression.
- Superior Energy Absorption (SEA) through Dual-Stage Mechanism: The innovative design of the new multi-stage anti-impact device shows significantly enhanced energy absorption characteristics. This excellent performance is due to the special two-stage deformation mechanism of the material wherein there is first elastic buckling of the cell walls followed by densification.

  This sequential process allows the material to dissipate energy in two similar stages making it a very efficient material to absorb energy.
- Validation of Computational Model: The theoretical calculations of Poisson's ratio and the simulations through FEA closely validate the computational model. The accuracy of the findings is validated by the strong correlation in the proposed FEA model analysis.

  The study helps in understanding auxetic mechanics well and also gives a robust design framework to design custom energy-absorbing materials. The word still matters. It refers to how the evidence (i.e. impact of the reentrant angle on NPR, how asymmetric cell walls give the coefficient. SEA an edge etc.) aren't merely incidental but actionable design principles to be used under specific conditions. This approach will change the way people view materials, going from 'discovering' materials to 'engineering' materials with targeted properties. For industries, this means that the needs of a material can be carefully designed to suit the specification that the material must fulfil, whether that is to have a specific impact energy absorption profile for a car bumper or to have a particular flexibility for a biomedical implant.

  The integrated approach wherein theory is used to guide computations, which are in turn used to guide the design, is a powerful research strategy. As noted in the

conclusion, the theoretical predictions and FEA results corroborate each other very closely. The modern field of materials engineering is characterized by a cycle of theory, simulation and design. This integrated cycle allows rapid prototyping of new designs as well as virtual testing. This benefit can greatly cut down the time and expenses involved in physical experiments. As a result, it hastens the process of converting concepts to reality. Moreover, it makes the designs of complex metamaterials easier for industries to use. These innovative designs and methodologies can push the engineering frontier through advanced integrated design of auxetic materials (negative Poisson ratio) for huge weight savings and more robust materials in aviation, automotive and health engineering. As studies keep coming to fore new knowledge about auxetic materials, it is becoming clear that they will be an important feature of modern technology.

6. CHALLENGES AND FUTURE DIRECTIONS IN AUXETIC STRUCTURES

Moreover, cross-disciplinary cooperation is essential. Brushing up on maths, biology and data science. could help discover new auxetics faster. Use of machine learning can help predict how a auxetic shape might fail under different conditions. loading situations. "While working towards auxetic designs we also have to think of sustainability." By considering recyclable compounds or biodegradable polymers, we can achieve a global standard. environmental objectives. The modified re-entrant auxetic material improved energy absorption. Fresh research and development opportunities arise in the field as a result of stiffness. Scientists. One may investigate new materials or combinations to enhance material performance properties like strength or stiffness. make use of modern materials to ensure better strength and conductivity. Use tools like machine learning to plot new materials Whether the above design. Whether it will be useful in real life or not will depend on many tests. Including things like controlling temperature or self-healing would also help make it more useful. Using pre-industrial methods to develop natural products that fulfil modern standards can involve beneficial redesign processes of standard industrial products. This framework shows promise for several uses, including:

- An automotive application would be vibration dampers and crash structure.
- Aerospace and defence: Strong and light aircraft components and blast-resistant panels.
- The helmets and pads are made to absorb more energy.
- Lightweight appliance and ballistic shields for aerospace and defence. Improved energy absorbing helmets and pads for sports.
- Helmets and pads with better energy absorption for the safety of the athlete.

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Enhancing Inventory Management with Progressive Web Applications (PWAs): A Scalable Solution for Small and Large Enterprises

Abhi Desai
New England College, Henniker, New Hampshire, US
adesai_gps@nec.edu | desai.abhi94@gmail.com

***Abstract*—Efficient inventory management is crucial for both small and large enterprises to optimize operational workflows and reduce overhead costs. This paper explores the development and implementation of a Progressive Web Application (PWA) designed to enhance the inventory management experience. The application integrates key functionalities such as barcode and QR code scanning, geolocation-based warehouse identification, and cross-device accessibility. By leveraging PWA technology, the solution ensures offline capabilities, responsive user experience, and seamless adaptability across various platforms. The study discusses the challenges and benefits of implementing PWA in inventory management systems, including its limitations in performance compared to native applications. Insights from the development process provide a roadmap for future developers looking to integrate PWA technology into enterprise applications. This research contributes to the growing domain of web-based inventory solutions, offering a scalable and cost-effective alternative to traditional inventory management software.**

I. Introduction

A. Problem Characteristics

Warehouse resource management is a key element of the effective functioning of many enterprises, especially in industries related to logistics, trade, and production. This problem becomes particularly important in the context of growing expectations related to process automation and the minimization of errors resulting from manual management.

Inventory management is crucial for the efficient operation of many businesses, particularly in the logistics, trade, and manufacturing sectors. This issue gains prominence as companies face increasing demands for process automation and a reduction in errors due to manual management. The challenge is exacerbated for new market entrants that often lack the necessary capital to develop specialized software for every device type.

B. Goal Header

Our goal is to create a tool that will help companies track and manage assets more efficiently. The main technical assumption was to create a PWA application in the MVP (Minimal Viable Product) version, i.e. with CRUD functions, enabling the management of warehouses, stock levels, product availability and assigned product categories. The functionality of the application has been extended to include a QR code and barcode scanning module. Another element is the implementation of geolocation, which aims to accelerate the identification of the warehouse based on the user's location. Our goal is to create a tool that will help companies track and manage resources more effectively. The main technical assumption was to create an MVP (Minimal Viable Product) version of the PWA application, i.e., one that has CRUD functionalities to manage warehouses, inventory, product availability, and assigned product categories. The goal of creating a PWA application was to create a single tool that could be used on many devices, regardless of whether the device is running on

ISBN: 978-93-343-2006-0

the preferred system. The application's functionality was supposed to be extended with a QR code and barcode scanning module. Scanning the codes was to enable faster obtaining of information about a given product. Another sensor-based functionality is geolocation, which can speed up warehouse identification based on the user's location. QR code scanning was to be extended to edit the warehouse status after scanning the QR code. The QR code was to contain data that the system would read and present to the employee for processing. This solution could significantly speed up the receipt and issuance of products from warehouses.

C. The Benefits

In the business context, this project sought to enhance resource management efficiency, decrease the time required for warehouse operations, and minimize errors stemming from manual tasks. On the technical side, the main objective was to develop a user-friendly and effective tool that seamlessly integrates with current enterprise systems and is and is usable on mobile devices and computers. In a business setting, the project sought to develop a user-friendly and effective tool that is readily accessible on both mobile devices and computers. Additionally, the system aimed to reduce mistakes associated with manual inventory management.

II. The Related Works

Enterprise Resource Planning (ERP) systems, such as SAP [1], Oracle NetSuite [2], and Odoo [3], are popular solutions in this domain offering comprehensive features ranging from inventory tracking to financial management. However, these platforms often require significant resources for deployment and maintenance, making them less accessible for smaller enterprises.

For small- and medium-scale enterprises, SaaS (Software as a Service) solutions like Zoho Inventory [4] and TradeGecko [5] are popular alternatives. These tools are user-friendly, lightweight, and integrate well with other software, but they lack scalability and deep customization for larger operations. The above-mentioned software is mainly used to process orders and ship items from given warehouses. We want to investigate whether achieving similar functionality, as well as automating some operations (receiving and issuing products) is possible using PWA (Progressive Web Application). PWA technology offers several significant advantages that can translate into greater flexibility and lower maintenance costs compared to classic SaaS solutions:

- Lower maintenance costs - PWAs do not require maintaining separate versions for different platforms (e.g., iOS, Android, desktop).
- Offline operation and resource savings - PWA can operate offline thanks to Service Worker's technology, which means that basic functions are available even with limited internet access.
- Independence from the App Store and Play Store - No need to publish applications in app stores eliminates the associated costs and waiting time for acceptance.

In the context of technology, barcode and QR code integration has become a cornerstone of modern inventory systems. Libraries such as ZXing [6] offer reliable and efficient methods for decoding these codes, making product identification and tracking much easier.

Progressive Web Apps (PWAs) [7] are gaining traction for their ability to combine the accessibility of web applications with the native performance of mobile apps. Their features include offline functionality, simple installation, and access to device capabilities such as cameras and geolocation. PWAs also enable unified development across platforms, reducing costs and maintenance efforts.

III. The Results

A. The Summary

The project implementation was successful. We included all important functionalities and comprehensively checked the usability and ease of use of PWA technology.

Our project builds upon these insights to deliver a PWA-based inventory management system tailored for enterprises of varying sizes. By integrating technologies such as Angular [8], Spring Boot [9], PostgreSQL [10], and AWS [11], we aim to create a scalable, cost-effective, and accessible solution

that combines the simplicity of SaaS tools with the power of ERP platforms.

The implementation of the project proceeded as planned and was successful. We managed to include all important functionalities and use of PWA technology.

B. The Project Assumptions

Our use of PWA implements on multiple devices while maintaining a single code base. At the same time, it provides access to device sensors, like the camera or geolocation, which we used to add additional functionalities, such as scanning bar codes and QR codes and pinpointing the exact warehouse the user is currently stationed in. This makes it especially helpful for businesses with multiple warehouses.

IV. THEFUNCTIONALITIES

- CRUD operations, i.e., Create, Read, Update, Delete, allowing full modification of data stored in the database.,
- Ability to scan barcodes and QR codes in an intuitive way for quick access to a specific product in the warehouse,
- Inventory management in multiple warehouses,
- Managing users and their access to functionalities offered by the system layer
- Create, Read, Update, and Delete (CRUD) operations, allowing for full modification of data stored in the database, such as items, warehouses, inventor,y and item categories,
- Ability to scan barcodes and QR codes in an intuitive way to quickly access a specific product in stock,
- Inventory management across multiple warehouses,
- Management of users and their access to functionalities offered by the system layer,

A. The Business Goals

1) Enhanced Inventory Management: The system integrates barcode and QR code scanning to improve asset tracking, streamline inventory control, and provide quick access to details such as stock levels and locations.
2) Improved Efficiency: Simplified management of incoming and outgoing deliveries enhances organization, reduces processing times, and boosts overall productivity.

B. The Technical Goals

1) Cross-Platform Compatibility: Using Progressive Web App (PWA) technology ensures the app works seamlessly across devices while maintaining a single codebase, reducing development and maintenance efforts.
2) Scalable Architecture: The backend, designed with Spring Boot and deployed on AWS using Terraform, is built to handle increasing data loads and user demands.
3) Secure Data Management: The app protects user data and ensures resource access authorization by using Amazon Cognito for authentication and other security measures.
4) Modern Development Practices: Technologies like Terraform, Docker, and Nginx highlight the use of efficient, modern tools for development, deployment, and infrastructure management.
5) Testability: The software that was developed is comprehensively tested with over 80% code coverage.

C. The TechStack

Our project uses a modern and robust tech stack designed to deliver both scalability and reliability: Angular [8], Spring Framework [9], AWS (Amazon Web Services) [11], Docker [12], Hashicorp Terraform [13].

Moreover, we used: ZXing: A library integrated into our application to facilitate barcode and QR code scanning. Utilizing the device's camera, we implemented ZXing to efficiently read both QR codes and EAN-13 barcodes, ensuring accurate and seamless data capture directly within the application. This approach leverages PWA capabilities to access hardware resources, eliminating the need for external scanning devices and enhancing usability on various platforms. [6]

D. The Project Assumptions

At the beginning of the project, we established various constraints and assumptions to limit the scope and guide the development in the right direction.

Our goal was to create a simple and intuitive application that would allow users of various skill levels to successfully use our application. Thanks to PWA technology, we wanted to obtain an application available on many devices, with simple installation and a native graphical interface.

We decided to limit the scope and support only one company with multiple warehouses. These warehouses may contain items shared between them and have individual inventories. There will be no registration form - each employee in the company will have to be added manually by the administrator

At the beginning of the project, we set multiple restrictions and assumptions to limit the scope and guide the development in the right direction.

We set out to create a simple and intuitive application to allow users across all skill levels to successfully use our application. Thanks to the PWA technology,y we wanted to achieve an application that is available on multiple devices with simple installation and a native feel.

We decided to limit the scope and support only a single company owning multiple warehouses. Those warehouses can contain items shared between them and have individual stocks. There will not be a registration form—the administrator will have to manually add each employee to the company. This will ensure that only users declared by the companies will use the application, reducing the cost of maintaining it.

E. The Additional Highlights

- Feasibility Demonstration: The app proves the potential of PWAs for small and medium-sized companies thanks to the quick development process. Additionally, the use of hardware sensors makes it a good solution for an inventory management application, allowing for quality-of-life features like scanning of the QR codes.
- Technical Design: Built with scalability and security in mind, the system employs modern tools such as AWS and Terraform, aligning with enterprise-level best practices and conventions. It makes use of AWS infrastructure, and through the usage of private subnets, appropriately applied security groups, and Amazon Cognito, the application is secured, and thanks to the application load balancing and auto-scaling, the application is scalable without generating unnecessary costs.

V. The Conclusion

To sum up, the application we designed is intuitive to use and provides basic functionalities required by warehouse workers. It will allow for more efficient and simpler inventory management. Thanks to PWA technology, it is available on both mobile devices and computers, supporting installation and quick and easy access in conditions of limited Internet access.

What is important for the technological recipient is that we have tested the capabilities of PWA technology and proved that it is profitable for creating applications for multiple devices while maintaining one code base.

In summary, the app we developed uses PWA technology to enable more flexible and cost-effective inventory management. Unlike traditional solutions that require dedicated barcode scanning devices, this app can be easily used on standard smartphones, making it a more attractive option for small businesses.

With PWA technology, the app works seamlessly on both mobile and desktop devices, eliminating the need for separate apps for different platforms. It runs as a native app, providing access to device resources such as camera and location services, and can maintain functionality even with limited or no internet access. This cross-platform compatibility, combined with reduced hardware requirements, makes it a practical solution for modern inventory management.

VI. The Further Research

For further development of the project, it would be necessary to take into account what other functionalities may be useful for employees and warehouse managers, e.g.

- optimization of the arrangement of items in the warehouse,
- using geolocation to determine the shortest route to the desired section in the warehouse,
- Calculating route and cart capacity requirements to complete an order from the warehouse,
- expanding the application to a commercial version that can support many companies in a comprehensive way,
- and many others.

For further development of the project, it would be important to consider what other functionality might be useful for warehouse workers and managers, such as:

- optimization of the layout of items in the warehouse,
- use of geolocation to determine the shortest route to the desired section in the warehouse,
- calculation of the route and cart capacity requirements to complete an order from the warehouse,
- expansion of the application to a commercial version that can support multiple companies in a comprehensive way
- handling deliveries and releases of products from the warehouse
- managing accounts through the company
- supporting inventory processes
- keeping statistics and generating appropriate reports and charts based on the data
- enabling integration with other systems to automate the processes of deliveries and releases from warehouses (adding generation of QR codes and invoices) or generating QR codes based on invoices.

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"DESIGN AND ANALYSIS OF A DOUBLE STAGE FLYOVER ACCEPTING MULTIPLE LOAD CASES AND DESIGN ISSUES USING SAP2000"

Prof. Madan Pawar[1], Mansi koli[2], Pranali Besulke[3], Prashant Rawle[4], Amar Shaikh[5],Vaibhav Ghube[6]
[1]Professor, Department of Civil Engineering
[2,3,4,5,6]Student, Department of Civil Engineering
[1,2,3,4,5,6]Marathwada Mitra Mandal's Institute Of Technology ,Lohegaon ,Pune
EMAIL:- madanpawar.2011@gmail.com[1] mansikoli2003@gmail.com[2]pranalibesulke11@gmail.com[3] prashantravle999@gmail.com[4],shaikhamar790@gmail.com[5],vaibhavghube4417@gmail.com[6]

Abstract

The massive urbanization and vehicular traffic have called for the evolution of intricate transportation infrastructure systems, e.g., double-stage flyovers. The multi-level flyovers offer efficient traffic segregation and enhanced mobility in high-density urban areas where horizontal area is scarce. This study addresses the structural design and analysis of a double stage flyover using SAP2000, a robust finite element program extensively utilized in civil engineering.The research includes modeling of a two-level flyover structure, comprising reinforced concrete super structures with common and independent substructure elements. The analysis takes into consideration a broad variety of load conditions such as dead loads, live loads (IRC Class AA and 70R), seismic loads (according to IS 1893:2016), wind loads, thermal effects, and vehicular impact loads. Suitable combinations of loads are imposed according to relevant IRC and IS code requirements so as to obtain a safe and serviceable design.Core design issues of differential deflection between stages, mechanisms for load transfer, vertical clearance specifications, and foundation-pier interaction are resolved by the use of sophisticated modeling methods. Response Spectrum Analysis is used to analyze the dynamic characteristics of the structure under seismic excitation, and staged construction analysis is taken into account to capture realistic construction sequences.Results show the structural efficiency and reliability of the designed double-stage flyover under different critical load cases. The research concludes that SAP2000 is a valid means of analyzing and optimizing complicated multi-level flyover systems, providing useful information to engineers and planners of urban infrastructure. The research is part of the increasing literature focused on addressing the problem of urban traffic congestion by innovative structural design

1. INTRODUCTION

Accelerated urbanization and population growth have led to a sharp rise in traffic volume, particularly within cities. The growing need for fast and seamless traffic flow has made it imperative to have improved transportation infrastructure. Double-stage flyover is one such option—a multi-level bridge structure aimed at providing smooth traffic movement at strategic intersections by vertically separating traffic streams. This type of grade separation not only reduces congestion but also maximizes the use of land in high-density urban settings.Traditional single-level flyovers usually lack in dealing with the nuances of multi

directional and high-density traffic. A double-stage flyover, however, involves two

independent levels of carriageways on a common or partially shared substructure. This method brings forth peculiar structural challenges, including augmented load requirements, seismic susceptibility, interaction forces between phases, and intricate staging of construction.Structural design and analysis of this type of system need sophisticated modeling techniques that can replicate actual behavior under various loading conditions. In the present research, SAP2000, a robust finite element analysis software tool, is utilized to simulate and analyze a two-level flyover structure. The flyover is constructed by reinforced concrete box girders and piers, keeping in mind various load conditions such as dead load, live load (IRC Class AA and 70R), seismic loads (IS 1893:2016), wind, temperature, and braking forces of vehicles.

The aim of this study is to examine the structural behavior of a double-stage flyover by using detailed modeling, analysis, and design verification. The research focuses on the determination of important stress zones, analysis of deflection and displacement characteristics, determination of the influence of load combinations, and satisfaction of applicable Indian standards. Moreover, the study delves into applied design issues like vertical clearance, foundation design, and construction sequencing.This paper adds to the body of knowledge in transportation infrastructure by proposing a systematic approach to the structural design and analysis of intricate multi-level flyover systems, providing insights useful for engineers, designers, and urban planners concerned with the development of sustainable urban mobility options.

1.1. Necessity For The Project

Urban cities are experiencing acute traffic congestion as a result of urban population growth and restrained road space. Conventional traffic solutions, such as single-level flyovers, are no longer adequate for busy intersections. Double-stage flyover offers an efficient method to divert traffic vertically, enhancing flow and minimizing delays without the need for extra land. Such structures, however, bring forth sophisticated design issues such as added loads, seismic susceptibility, and constructional difficulties. For structural efficiency and safety, the use of advanced analysis with tools such as SAP2000 is necessary. The project responds to the critical necessity for innovative, space-savvy, and technically viable solutions for urban traffic control.

1.2. Objectives:

- To investigate high traffic density requirements of a flyover bridge
- To examine essentials for seamless industrial and agriculture good movement
- To reduce the traffic delay and propose flyover with good ethics and architectural outlook.

2. LITERATURE SURVEY

In this paper the research addresses the issues which arise in high traffic region in Trichy.The

study affects traffic behavior of both the structural elements of highway and flyover bridge systems. In addition, it is also illustrated that has positive impact on the superstructure response and at times create unwanted effects on the system behavior and depends on the nature of the high volume of vehicle movement intensity. In my case here, I take the location to be between Trichy to Chennai Highway since there are more traffic issues particularly during peak hours. It is an overpass and underpass combined form a grade separation. Stack interchanges consist of numerous over passes. For Pedestrians cross over busy road without affecting traffic. Survey is a research methodology employed for gathering data from various sources in order to carry out the project effectively. To carry out the project, I have carried out survey to gather the density of traffic flow and to find out the density of traffic flow in moments of time. Here by me I have surveyed for density of vehicles at on at various intervals of time to get proper results at that specific junction. I have also seen that there are various types of vehicles passing through on at various moments of time. There is difference in vehicles that. Pass through this junction, I here have recorded the density of traffic follow which passes through

[1].Paper name:- Analysis of flyover structures with various loads M. Alla Rangaswamy, International Journal of Engineering Sciences & Research Technology, and March 2022

Author name :- M.Alla Rangaswamy

Description:- It takes time to construct flyover design, construction, and installation traffic easing devices. ONGOLE's 600m-long, 6.6m-wide flyover also has the same. Higher cost of flyover is offset by seismic durability, lifetime, and life cycle cost savings. Bridges and fly overs don't have roadblocks. Road, railroad, or valley route is what this is. Creativity, practicability, safety, and economy are needed in bridge design. A structure should be constructed to withstand all anticipated use during its lifespan. The structure must be durable.
Congested traffic requires flyovers or over bridges. We are designing a flyover. Four motorways intersect at a pipeline, producing traffic issues

[2].Paper name:- Design of Flyover Construction using Fibre Reinforced Concrete and Timber Pile Foundation J Prakash Arul Jose, International Journal of Applied Engineering Research, 2022

Author name :- J.Prakash Arul Jose

Description:- The project is one of a kind among other construction systems in which the deck and pile foundations consist of huge timber concrete vertical support through earth matters up to the rock layers. The superstructure's girders are constructed from fibre reinforced concrete. The design, right from its inception until its completion, is depicted with requisite diagrams.
The construction is subjected to a series of tests to ascertain its stability and durability.

[3].Paper name:- Analysis and Design of Skew Flyovers Nikhil V. Deshmukh, International

Journal of Science and Research (IJSR) 2018

Author name :- Nikhil V. Deshmukh
Description:- Flyovers are extremely unique type of structures. They are distinguished by their simplicity in geometry and load conditions. The Flyovers of reinforced concrete used to carry uniformly distributed dead load, vehicular live load to its surface and transfer same to the support through flexure, shear and torsion. Newly constructed Flyovers are frequently skew. This is because space limitations in dense urban environments. It can also be required because of geographical reasons like mountainous areas. But force flow in skew Flyovers is far more complex than straight Flyovers. Hence thorough study and numerical analysis must be done, where a skew Flyovers can be modelled in a variety of ways. Distorted slab Flyovers were analyzed with finite-element techniques with Csi Flyover computer software to investigate their behavior under uniform and moving loads with in order to ascertain the most suitable force response for design.

3. RESEARCH OF METHODOLOGY

This research adopts a systematic method for modeling, analyzing, and assessing the structural behavior of a double-stage flyover under loads of different nature using SAP2000. The adopted methodology for the research includes the following major steps:

3.1 Data Collection and Preliminary Planning

Choice of representative urban site with common traffic loads. Choice of span length, carriageway widths, number of levels, pier heights, and support conditions from standard flyover configurations. Use of applicable design codes like IRC 6, IRC 112, IS 456:2000, and IS 1893:2016 for load requirements and design specifications.

3.2 Modeling in SAP2000

Generation of a 3D finite element model for the double-stage flyover.Declaration of material properties (M40 concrete, Fe500 steel).Allocation of cross-sectional properties for box girders, piers, and substructure elements. Utilization of shell elements for deck slabs and frame elements for girders and piers.Incorporating boundary conditions (fixed and spring supports for piers and foundations).

3.3 Load Application

- Loading of various load cases according to Indian standards:
- Dead Load: Self-weight, parapets, wearing coat.
- Live Load: IRC Class AA and Class 70R vehicle loading.
- Seismic Load: According to IS 1893:2016 by Response Spectrum Analysis.
- Wind Load: According to IS 875 Part 3.
- Temperature Effects and Braking/Impact Loads.

Conduction of Linear Static Analysis and Response Spectrum Analysis.
Assessment of important structural responses like:

- Bending moments
- Shear forces
- Axial forces
- Deflections
- Support reactions
- Location of maximum stress points and possible design issues.

3.5 Design Checks

- Checking of structural members for:
- Ultimate load capacity
- Serviceability limits (deflection, vibration, crack width)
- Reinforcement detailing according to IRC 112 and IS 456
- Foundation check for design based on pier load reactions.

3.6 Interpretation and Documentation

- Tabsulation of results of analysis and interpretation of structural behavior.
- Comments on design complexities and recommendations for double-stage flyover schemes.
- Preparation of detailed design documentation, drawings, and conclusions

4. RESULTS:-

I-Girder of Double Decker Auto-Seismic IS-1893:2016

TABLE: AUTO SEISMIC - IS1893:2016					
Load Patterns	Directions	Z-Code	Soil Type	I	R
Text	Text	Text	Text	Unit less	Unit less
EX	X	0.10	II	1	5
EY	X	0.10	II	1	5

I-Girder of Double Decker Auto-Seismic IS-1893:2016

TABLE: AUTO SEISMIC - IS1893:2016					
Load Patterns	Directions	Z-Code	Soil Type	I	R
Text	Text	Text	Text	Unit less	Unit less
EX	X	0.10	II	1	5
EY	X	0.10	II	1	5

5. ACKNOWLEDGEMENT:-

I would like to thank all the people who have inspired and guided me through the successful completion of this project on the Analysis and Design of a Double-Stage Flyover with the help of SAP2000.I am first immensely thankful to Marathwada Mitra Mandal Institute Of Technology, Lohgaon and the Department of Civil Engineering for the generous kindness of providing me the opportunity and resources to carry out this project. I would like to thank my project guide, Prof.M.P.Pawar, whose professional guidance, fruitful suggestions, and continuous motivation were instrumental in shaping this work. My thanks to the faculty and staff members of the Civil Engineering department for their valuable suggestions, technical input, and encouragement throughout the course of this project.

I owe thanks to the SAP2000 developers, with their high-end structural analysis and design capabilities, for enabling it to perform the intricate modeling and analysis needed in a double-stage flyover structure. Finally, I thank my family and friends for the constant support, who were patient and motivated me to stay determined and focused on achieving the aim of this project.

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TerrainDependent Wind Loading And Structaral Response Of Tall Buildings

line 1: 1st Akshata Rajendra Bodke
line 2: P.G. Student, Structural Engineering, Department of Civil Engineering,
line 3: K. J. College of Engineering & Management Research, Pune, MS India, 411048
line 4: Pune, India
line 5: akshatabodke31@gmail.come

line 1: 2nd Dr. Santosh.K.Patil
line 2: Head of Department of Civil Engineering
line 3: K. J. College of Engineering & Management Research, Pune, MS India, 411048
line 4: Pune, India
line 5: santosh68.patil@gmail.com

line 1: 3rd Dr Atul.B.Pujari
line 2: Associate Professor, Department of Civil Engineering,
line 3: K. J. College of Engineering & Management Research, Pune, MS India, 411048
line 4: Pune India
line 5: atulpujari.kjcoemr@kjei.edu.in

Abstract— This study presents a detailed parametric investigation into the effects of wind loads on tall buildings constructed in different terrain categories, as defined in IS 875 (Part 3): 2015. The primary aim is to evaluate and compare the wind-induced structural responses of a G+10 reinforced concrete framed building under varying terrain conditions—namely Terrain Category I, II, III, and IV. Each terrain type has a significant influence on the wind pressure acting on the building, due to differences in surface roughness and obstruction levels. Using ETABS software, the building is modeled and analyzed with wind loads applied in both the X and Y directions, considering linear static wind load analysis for each terrain condition.

The structural parameters studied include base shear, overturning moment, lateral displacement, and storey drift. These are extracted from the software output and compared to assess the performance and stability of the building across different terrain categories. The allowable deflection is limited to H/500, and the building's response is checked against this criterion to ensure code compliance.

Results show that the wind effects are most severe in Terrain Category I due to minimal surface obstruction, while Terrain Category IV, representing densely built-up urban zones, leads to significantly reduced wind pressures and corresponding structural responses. The study emphasizes the importance of terrain categorization in wind load design, highlighting how incorrect assumptions can lead to unsafe or uneconomical structures. The conclusions derived from this project offer practical insights for structural engineers and designers, supporting terrain-sensitive design decisions for enhanced safety, performance, and cost-efficiency in tall building construction.

Keywords: Wind Load, Terrain Categories, IS 875 (Part 3): 2015, Tall Buildings, G+10 Building, ETABS, Base Shear, Overturning Moment, Storey Drift, Lateral Displacement, Structural Analysis, Wind Pressure, Surface Roughness, Building Design, Terrain Roughness, Wind Response, Static Wind Analysis, Structural Performance, Mid-Rise Structures, Code Compliance.

I. Introduction

In recent years, the demand for tall buildings has significantly increased due to rapid urbanization, limited land availability, and the growing need for vertical expansion in cities. As the height of buildings increases, the influence of lateral loads, particularly wind loads, becomes a dominant factor in structural design. Wind can exert considerable forces on high-rise structures, causing displacements, drifts, and moments that must be carefully analyzed to ensure safety, stability, and comfort. The behavior of a building under wind loading is not only governed by its height and geometry but also by the surrounding terrain, which directly influences wind speed and pressure distribution on the structure.

The Indian Standard IS 875 (Part 3): 2015 provides comprehensive guidelines for estimating wind loads on buildings and structures. One of the critical factors addressed in this code is the classification of terrain categories, which represent different types of ground surface conditions—from open fields to densely built-up urban areas. Each terrain category affects the wind flow characteristics and modifies the design wind speed through the use of terrain roughness and height-dependent coefficients. The terrain categories are broadly divided into four types: Terrain Category I (open terrain with few obstructions), Terrain Category II (open terrain with scattered obstructions), Terrain Category III (suburban areas with medium-density construction), and Terrain Category IV (city centers with tall buildings closely spaced). These classifications play a vital role in determining the magnitude of wind pressure that a structure will experience.

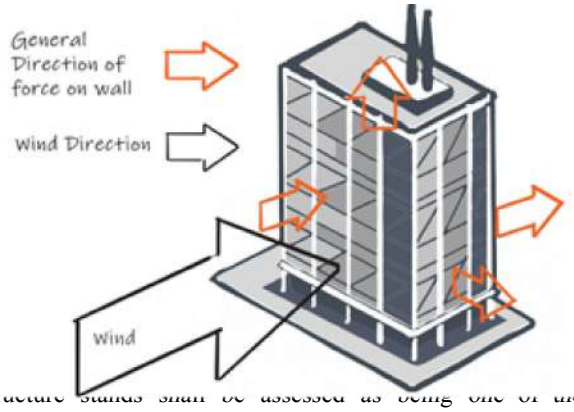
This study focuses on understanding how these terrain categories impact the wind-induced behavior of a mid-rise structure. A G+10 reinforced concrete framed building is considered for analysis, representing a typical tall building design used in urban environments. The structure is modeled and analyzed using ETABS, a widely accepted software for structural analysis and design. Wind loads are applied according to the code specifications for each terrain category, and the structural response is examined in terms of base shear, overturning moment, lateral deflection, and inter-storey drift. The analysis is conducted for wind loads in both principal directions (X and Y), and results are compared to evaluate the significance of terrain variation.

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By performing a comparative study, the project aims to provide valuable insights into how different terrain conditions affect wind load distribution and overall structural behavior. The findings are intended to assist structural engineers in making informed decisions when designing wind-resistant structures, especially in regions where terrain conditions can vary widely over short distances. The study also evaluates the compliance of the structure with serviceability limits, such as the allowable deflection (H/500), ensuring that the building not only remains structurally sound but also functions effectively without causing discomfort to occupants.

The importance of this analysis lies in its practical application. A thorough understanding of terrain influence helps optimize material use, avoid overdesign, and enhance the safety and performance of the building. In real-world scenarios, overlooking terrain effects can lead to either underestimation or overestimation of wind forces, resulting in unsafe designs or unnecessary construction costs. Therefore, incorporating terrain-based wind analysis in structural design is essential for efficient, economical, and reliable building construction.

Through this project, the dynamic interaction between wind forces and terrain features is explored in depth, contributing to the broader goal of sustainable and resilient infrastructure development.



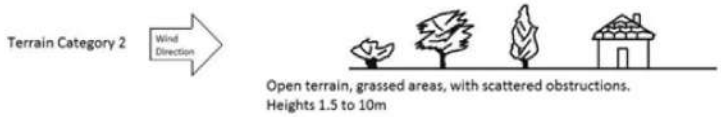
structure stands shall be assessed as being one of the following terrain categories:

1.1.1 Terrain Category 1: Open Terrain with Very Few Obstructions

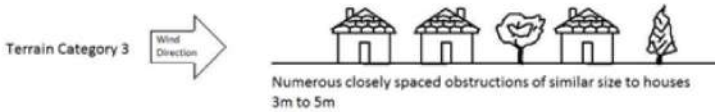
This category represents open terrain with very few or no obstructions. It includes flat, open areas such as seashores, airfields, or deserts where the wind flow is unobstructed for long distances. Wind speeds are highest in this category due to minimal surface roughness.



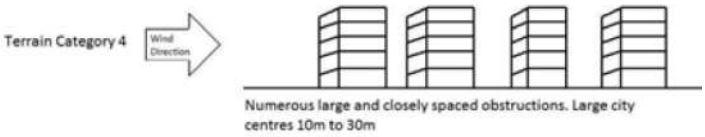
This terrain consists of open areas with scattered obstructions that are typically less than 10 meters high. Examples include grasslands, agricultural fields with sparse trees, and lightly populated areas. Wind flow is slightly reduced compared to Category I.



This category includes areas with numerous closely spaced obstructions, generally between 10 to 15 meters high. Typical examples are suburban areas, industrial zones, or semi-urban regions with medium-density buildings and trees.



buildings or structures. Commonly found in city centers and dense urban zones, this category has the highest surface roughness, significantly reducing the effective wind speed near ground level.



1. Durgesh Nandan Yadav and Anjali Rai, presented “Study of Wind Load on Tall RC Frame Building with Shear Wall in Coastal Region” In this study, the performance of a high-rise reinforced concrete (RC) frame building under lateral wind loads is evaluated, focusing particularly on the structural behavior with and without the inclusion of shear walls. The aim is to determine the most effective shear wall configuration that enhances the lateral load resistance of the building. A G+31 RC frame structure is taken as the model for this analysis, and it is subjected to lateral forces generated by wind with a basic wind speed of 50 m/s, as per the guidelines of IS 875 (Part 3): 2015.

Several configurations of shear walls are incorporated into the model to assess their influence on structural response. Key parameters analyzed include the natural time period, storey drift, and storey displacement. The results are then compared to identify the optimal positioning of the shear wall for improved performance.

The findings indicate that the bare frame (without shear walls) exhibits the highest natural time period due to the absence of lateral stiffness at joints. Introducing shear walls at the corners significantly enhances the stiffness, resulting in the lowest time period among all configurations. When evaluating inter-storey drift, the normal frame shows the highest value of 12.761 mm. This is followed by slightly reduced drift values for the configurations with outer center (5.88 mm) and core shear walls (5.74 mm), while the corner shear wall configuration exhibits the lowest drift at 4.609 mm.

Moreover, the natural time period decreases with the corner shear wall arrangement because the added stiffness outweighs the increase in structural mass. Similarly, the maximum lateral displacement is observed in the bare frame at 303.339 mm, while the corner shear wall model records the minimum displacement of 108.508 mm, highlighting its effectiveness in minimizing structural deformation under wind loads.

In conclusion, the corner shear wall configuration proves to be the most effective in enhancing stiffness, reducing lateral displacements, and limiting storey drift, thereby offering the ance to wind-induced lateral forces in high-rise res.

2. Mohammed Ali, Mohammed Zaker, Syed Farrukh Anwar Investigate on “Effect of Wind Load On Low, Medium, High Rise Buildings in Different Terrain Category” This research investigates the effects of wind-induced forces—specifically storey drift, storey shear, and support reactions—on buildings of varying heights, namely low-rise, mid-rise, and high-rise structures. A total of 12 models comprising G+5, G+10, and G+15 storey reinforced concrete (RC) frame buildings were created and analyzed using ETABS version 9.7.4. The primary objective is to study how these structural responses vary with building height and under different terrain categories as per IS 875 (Part 3): 2015. The analysis includes a comparative evaluation of the percentage changes in drift and shear for the same building model located in varying terrain conditions.

Tall buildings are susceptible to wind-induced vibrations in both along-wind and across-wind directions. Even when designed to meet lateral displacement criteria, these structures can experience considerable oscillations during strong wind events. Such movements, while not always structurally dangerous, may cause discomfort to occupants, thereby raising concerns related to serviceability. Therefore, an accurate analysis of a building’s dynamic behavior under wind loading becomes essential to ensure both structural safety and occupant comfort.

Wind, being a naturally occurring movement of air relative to the Earth's surface, exerts dynamic pressure on all exposed structures. The speed of wind is influenced significantly by the surface characteristics of the terrain—it tends to move faster over smooth terrain and slower over rough surfaces. The current study is aimed at understanding how wind behavior impacts RC framed buildings by analyzing the performance of symmetrical bare frame models subjected to wind loading across different terrain types.

The terrain categories considered in this work include Terrain Category I (open terrain), Terrain Category II (scattered obstructions), Terrain Category III (suburban areas), and Terrain Category IV (urban areas with dense construction). Each of these terrains affects wind speed and pressure distribution differently, which in turn influences the structural response of buildings.

Dynamic analysis methods were employed to simulate wind action and evaluate its effect on buildings with 6, 11, and 16 storeys. These height variations represent typical low-, medium-, and high-rise structures. The findings of this study provide important insights into the changing behavior of wind-induced responses such as drift and shear across different building heights and terrain categories. It emphasizes the necessity of accounting for terrain conditions when designing buildings to resist wind loads, particularly as the height of the building increases.

This study contributes to a better understanding of the performance of RC structures under varying wind conditions and highlights the importance of terrain categorization in structural wind analysis. The results are valuable for engineers involved in designing wind-resistant buildings, ensuring both structural efficiency and comfort for occupants.

3. Amit K. Mali, Vishal Kumar B. Patel, Atul N. Desai research on “Effect of Dynamic Wind Load On Tall Structure Using Gust Factor Method” In this research, a comprehensive study was carried out to evaluate shear force and bending moment multipliers using MATLAB, based on an extensive dataset comprising 155,040 samples. The core objective was to analyze the influence of the gust factor on a 100-meter-tall structure, while considering a breadth-to-height (B/H) ratio ranging from 0.2 to 1.2, and varying the length-to-breadth (L/B) ratio from 0 to 50. To assess the impact on structural behavior, the height of the buildings was extended from 50 meters to 450 meters.

The research also focused on understanding how the fundamental frequency of a structure affects the gust factor, which led to the development of elastic spectra for further analysis. Given the rapid advancements in construction techniques and materials, along with escalating urbanization and rising land costs, the vertical expansion of cities through high- rise buildings is becoming more prevalent. It was observed that as the slenderness of a building increases, the gust factor also tends to rise. Flexible structures were found to have higher gust factors when compared to stiffer counterparts.

The generated elastic spectra indicated that the gust factor decreases as the natural frequency of the structure increases, eventually reaching a plateau beyond a specific frequency threshold. This study utilized pre-calculated multipliers for shear force and bending moment along with elastic gust spectra, offering a significantly faster method compared to traditional manual calculations. These results were cross-referenced with values obtained using the IS 875:2015 code, showing a margin of error of less than 10%.

One of the significant findings was the variation of shear force and bending moment multipliers along the height of a structure. These multipliers decreased progressively from a value of 1 at the base to approximately 0 at the top. For taller structures, the values of these multipliers were observed to be greater than those of shorter buildings. Additionally, as the terrain category changed—specifically moving from smoother to rougher terrains—the multipliers also increased.

Furthermore, the study highlighted that the gust factor is sensitive to variations in the building's plan aspect ratio. As the time period of a structure increases—or conversely, as its natural frequency decreases—the gust factor tends to rise. Consequently, flexible or slender buildings experience greater wind-induced effects than more rigid ones. It was also noted that with an increase in the length-to-width ratio of a building, various wind-responsive parameters begin to stabilize and eventually become constant, resulting in a diminished wind load on the structure.

Overall, the research presents a detailed and efficient approach to understanding the influence of wind dynamics on tall structures, particularly focusing on gust factors and their interaction with building geometry, frequency characteristics, and terrain conditions.

1.1 Advantages

i. Quantitative Terrain Impact: Clearly demonstrates how moving from Terrain I to IV reduces base shear, overturning moment, deflection, and drift by up to ~28 %, giving designers concrete data on exposure effects.

ii. Serviceability Focus: Confirms that maximum deflections remain within the H/500 limit (64 mm), ensuring occupant comfort and proper cladding/equipment performance under design wind loads.
iii. Code Validation: Reinforces confidence in IS 875 (Part 3) by showing that its simplified, quasi‑static formulas predict intuitive and consistent reductions in wind effects across terrain categories.
iv. Cost Optimization: Illustrates how correct terrain classification avoids both over‑design (inflated material costs) and under‑design (safety risks), enabling economic steel, concrete, and damping system sizing.
v. Framework for Extensions: Establishes a controlled baseline (G + 10, flat terrain) that can be built upon in future studies to include topography factors, varied geometries, or dynamic analyses.

1.2 Disadvantages

i. Simplified Wind Modelling: Uses code‑based, quasi‑static wind formulas that cannot capture sitespecific dynamic phenomena (vortex shedding, gust resonances), potentially underestimating peak responses.
ii. Limited Building Typology: Focuses on a single G + 10 rectangular towers; results may not generalize to taller, more slender, setback, or mixeduse configurations with different stiffness characteristics.
iii. Neglect of Local Effects: Omits complex topographic accelerations (hills, valleys) and microclimate variations (coastal vs. inland wind patterns), which can significantly alter exposure beyond flat‑terrain categories.
iv. No Facade or Urban Canyon Modelling: Ignores the impact of balconies, porous facades, neighboring structures, and street‑canyon turbulence that affect local pressure distributions in dense urban settings.
v. Lack of Uncertainty Analysis: Does not include probabilistic wind speed variability or terrain classification ambiguity, leaving potential gaps in risk‑based design and worstcase scenario assessment.

2. OBJECTIVES

Objectives of study:

i. To evaluate the impact of different terrain categories on the wind load experienced by a tall building as per IS 875 (Part 3): 2015, focusing on Terrain Categories I, II, III, and IV.
ii. To analyse wind-induced structural responses such as base shear, overturning moment, lateral displacement, and storey drift for a mid-rise structure subjected to varying terrain conditions.
iii. To model a G+10 reinforced concrete framed building using ETABS software, ensuring accurate representation of geometry, material properties, and load combinations in compliance with IS codes.
iv. To apply wind loads in ETABS based on terrain-dependent wind pressure coefficients and height-wise variation of wind speed, using standard parameters like basic wind speed, importance factor, and gust factor.
v. To compare the structural performance of the building under each terrain category, emphasizing how surface roughness affects the magnitude and distribution of wind forces on the structure.
vi. To verify that the computed displacements due to wind loading are within the allowable deflection limits (H/500), ensuring both safety and serviceability criteria are met.
vii. To study the directional influence of wind (WLX and WLY) on building behavior, identifying the governing wind direction and most critical terrain category for design.
viii. To generate comparative graphs for key wind-induced parameters across terrain categories, enabling visual understanding and interpretation of results for design decisions.

3. METHODOLOGY

The methodology adopted in this research is a systematic process designed to evaluate the influence of wind load on a G+10 reinforced concrete (RC) framed building situated in different terrain categories as per IS 875 Part 3:2015. The study begins with a comprehensive review of relevant literature and Indian Standards to gain a deep understanding of the principles governing wind loads on tall buildings. Special attention is given to the wind load calculations, terrain classification, and structural response under lateral loading. The terrain categories as defined in IS 875—namely Category I, II, III, and IV—are critically studied based on their roughness, openness, and obstruction levels to appreciate their role in wind behavior.

The building chosen for this study is a G+10 structure with a total height of 32 meters and a typical floor height of 3 meters. The structure is modeled as a bare RC frame without any shear walls or bracing systems, to isolate and analyze the pure effect of terrain- induced wind loads. The modeling is carried out using ETABS v18, a widely used software for structural analysis and design. Standard design parameters are used, with M30 grade concrete and Fe500 grade reinforcement steel. The building plan is kept constant for all models, with uniform bay spacing, to maintain consistency in geometric configuration and allow a direct comparison of results across different terrain categories.

Wind loads are calculated in accordance with IS 875 Part 3:2015, considering a basic wind speed of 50 m/s, which is suitable for structures located in critical wind-prone zones. Wind pressures are determined for each height level of the building and applied in both the X and Y directions (WLX and WLY). Separate wind load profiles are assigned to each model based on the specific terrain category: Category I represents open terrain with few obstructions; Category II includes open terrain with scattered obstructions; Category III corresponds to suburban terrain with numerous closely spaced obstructions; and Category IV represents urban terrain with high building density and vegetation. These classifications influence the design wind pressure, which directly impacts the structural response.

The analysis phase involves performing a static wind load analysis for each model under its respective terrain condition. Key structural responses, such as story displacement, story drift, base shear, and overturning moment, are recorded from the analysis. The displacements are checked against the permissible limits defined in the IS code, particularly the deflection limit of H/500, which corresponds to a maximum allowable displacement of 64 mm for the 32-meter-tall structure. Results are extracted and compiled for each floor level to observe the variation in structural behavior across the height of the building.

To better visualize and interpret the results, various plots are generated for comparison. These include displacement vs. height, drift vs. height, and variations in base shear and overturning moment for different terrain categories. The comparative analysis highlights how terrain conditions significantly affect wind pressure distribution and the resulting structural response. For example, buildings in Terrain Category I experience higher displacements and drift due to less obstruction to wind flow, whereas Terrain Category IV shows significantly reduced responses due to the shielding effect of surrounding structures.

The final part of the methodology involves interpreting the results in light of codal provisions and practical performance expectations. Structural performance in each terrain category is evaluated based on compliance with serviceability and strength criteria. The methodology allows for a detailed understanding of how terrain variations impact wind-induced forces and deformations in a tall building, which can guide future design optimizations. The study concludes with key observations, emphasizing the importance of terrain consideration in wind load analysis and recommending further exploration, such as integrating shear walls or altering geometrical layouts to enhance wind resistance in exposed terrains.

4. MODELING AND ANALYSIS

4.1 Material Properties and Section Properties:

Concrete grade: M30, Steel grade: HYSD500
Beam - 450X600 MM
300X600 MM
Column - 600X900 MM
Slab thickness -150MM

4.2. Load calculations:

Dead load and live load calculation on slab (As Per IS 875-2015 Part-1 & Part-2 clause 3.1 Table 1) :

Dead load calculation (from IS 875 part 1):
Dead Load = 1.5 KN/m2
Live Load = 2 KN/m2

4.3 Wind load calculations:

The wind load acting on the G+10 RC building in this study is calculated based on the provisions of the Indian Standard Code IS 875 (Part 3) – 2015, which deals with the "Design Loads for Buildings and Structures – Wind Loads". The methodology and parameters considered in this wind load calculation are explained below:

Basic Wind Speed (Vb)
For this study, a basic wind speed of 47 m/s has been considered. This corresponds to high wind pressure regions like Coastal and Zone V areas in India.
Design Wind Speed (Vz)
The design wind speed at any height z is calculated using the formula:
$Vz=Vb\times k1\times k2\times k3$
Where:
Vb = Basic Wind Speed (47 m/s)
k_1 = Risk Coefficient (Importance Factor)
k_2 = Terrain, height and structure size factor
k_3 = Topography factor (assumed 1.0 for flat terrain)
Risk Coefficient (k_1)
As per IS 875 Part 3:2015, for general buildings with a design life of 50 years, the risk coefficient is: k1=1.0
Terrain Category & k_2 Factor
The k_2 factor depends on the terrain category, height of the building, and size of the structure. The building is modelled in four different terrain categories.
Topography Factor (k_3)
Assuming flat terrain without significant topographic features:
k3=1.0
Design Wind Pressure (Pz)
Once the design wind speed is determined, the wind pressure is calculated as:
$Pz = 0.6\times Vz2$ (in N/m2)
Where, Vz is in m/s.
Wind Load on Structure (F)
The wind load on each storey is calculated as:
$F = Pz \times A \times Cf$
Where:
Pz = Wind pressure at height z
A = Effective area of the wall/structure exposed to wind
Cf = Force coefficient (typically 1.0 to 1.3 for flat surfaces)
This wind load data serves as the primary lateral load input in the structural model. The analysis results such as base shear, overturning moment, displacement, and drift are directly influenced by these loads, and the impact of terrain category on wind-induced forces is evaluated in detail throughout the study.

4.4. Modeling in ETABS 2018- version 18.1.1

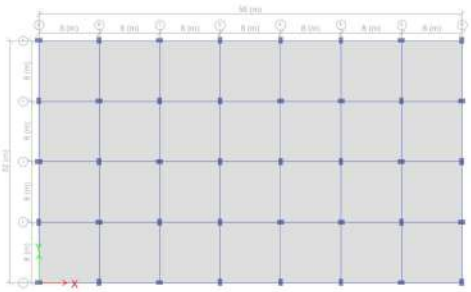
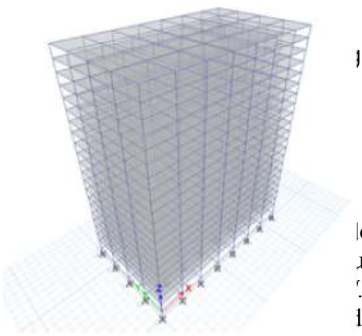


Figure 3. Plan View of Building

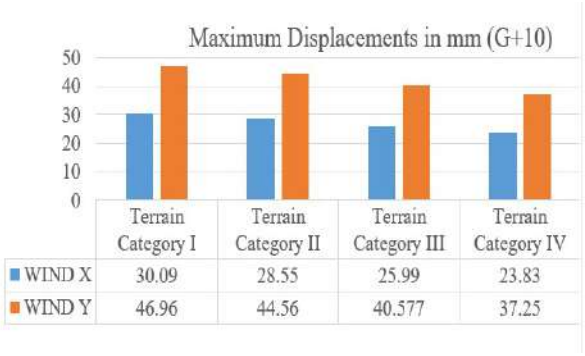


loads acting on buildings
nding terrain conditions,
. This study analyzed a
l to wind loads in both X and Y directions across these terrain types. The permissible lateral deflection limit was considered as H/500 (64 mm).

In Terrain Category I (open terrain), the building showed the maximum displacement: 30.09 mm in X and 46.96 mm in Y direction, due to unrestricted wind flow. Moving to Terrain Category II (scattered obstructions), displacements slightly reduced to 28.55 mm (X) and 44.56 mm (Y). In Terrain Category III (urban residential areas), values dropped further to 25.99 mm (X) and 40.577 mm (Y). Terrain Category IV, representing dense urban zones, resulted in the minimum displacement of 23.83 mm (X) and 37.25 mm (Y), indicating effective wind shielding.

Across all categories, Y-direction displacements were higher than X-direction, highlighting directional flexibility in the structure. Importantly, all displacements remained within the allowable limit, proving the design's adequacy. The study emphasizes the significance of proper terrain classification to ensure safe, serviceable, and economically efficient structural design under wind loads.

Figure 4. Maximum horizontal displacement due to lateral force



5.2 Drift :

As per the drift limitations prescribed in IS 1893 (Part I): 2016, the allowable storey drift for any building should not exceed 0.004 times the respective storey height. In this study, a detailed assessment of a G+10 reinforced concrete building was conducted to evaluate storey drift due to wind loads in both the X and Y directions, across all four terrain categories defined by IS 875. The results are presented through comparative graphs and tables that highlight the drift variations at each storey level.

The analysis indicates that maximum drift consistently occurs at the first storey level in all scenarios, gradually decreasing toward the top storeys. This pattern is typical in wind load behavior, where the base stories, being more constrained, undergo greater deformation due to the accumulation of lateral forces and the structural continuity.

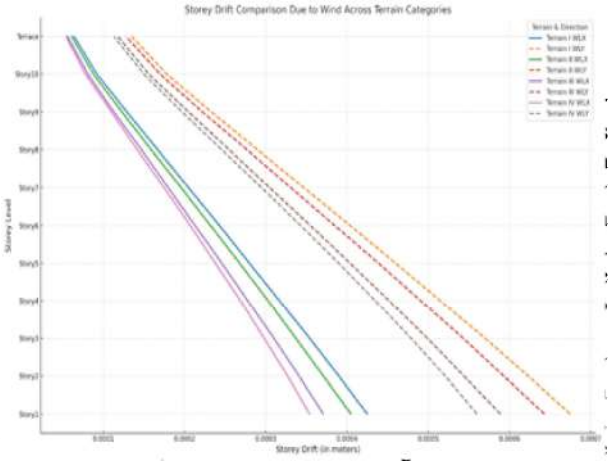
Terrain Category I, which denotes open areas with minimal obstructions such as open countryside or coastal zones, leads to the highest drift values. For this category, the first-storey drift was observed as 0.000425 meters in the WLX (X-direction wind) and 0.000675 meters in the WLY (Y-direction wind). On the other hand, Terrain Category IV, representing densely developed urban zones with numerous high-rise obstructions, yielded the lowest drift values: 0.000354 meters (WLX) and 0.00056 meters (WLY). This difference signifies a reduction in drift by approximately 17%, highlighting the mitigating effect of dense urban surroundings on wind-induced structural displacement.

Across all terrain categories, the Y-direction (WLY) consistently resulted in greater drift values compared to the X-direction (WLX). For example, in Terrain Category II, the drift at the first storey was measured at 0.000643 meters in the Y direction, as opposed to 0.000405 meters in the X direction — a difference of nearly 59%. This indicates the building's relative flexibility or higher exposure in the Y-axis, possibly due to geometrical dimensions, orientation, or elevation profile.

While the overall drift pattern remains uniform across all terrain conditions—starting higher at the bottom and tapering off towards the top—the magnitude of drift varies significantly. This variation confirms that terrain roughness affects the intensity of wind forces, though not the distribution trend of structural response.

In summary, the findings underscore the critical role of terrain classification in wind load analysis. Structures located in open terrains are more susceptible to higher wind-induced deformations and require more robust lateral load-resisting systems. In contrast, buildings situated in dense urban zones benefit from the shielding effect of adjacent structures, potentially allowing for more efficient and economical design. Proper terrain-specific wind evaluation is therefore essential to ensure safety, serviceability, and cost-effectiveness in the design of wind-resistant buildings.

Figure 5. Drift in structure due to lateral force



overturning moment exceeds the stabilizing moment provided by the weight of the structure and any resisting elements, the building may become unstable, leading to partial or total structural failure.

Design codes, including the IS Code (Indian Standards), prescribe methods to compute wind loads and associated overturning moments, incorporating factors such as building height, shape, exposure category (terrain type), and wind speed.

The presented analysis compares the overturning moments (in kN·m) experienced by a G+10 structure under wind loads across different terrain categories, in accordance with IS code standards. Both wind directions — WLX (X-axis) and WLY (Y-axis) — are considered to examine the influence of terrain roughness on the magnitude of these moments.

It is clearly observed that Terrain Category I, which signifies open and unobstructed areas like coastal zones or open fields, results in the highest overturning moments — 163,114 kN·m in WLX and 233,550 kN·m in WLY. As the terrain becomes rougher with increased obstructions, the overturning moments decrease gradually, indicating the protective effect of surrounding built-up environments.

In Terrain Category II, representing partially obstructed suburban areas, the overturning moments reduce to 154,722 kN·m (WLX) and 221,534 kN·m (WLY), showing a moderate decline of approximately 5% compared to Terrain I. Moving further into Terrain Category III, typical of semi-urban localities, values drop more significantly to 140,784 kN·m (WLX) and 201,577 kN·m (WLY), reflecting a reduction of nearly 13.7% in both directions.

The lowest overturning moments occur in Terrain Category IV, which corresponds to dense city environments with many high-rise obstructions. Here, the values reach 128,868 kN·m in WLX and 184,516 kN·m in WLY, marking a total decrease of about 21% compared to open terrain.

Across all categories, the WLY values remain consistently higher than WLX, with a variation of approximately 42% to 44%. This suggests a directional sensitivity in the structural response, likely influenced by the building's geometry or orientation relative to prevailing wind flow.

In conclusion, the findings underline the significant role of terrain category in determining overturning moment magnitudes due to wind. Structures in open terrain face greater wind-induced demands, necessitating stronger lateral load-resisting and foundation systems, while those in dense urban zones benefit from natural wind shielding. Such considerations are essential in designing efficient and safe tall buildings.



Figure 6. Overturning moment comparison

5.4 Base Shear :

Table 2. Base in structure due to wind

	Terrain Category I	Terrain Category II	T C
Base shear WLX (kN)	4151.68	3908.82	3
Base shear WLY (kN)	5944.46	5596.73	5

The table offers a comparative overview of base shear forces (in kN) acting on a G+10 building due to wind, across different terrain categories as per IS code provisions. Base shear, the total lateral force at the structure's base, is a crucial factor in wind load analysis.

The data shows that Terrain Category I, characterized by open landscapes with minimal obstructions, results in the highest base shear — 4151.68 kN in the X-direction (WLX) and 5944.46 kN in the Y-direction (WLY). This is expected, as unobstructed terrain allows wind to exert greater pressure on the structure.

In contrast, Terrain Category IV, typical of densely built urban settings, yields the lowest base shear values — 3047.74 kN (WLX) and 4363.82 kN (WLY). This marks a reduction of around 26.6% in both directions when compared to Category I, highlighting the wind-shielding effect of surrounding buildings.

The trend continues across intermediate terrain categories. Terrain II registers 3908.82 kN (WLX) and 5596.73 kN (WLY), while Terrain III records 3509.47 kN (WLX) and 5024.92 kN (WLY). These gradual reductions demonstrate the influence of terrain roughness on wind force intensity.

Additionally, the Y-direction base shear (WLY) is consistently greater than that in the X-direction (WLX) across all terrain types. For instance, in Terrain II, the WLY value is about 43% higher than WLX, suggesting a greater vulnerability or exposure along the Y-axis, likely due to the building's geometry or wind-facing orientation.

In summary, terrain conditions significantly impact base shear magnitudes, and the wind direction also plays a critical role. Accurate terrain classification and directional wind load analysis are essential for effective lateral load design in tall buildings, especially in wind-prone areas.

6. CONCLUSION

i. Effect of Terrain on Wind Response: The study demonstrates that terrain conditions have a significant influence on the wind-induced behavior of buildings. Terrain Category I, characterized by open, flat terrain with minimal obstructions, leads to the highest wind loads acting on the structure. This is due to greater wind speeds being maintained near ground level in such environments. On the other hand, Terrain Category IV, representing dense urban areas with closely spaced buildings and obstructions, shows a considerable reduction in wind effects. This reduction is attributed to the obstruction of wind flow, which increases surface roughness and turbulence, thereby reducing the overall wind pressure on buildings.

ii. Base Shear Comparison: The base shear, which represents the total horizontal wind force transferred to the building's foundation, is highest in Terrain Category I — recorded as 4151.68 kN (WLX) and 5944.46 kN (WLY). As the terrain becomes progressively more obstructed (Categories II to IV), the base shear decreases. For Terrain Category IV, it reduces to 3047.74 kN (WLX) and 4363.82 kN (WLY). This corresponds to a reduction of around 26% to 28%, indicating how effective surface roughness is in mitigating lateral forces. These findings highlight the necessity of selecting the correct terrain category for accurate wind force predictions during structural design.

iii. Overturning Moment Trend: Overturning moment, which measures the rotational effect of wind forces on the structure about its base, follows a similar pattern. The maximum overturning moments in Terrain Category I are 163114 kN·m (WLX) and 233550 kN·m (WLY). These values decrease steadily across higher terrain categories, reaching 128868 kN·m (WLX) and 184516 kN·m (WLY) in Terrain Category IV. This reduction of approximately 21% to 22% is significant because high overturning moments can lead to instability or excessive foundation stresses. Hence, accounting for terrain conditions during foundation and lateral load-resisting system design is crucial for safe and economical construction.

iv. Maximum Deflection: The maximum lateral deflection of the building, observed at the terrace level, is a key parameter for serviceability. The largest values were seen in Terrain Category I, with 30.09 mm in WLX and 46.96 mm in WLY, gradually reducing to 23.83 mm and 37.25 mm in Terrain Category IV. Despite the variation, all deflection values remain well within the permissible limit of 64 mm (H/500) for a 32-meter-tall building. This confirms that the structure maintains adequate lateral stiffness under all terrain conditions, though additional stiffness may be warranted in less sheltered environments.

v. Storey Drift Behavior: Drift, defined as the relative lateral displacement between two adjacent storeys, is another critical parameter that affects the comfort of occupants and structural performance. The drift values are maximum at the lower floors and peak in Terrain Category I, where the first storey shows drift values of 0.000425 (WLX) and 0.000675 (WLY). These values consistently decline across Terrain Categories II to IV, reaching 0.000354 and 0.000560 respectively. Since excessive drift can lead to non-structural damage and discomfort, especially in high-rise buildings, the observed trend supports the use of accurate terrain-based wind load assessments to prevent overdesign or underestimation.

vi. Direction Sensitivity: Across all terrain categories, it is evident that the Y-direction (WLY) consistently experiences higher wind-induced responses than the X-direction (WLX). This pattern is observed in base shear, overturning moment, deflection, and drift values. Such directional sensitivity may arise from the building's geometry, plan dimensions, or orientation relative to prevailing wind directions. This highlights the need for designers to evaluate both principal directions carefully and ensure that the lateral load-resisting system is appropriately distributed.

vii. Design Implications: The results of this parametric study emphasize the importance of incorporating the correct terrain category during wind load estimation, as per IS 875 (Part 3). The selection of an inappropriate terrain category could lead to either unsafe design (if wind forces are underestimated) or uneconomical overdesign (if overestimated). Terrain effects directly influence the magnitude of wind pressure, which in turn affects member sizing, connection detailing, and foundation design.

iii. Overall Observation: In conclusion, the study highlights a clear and consistent relationship between terrain category and the structural response of buildings to wind. As the terrain category increases from I to IV, there is a marked and predictable reduction in base shear, overturning moment, lateral deflection, and storey drift. These findings not only validate the provisions of the IS code but also provide a strong rationale for designers to integrate terrain considerations early in the design process to ensure structural efficiency, safety, and cost-effectiveness.

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EFFECT OF VERTICAL MASS IRREGULARITY ON P-DELTA AMPLIFICATION IN TALL STRUCTURES AN ETABS INVESTIGATION

Madhusudhan Anil Wani

PG Student

Department of Civil Engineering,

K.J. College of engineering and management research

Pune, India

madhusudhanwani0990@gmail.com

Dr. Santosh K. Patil

Head of Department,

Department of Civil Engineering,

K.J. College of engineering and management research

Pune, India

santosh68.patil@gmail.com

Dr. Atul B. Pujari

Professor

Department of Civil Engineering

K.J. College of engineering and management research

Pune, India

atulpujari.kjcoemr@kjei.edu.in

Prof. Abhijeet R. Undre

Assistant Professor,

Department of Civil Engineering,

K. J. College of Engineering & Management Research,

Pune, India

abhijeetundre.kjcoemr@*kjei*.edu.in

Abstract: *The stability and performance of tall buildings are significantly influenced by both the distribution of mass along their height and the effects of seismic loading, especially in high-risk zones. This study focuses on investigating the effect of vertical mass irregularity on P-Delta amplification in a G+20 building located in Seismic Zone V. Using ETABS software, detailed structural models were developed with varying mass distribution patterns, and analyses were conducted both with and without considering the P-Delta effect.*

The P-Delta effect, which arises from the secondary moments generated due to lateral displacements under seismic forces, can significantly impact the design and safety of tall structures. In this research, different types of mass irregularities such as top-heavy, base-heavy, and random mass distributions were introduced, and their influence on key structural parameters including storey drift, base shear, and lateral displacements was evaluated.

Comparative analysis revealed that vertical mass irregularities lead to noticeable amplification of P-Delta effects, resulting in increased displacements, higher storey drifts, and additional internal forces. The study highlights the critical need to incorporate the P-Delta effect in the seismic analysis and design of tall buildings with vertical mass irregularities to ensure structural safety and serviceability. Finally, design recommendations are proposed to mitigate the adverse effects associated with mass irregularities in tall structures.

Keywords: ***Vertical Mass Irregularity, P-Delta Effect, G+20 Building, Seismic Zone V, Tall Structures, ETABS, Seismic Analysis, Storey Drift, Base Shear, Structural Stability***

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1. INTRODUCTION

In the design of high-rise buildings, especially in regions prone to earthquakes, structural irregularities can significantly influence how a building responds to seismic forces. One such irregularity is vertical mass irregularity, which refers to an uneven distribution of mass along the height of a structure. This irregularity can result from architectural features, changes in material usage, or functional needs such as accommodating heavier machinery or mechanical floors on certain levels. When present, it alters the dynamic characteristics of the building and can lead to unexpected stress concentrations during seismic activity.

Another important consideration in tall structures is the P-Delta effect, a second-order phenomenon that arises due to the interaction between vertical loads and lateral displacements. As a structure sways during an earthquake, the vertical forces acting on displaced columns generate additional moments, which can amplify internal forces and lateral movements. This amplification can become critical in tall buildings, where the effects of height and flexibility make them more vulnerable to instability if not properly addressed in design.

This study focuses on understanding the combined impact of vertical mass irregularity and P-Delta effects on the seismic performance of a G+20 reinforced concrete building situated in Seismic Zone V, the highest seismic risk zone according to Indian standards (IS 1893:2016). The investigation uses ETABS software to model and analyze different scenarios, considering various mass distribution patterns such as concentrated mass at upper floors, lower floors, and uneven/random arrangements.

By comparing the behavior of the structure with and without considering the P-Delta effect, this research aims to highlight how mass irregularities influence seismic response parameters such as story drift, base shear, and overall displacement. The outcomes of this study are intended to provide insights that can help structural engineers make informed decisions during the design process, ensuring that tall buildings in high-risk seismic areas remain safe and stable under earthquake loading.

1.1 Vertical Mass Irregularity

Vertical mass irregularity occurs when there is an uneven distribution of mass along the height of a building. This condition can arise due to architectural or functional needs, such as placing heavy equipment or storage on specific floors, designing mezzanines, or creating open spaces with lighter structural elements at certain levels. In structural terms, this irregularity disrupts the uniform dynamic behavior of the building, leading to concentrated seismic forces at certain levels. As a result, floors with sudden increases or decreases in mass can experience higher accelerations and inter-storey drifts during seismic events. This irregularity can compromise the structural performance, particularly in tall buildings, where the mass distribution significantly influences the building's natural period and seismic response. The Indian seismic design code (IS 1893:2016) recognizes vertical mass irregularity as a critical parameter in assessing earthquake vulnerability and recommends special considerations during structural analysis and design.

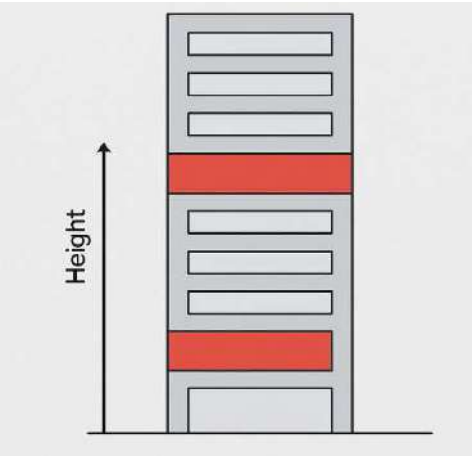


Figure 1. Vertical Mass Irregularity

1.2 P-Delta Effect

The P-Delta effect, also known as the geometric nonlinearity effect, refers to the additional moment generated in a structure due to the interaction between axial loads (P) and lateral displacements (Δ). When a tall structure undergoes lateral movement due to wind or seismic forces, the vertical loads acting through the displaced structure create an additional overturning moment. This secondary moment increases the internal stresses and deformations, potentially leading to instability or failure if not accounted for in design. The P-Delta effect becomes more pronounced in slender, flexible, or high-rise buildings where lateral displacements are significant. In seismic zones, ignoring this effect can lead to underestimating displacements and forces, resulting in unsafe structural behavior. Modern structural analysis tools, like ETABS, include options to consider the P-Delta effect, enabling engineers to design buildings that remain stable and resilient even under large lateral movements.

ISBN: 978-93-343-2006-0

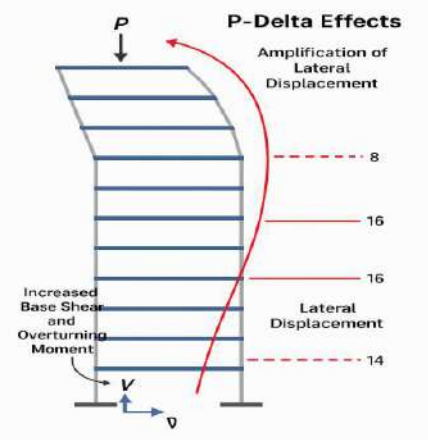


Figure 2. P-Delta Effect

Accordingly, by the review of the researchers on prefabricated modular building the few concerning factors for the structural design of the such buildings are as,

1. Rahman and Salik (2018) examined the "Seismic analysis of plan and vertical irregularity of building with and without infill action using ETABS." Their research explored how lateral forces from seismic activity are distributed across different levels of vertically irregular structures when the mass of the frame changes. Specifically, they investigated the effect of mass irregularity on a G+10 story building with vertical geometric irregularity, using the finite element software ETABS. The authors employed linear static and linear dynamic analyses to evaluate structural behavior, measuring storey shear, displacement, and drift. These responses were plotted, compared, and used to draw conclusions. The authors highlight that numerous reinforced concrete (R.C.C.) multi-story buildings in earthquake zones suffer severe damage or collapse due to vertical irregularities. They emphasize the importance of studying the uncertainties and structural behavior of all civil engineering structures, noting that vertical irregularities in buildings subjected to strong earthquakes are a significant concern. Sudden changes in stiffness, mass, and strength create weak points in these structures. Therefore, understanding how irregularity affects a building's response to lateral loads is crucial for designing safe irregular buildings. In their study, Rahman and Salik analyzed two frames with different irregularities but identical dimensions, examining their response to lateral loads. Both frames were analyzed according to the provisions of IS 1893 (Part 1):2002. Their findings indicated that the vertically irregular frame (frame-1) experienced the least storey drift. In contrast, the frame with mass irregularity on a vertically irregular building (frame-1) exhibited the greatest storey drifts at the respective storey levels. The authors concluded that this configuration is the most susceptible to damage under this type of loading. Additionally, this frame, when heavily loaded, develops maximum storey shears, which they recommend should be considered in the design of columns.

2. Chandana and Kumar (2023) examined the "P-Delta Analysis of Multi-Story Building Using ETABS Software." Their study investigated multi-story buildings, performing both linear static analysis (without considering P-delta effects) and second-order analysis (including P-delta effects). They created a building model with a constant height of G+24 stories, both with and without shear walls. For each case, they conducted linear static (first-order) and P-delta (second-order) analyses under gravity and earthquake loads. The maximum responses of the building, including displacement, drift ratio, moment, and shear forces, were determined and compared. The structural analyses of the multi-story reinforced concrete (RC) buildings were conducted using the ETABS 2016 software.

The authors note the increasing prevalence of tall structures due to urbanization, population growth, and rising land costs. They emphasize that tall structures must be designed to withstand lateral loads, such as earthquake forces, within the limits specified by relevant standards. For these structures, it's essential to account for nonlinearity, which is commonly observed in both the geometry and materials. Their research focuses on P-delta analysis, a method that incorporates geometric nonlinearity. The study utilizes the structural analysis software ETABS. The P-delta effect, also referred to as a 'geometric nonlinearity effect,' is described as a secondary effect on structures. Its significance increases with the number of stories. The authors state that if bending moments and displacements vary by more than 10%, the P-delta effect should be considered in the design.

3. Netke and Salunke (2018) also investigated the "Seismic Effect of Vertical and Mass Irregularity on Multistoried Building." Their project examined how vertical and mass irregularities affect the seismic response of multi-story structures. They aimed to conduct a comprehensive investigation into the seismic effects on high-rise structures with vertical irregularity and mass irregularity at different levels. They considered two types of irregularities: mass irregularity and vertical geometric irregularity. They also compared the results of regular and irregular structures. Modeling and analysis were performed using the finite element software ETABS 2016 (V 16.2.0). Four G+40 structures were analyzed, with vertical irregularity and mass irregularity at the base, middle, and top stories. The main parameters studied

were lateral displacement, story drift, base shear, and bending moment.

1.1 Advantages

i. Enhanced Understanding of Structural Irregularities: Provides detailed insight into the dynamic behaviour of tall buildings with vertical mass irregularities.
ii. Focus on Combined Impact: Examines how vertical mass irregularity amplifies P-Delta effects, increasing displacements and structural demand in seismic zones.
iii. Realistic Modelling Approach: Uses ETABS to model a G+20 building with realistic mass irregularities, enhancing the applicability of the results.
iv. Codal Compliance and Interpretation: Adheres to and interprets IS 1893 (Part 1): 2016 and IS 456:2000, clarifying their significance for engineers and students.
v. Importance of Second-Order Effects: Highlights that neglecting P-Delta effects can underestimate seismic demand in tall buildings.
vi. Identification of Critical Zones: Shows that irregular storeys with heavy mass experience amplified displacements and higher shear and moment demands.
vii. Application in High Seismic Zones: Offers insights for engineers in high-risk areas, emphasizing the need for dynamic analysis and adherence to code limits.
viii. Relevance to Modern Practices: Aligns with current trends in structural engineering, such as Performance-Based Seismic Design and nonlinear modeling.

2. OBJECTIVES

Objectives of study:

1. To investigate the effect of vertical mass irregularity on the structural performance of a G+20 building located in Seismic Zone V.
2. To analyze the amplification of P-Delta effects in tall structures with varying vertical mass irregularities.
3. To compare the behavior of the building with and without considering the P-Delta effect under seismic loading.
4. To assess the impact of different types of vertical mass irregularities (e.g., top-heavy, base-heavy, and random) on the P-Delta amplification.
5. To use ETABS software for modeling and dynamic analysis of the building under seismic loads.
6. To evaluate the change in story drifts, displacements, base shear, and internal forces due to the inclusion of the P-Delta effect.
7. To determine the influence of vertical mass irregularity on the stability and safety of the building during seismic events.
8. To provide design recommendations for mitigating P-Delta amplification in tall buildings with vertical mass irregularities.

3. METHODOLOGY

The thesis methodology centers on a comprehensive investigation of how vertical mass irregularity influences the seismic performance of tall buildings, specifically focusing on the amplification of P-Delta effects. This involves a detailed process of creating and analyzing structural models using ETABS software. A G+20 building is modeled, incorporating standard plan dimensions and realistic element sizes for accuracy. To simulate real-world conditions, heavy mass floors are introduced at the 8th and 16th stories, creating the vertical mass irregularity. The study employs both linear static and dynamic analyses, adhering to the latest provisions of IS 1893 (Part 1): 2016 and IS 456:2000, which are Indian standards for seismic design and general building construction. A critical aspect of the methodology is the comparative analysis of building performance, with and without consideration of P-Delta effects. This comparison aims to highlight the significance of geometric nonlinearity in seismic design, showing how it affects the building's response to lateral loads. The methodology also includes the evaluation of key parameters such as lateral displacement, inter-storey drift, base shear, and bending moment. These parameters are crucial for identifying critical storeys and understanding the overall structural demands, particularly in the context of high seismic zones. By following this approach, the thesis aims to provide a thorough understanding of how mass irregularities affect structural response under seismic loads, offering valuable insights for both academic research and practical engineering applications.

4. MODELING AND ANALYSIS

4.1 Material Properties and Section Properties:

- **Columns:** 450 × 900 mm
- **Beams:** 300 × 600 mm and 450 × 600 mm (based on span/load)
- **Shear Walls:** 300 mm thick; placed centrally and along periphery
- **Slabs:**

- Typical floors: 150 mm thick
- Storeys 8 & 16: 350 mm thick (to model mass irregularity)

- **Materials:**
  - Concrete: M30
  - Steel: Fe500

4.2 Loading Considerations:

- **Dead Load (DL):**
  - Regular floors: 3 kN/m²
  - Storeys 8 & 16: 5 kN/m² (due to heavier slabs)
- **Live Load (LL):**
  - Regular floors: 2 kN/m²
  - Storeys 8 & 16: 9 kN/m² (to simulate heavy usage)

4.3 Seismic Load Parameters (IS 1893:2016):

- Seismic Zone (Z): 0.36 (Zone V)
- Importance Factor (I): 1.2
- Response Reduction Factor (R): 5 (SMRF)
- Soil Type: Medium (Type II)

Vertical mass irregularity occurs when the seismic weight of a floor exceeds 150% of an adjacent floor, as defined in IS 1893 (Part 1): 2016, Clause 7.1. This irregularity is critical in tall buildings, causing localized dynamic amplifications during seismic events. In this study, storeys 8 and 16 were modeled as Heavy Mass Floors by increasing their slab thickness (350 mm vs. 150 mm) and applying higher dead (5 kN/m²) and live loads (9 kN/m²). This mass increase leads to significant changes in seismic forces, resulting in inter-storey drift concentration and higher lateral deformations. In ETABS, the mass was increased for these floors, with modified slab sections and live loads, ensuring accurate seismic analysis and reflecting the impact of the irregularity.

P-Delta effects are second-order effects caused by axial forces acting on displaced members, amplifying displacements, internal forces, and moments, especially in tall structures subjected to lateral loads (e.g., earthquakes). In this study, two models were analyzed:

- Model A: No P-Delta Effects (linear static response)
- Model B: With P-Delta Effects (nonlinear static, geometric nonlinearity included)

In ETABS, P-Delta analysis was enabled in Model B to assess the impact of gravity loads on displaced geometry. Key observations include:

1. Amplified Lateral Displacement: Floors with mass irregularity (Storeys 8 and 16) showed higher inter-storey drifts, worsened by P-Delta effects.
2. Increased Base Shear and Overturning Moment: Additional mass and second-order effects led to higher base shear and overturning moments, particularly in the seismic direction aligned with mass irregularity.
3. Reduced Stability Margin: The structure, especially near irregular floors, showed decreased lateral stiffness, increasing susceptibility to soft-storey behavior.
4. Force Redistribution: P-Delta effects caused a different force distribution across frames and shear walls compared to the linear model, impacting member design forces.

Ignoring P-Delta effects in high seismic zones can lead to unsafe performance, underestimated drift, and undetected critical storeys needing extra reinforcement or damping. The analysis showed that both vertical mass irregularity and P-Delta effects are essential for accurate design, particularly in seismic-prone regions.

4.5. Modeling in ETABS 2018- version 18.1.1

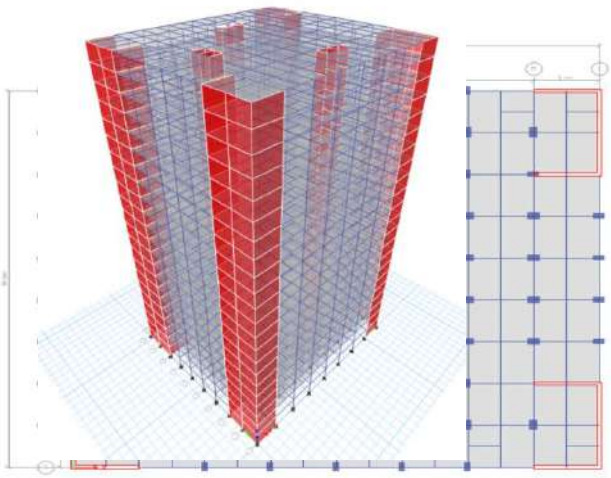


Figure 3 And Figure 4

3D View of Building And Plan View of Building

5. RESULTS AND DISCUSSION

5.1 Displacement :

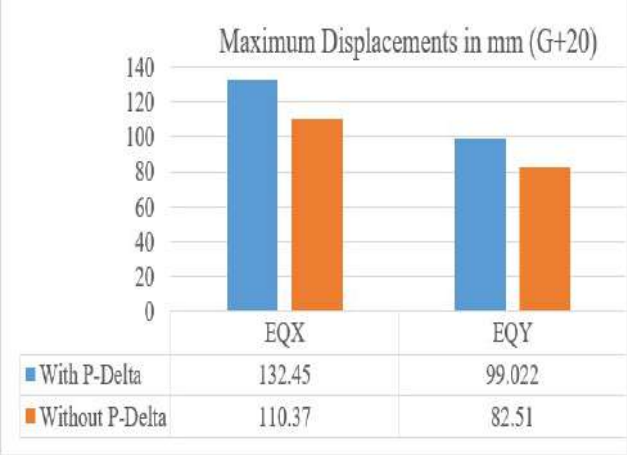


Figure 5. Maximum horizontal displacement due to lateral force

The analysis of a G+20 story building under seismic loading conditions reveals the significance of the P-delta effect in structural behavior. Using ETABS, the maximum lateral displacements were evaluated for two scenarios—considering and neglecting the P-delta effect—under earthquake loads in both the X (EQX) and Y (EQY) directions. In the X-direction, the maximum displacement increased from 110.37 mm (without P-delta) to 132.45 mm (with P-delta), while in the Y-direction, it rose from 82.51 mm to 99.022 mm. This translates to an approximate increase of 20% in each direction due to the inclusion of the P-delta effect.

The allowable lateral displacement for a structure of 66 meters in height, based on the commonly accepted limit of H/250, is 264 mm. When comparing this threshold with the calculated displacements, even with the P-delta effect taken into account, both EQX (132.45 mm) and EQY (99.022 mm) fall well below the permissible limit. This confirms that the structure remains within acceptable safety margins concerning lateral drift.

The P-delta effect, a geometric nonlinearity, becomes increasingly critical in the analysis of tall structures. It arises from the interaction between vertical axial loads and the lateral displacements of the building. As the structure sways under lateral forces, the vertical loads create additional moments due to the eccentricity between the original and displaced positions, further amplifying deflections. This iterative amplification can significantly affect the structural response if not accounted for. The observed results reinforce the importance of incorporating the P-delta effect in the design and analysis of high-rise buildings to avoid underestimating displacements and potential stability concerns. Despite this amplification, the structure analyzed remains compliant with the displacement criteria, indicating adequate performance under seismic loading.

5.2 Drift :

As per IS 1893 (Part 1): 2016, the inter-storey drift in a building during seismic events should not exceed 0.004 times the storey height. This limit is prescribed to prevent structural and non-structural damage during earthquakes. In the case of buildings equipped with base isolation systems, the behavior differs significantly from conventional structures. These systems are designed to absorb and dissipate seismic energy at the base, thereby protecting the superstructure.

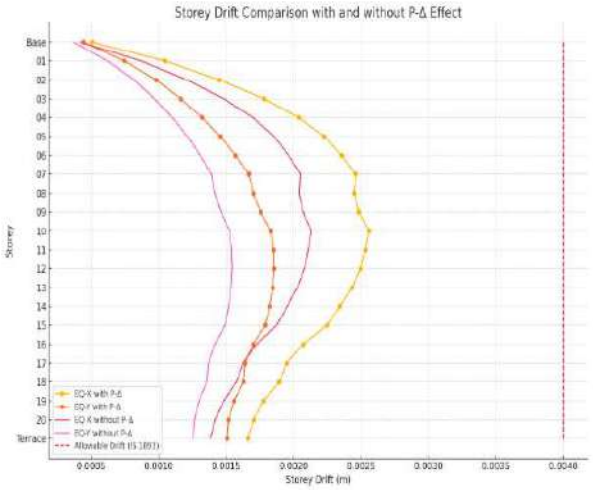


Figure 6. Drift in structure due to lateral force

The comparison of storey drift values for a building subjected to seismic forces, both with and without accounting for the P-Delta (P-Δ) effect, highlights the notable influence of this second-order phenomenon on structural response. The graph under review shows that incorporating the P-Δ effect leads to a significant increase in lateral displacements across most storeys, with a particularly noticeable amplification between the 6th and 15th floors. Specifically, in the EQ-X direction, the maximum storey drift occurs at the 10th level, where the value rises from approximately 0.00213 meters (without P-Δ) to about 0.00256 meters (with P-Δ), reflecting a near 20% increase. This substantial rise in drift underscores the critical role that the P-Δ effect plays in accurately assessing seismic performance. The P-Δ effect arises due to the

interaction between gravity loads and the lateral displacement of a structure during seismic excitation. As the structure sways, vertical loads generate additional moments through the displacement, which in turn intensify the lateral deflections and internal stresses. This phenomenon is especially relevant for tall or flexible buildings where these displacements can be significant. Neglecting this effect in analysis can result in an underestimation of storey drifts and internal forces, potentially leading to insufficient structural detailing and vulnerability during earthquakes.

The analyzed graph shows that the drift values, even after including the P-Δ effect, remain within this limit, indicating compliance with the code's safety requirements.

5.3 Overturning Moment :

Overturning moment refers to the rotational force generated in a structure due to lateral loads, such as those from wind or earthquakes, which tends to overturn the entire structure about its base. This force can be particularly critical in tall buildings or irregular structures, where the lateral load induces significant rotational effects. One of the key consequences of a high overturning moment is the induction of torsion, especially in structures with asymmetrical mass or stiffness distribution. This torsional behavior can lead to uneven displacements and stress concentrations, increasing the risk of structural failure.

Given the potential for overturning moment to compromise structural stability, it is essential for structural engineers to closely consider the torsional effects during seismic or wind load analysis. To ensure safety and structural integrity, the Indian Standard code IS 1893 has established specific guidelines and criteria. These include requirements related to modal mass participation—ensuring that a sufficient percentage of the total mass is represented in the dynamic analysis—and evaluation of the first three natural modes of vibration. These criteria help in capturing the true dynamic behavior of the structure, especially under lateral forces.



Figure 7. Overturning moment comparison

The bar chart presents a comparison of overturning moments (in kN·m) for a G+20 storey building subjected to seismic loading, analyzed both with and without incorporating the P-Delta effect in the EQ-X and EQ-Y directions. The results clearly indicate a significant increase in overturning moments when the P-Delta effect is considered. In the EQ-X direction, the moment increases from 1,486,041 kN·m to 1,783,268 kN·m—an approximate rise of 20%. Similarly, for the EQ-Y direction, it climbs from 1,400,014 kN·m to 1,680,017 kN·m, again reflecting a 20% increase.

This notable rise is attributed to the P-Delta effect, a second-order geometric phenomenon that becomes prominent during lateral displacements caused by seismic activity. As the structure sways, vertical loads (such as gravity loads from floors and columns) interact with horizontal movements, generating additional overturning moments that are not captured in a linear (first-order) analysis. These added moments amplify the structural response, especially in high-rise or flexible buildings where axial loads and displacements are substantial.

An increased overturning moment due to the P-Delta effect indicates a greater demand on critical structural elements such as foundations, columns, core systems, and shear walls. If this effect is neglected, it could lead to an underestimation of the actual seismic forces acting on the structure, potentially compromising safety, performance, and structural integrity during an earthquake.

In summary, the chart reinforces the importance of considering the P-Delta effect in seismic analysis, particularly for tall structures. Incorporating this effect ensures a more accurate and conservative estimation of overturning moments, which is essential for designing resilient and code-compliant buildings that can withstand the demands of seismic forces.

ISBN: 978-93-343-2006-0

Table 1. Base in structure due to earthquake

	With P-Delta	Without P-D
Base shear EQX (kN)	34575.5334	28812.6377
Base shear EQY (kN)	32801.0053	27334.1711
Dead Load (kN)	535512.7058	535512.7058
Live Load (kN)	78960	78960
% of earthquake (EQX)	5.6	5.313
% of earthquake (EQY)	4.0	3.75

5.4 Base Shear :

The table highlights the effect of the P-Delta phenomenon on base shear forces for a building under seismic loading, showing a clear increase when this second-order effect is taken into account. In the EQ-X direction, the base shear rises from 28,812.64 kN without the P-Delta effect to 34,575.53 kN when it is considered—an increase of approximately 20%. A similar trend is observed in the EQ-Y direction, where base shear increases from 27,334.17 kN to 32,801.01 kN, again reflecting a 20% amplification.

This rise in base shear is a direct result of the P-Delta effect, which occurs when vertical loads (such as gravity) interact with lateral displacements during seismic events. These interactions introduce additional internal forces and moments in the structure, increasing the overall seismic demand. Consequently, the structural system must resist not only the primary lateral loads but also the enhanced effects caused by these interactions, resulting in higher base shear forces.

If the P-Delta effect is not included in the analysis, it can lead to an underestimation of seismic forces, potentially compromising the design of essential structural components such as foundations, shear walls, and moment-resisting frames. This is particularly critical in tall or slender structures, where both vertical loads and lateral displacements are substantial.

In summary, considering the P-Delta effect significantly increases the base shear, emphasizing the need to account for second-order effects in seismic design. This approach leads to more accurate and conservative results, ultimately ensuring greater structural safety and compliance with modern design standards.

6. CONCLUSION

i. Base Shear Increases with P-Delta: When the P-Delta effect is considered, base shear values rise by approximately 20% in both the X and Y directions. This increase is due to additional internal forces generated by the interaction of vertical and lateral loads.

ii. Overturning Moments Are Higher: Overturning moments also increase by about 20% with P-Delta. The added lateral displacement under vertical loads creates larger moment arms, leading to higher overturning forces on the structure.

iii. Lateral Displacements Are Amplified:The maximum lateral displacements at the roof level are significantly higher (around 20%) when P-Delta effects are included. This indicates more structural sway, which may affect serviceability and comfort.

iv. Storey Drift Grows with Height:Storey drift values increase at every level, especially between the 10th and 14th floors, where the rise is about 8–15%. These mid-height levels are more vulnerable to instability due to the cumulative P-Delta effect.

v. Greater Structural Demands: Including P-Delta makes the structure face higher demands—greater base shear, larger displacements, and increased drift. This shows the structure is working harder to resist the same seismic forces.

vi. Crucial for Tall Buildings: For tall buildings like a G+20 structure, omitting P-Delta effects can lead to underestimating critical forces and displacements, resulting in an unsafe and non-compliant design.

ii. Mass Irregularity Amplifies the Effect: In buildings with uneven mass distribution across floors, the P-Delta effect becomes even more severe. It intensifies localized instability, which can affect the overall safety of the building.

ii. Impacts Design Choices: Due to the increased demands, engineers may need to design stronger lateral load-resisting systems (e.g., shear walls, bracing), use stiffer structural members, and enhance foundation design to handle higher overturning forces.

P-Delta effects significantly influence how a tall building responds to seismic forces, especially if mass irregularities are present. Including this effect in structural analysis is not just recommended but essential for safe, efficient, and code-compliant design.

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TOWARDS A BETTER UNDERSTANDING OF UNSATURATED SOIL BEHAVIOUR: A COMPREHENSIVE OVERVIEW

Akshaya Gangayya Ghalimath, Assistant Professor, Dr. D.Y. Patil Institute of Technology

ABSTRACT.

Understanding the behavior of unsaturated soils is crucial for safe and efficient geotechnical design, particularly in regions with fluctuating moisture conditions. This paper offers a concise review of the key aspects of unsaturated soil mechanics, including shear strength, permeability, and volume changes influenced by matric suction and degree of saturation. It explores the role of soil-water characteristic curves (SWCC) and compares experimental methods and constitutive models used to analyze unsaturated soils. Additionally, the impact of environmental factors such as rainfall and temperature are highlighted. Recent advancements in modeling and monitoring techniques are also discussed to enhance predictive capabilities in engineering practice.

KEYWORDS: Unsaturated soil; Matric suction; Soil-water characteristic curve (SWCC)

1. INTRODUCTION

The technology and practice of geotechnical engineering evolved mostly in the world temperate regions. Research was therefore focused on issues pertaining to soil having positive pore-water pressures. Seepage, shear strength, and volume change were the traditional study areas. Nonetheless, there have been ongoing changes to the field of geotechnical engineering. Soil mechanics was mostly an art until around 60 years ago, when it began to take on a scientific foundation. Soil mechanics has only been a required component of university curricula in civil engineering within the past four to five decades. Having the ability to model intricate geotechnical issues has been significantly impacted by computers only in the last two to three decades. As a result of ongoing development, geotechnical engineering has now broadened to address a wide range of issues arising in the geoenvironmental field. People who live in arid climates are becoming more conscious of how special their soil mechanics issues are. There has been a growing interest in creating a scientific foundation for the wide range of issues pertaining to unsaturated soil as geotechnical engineering has grown as a field. A science that is gaining worldwide credibility now seems to be gaining ground. This essay will try to give a general overview of the types and extent of unsaturated soil behavior.

2. NEED FOR AN UNSATURATED SOIL FRAMEWORK

ISBN: 978-93-343-2006-0

Strength, strain, and seepage issues are an emphasis of geotechnical engineering, which has traditionally been recognized as a field of engineering with a strong foundation in engineering mechanics. This rapid global diffusion of geotechnology can be attributed to the effective stress principle. In the same way that unsaturated soil behavior has been progressively given away from one continent to another using the stress-induced state variable approach. Over one-third of the earth's surface has been composed up of arid and semi-arid regions. These areas have dry, drought-stricken soil close to the earth. In certain instances, the water table may be more than 30 meters below the ground surface, indicating that these circumstances may persist to a significant depth. The soil utilized in building are unsaturated, and the groundwater table can be much below the ground surface even in humid climates. The necessity for a scientific discipline that focuses on the soil mechanics issues associated with unsaturated soil has been recognized by engineering organizations. A committee on soil in Arid Regions has been established within the Transportation Research Board (TRB), a committee on Unsaturated Soil within the American Society of Civil Engineering (ASCE), and a committee on Soil in Arid Regions within the International Society for Soil Mechanics and Foundation Engineering (ISSMFE). The creation of these committees demonstrates a growing comprehension of the necessity to comprehend the behavior of unsaturated soil.

The earth structures that designers are developing contain dense soil components. Examples include roads, airfields, earth dams, and many other structures that are part of our society's infrastructure. Unsaturated soil encountered in engineering practice include residual soil, collapsing soil, and swelling soil. "Problem soil" is a common term used to describe this soil. A characteristic found in all the soil mentioned above is their negative pore-water pressures, which are important for their mechanical behavior and make laboratory testing challenging. In just 20 years, the world's attention has shifted from exploring designed structures to mitigating the effects of technological advances and changes on the environment. By virtue of their education and expertise, geotechnical engineers are in a strong position to examine the effects of various types of improvements. In as a whole, geotechnical engineers have rapidly grown their domain of competence. In contemporary times, over 75% of the work rendered by many geotechnical consulting companies in North America and other parts of the world is related to geoenvironmental projects. Monitoring the mass flux of pollutants transmitted to the groundwater system has turned essential as part of geoenvironmental initiatives. Since the majority of these issues present themselves neighboring to the ground surface, understanding the behavior of unsaturated soil is beneficial.

3. HISTORICAL PERSPECTUS ON CLASSICAL SOIL MECHANICS

In order to illustrate the behavior of saturated soil, the effective stress variable, (σ'), became integral in the 1930s (Terzaghi, 1936). From an empirical foundation to a scientific one, soil mechanics benefited from its inferred standing. Effective stress, which was unrelated to soil characteristics, was linked to soil behavior.

ISBN: 978-93-343-2006-0

Three main areas were included in the scope of saturated soil mechanics: (1) Seepage analyses in which issues (Casagrande, 1961) has been separated into three categories: (1) finite or determinate flow analysis; (2) plasticity and limit equilibrium analysis, which deals with problems ranging from slope stability to bearing capacity and lateral earth pressures; and (3) volume change analysis, which focuses primarily on predicting settlement in soft clays.

In traditional soil mechanics, the main parameters are mostly static and steady-state in nature. The theory of consolidation, which showed how seepage and deformation interacted, was a variation. The theory of consolidation provided an excellent mathematical and rheological tool to enable engineers to visualize the behavior of saturated soil. It became the epitome of classical soil mechanics and made it possible to predict pore-water pressures in both space and time. A broad spectrum of transient state or transient related assessments is required over time. Predicting chemical concentrations in relation to time and space is one of the efforts that geotechnical engineers in the geoenvironmental field are expected to perform.

Chemical diffusion is superimposed on the conductive movement of the water. In other terms, reviewing water seepage through soil is supplemented with additional unsteady state analysis. A common belief is that permeability is the most diligent soil characteristic to evaluate. Nowadays, many analyses emphasize this characteristic and a considerable amount of research has been done to validate it. Many of the activities of concern occur in the vadose zone, which is the most anterior part of the soil profile where pore-water pressure is negative, further complicating matters. Non-linear flow equations in this region state that the coefficient of permeability depends on the negative pore-water pressure. Furthermore, the upper limit of concern is no longer the groundwater table. Instead, the subsurface geometry serves as the boundary of the problem, and movement through the unsaturated zone becomes important. Alongside the multifaceted nature of geotechnical issues, there has been an improvement in the ability to manage them. Engineers are capable of put together and evaluate data in an abundance of ways attributable to the microcomputer. The computer programs that are often employed are likely to differ from sophisticated coupled, transient applications software to spreadsheet software. In their natural state orientation has also been adopted in the way consulting firms use application-type software. In order to accommodate potential field conditions and to make geotechnical engineers aware of soil behavior deficiencies, software is usually implemented in a parametric or cognitive manner.

4. KEY STEPS TOWARDS THE DEVELOPMENT OF UNSATURATED SOIL

In contradiction to saturated soil mechanics, unsaturated soil mechanics has developed at a slower pace. astonishingly, the first International Conference on Soil Mechanics and Foundation Engineering (ISSMFE), held at Harvard in 1936, had a large number of scientific presentations addressing unsaturated soil behavior. Unsaturated soil behavioral problems were evidently regarded as a

ISBN: 978-93-343-2006-0

significant component of engineering practice at the time. The flow of water in the capillary, unsaturated zone encountered an extensive amount of emphasis. Addressing the existence of the "siphon" effect which occurs when water passes through a dam above the phreatic line was a persistent challenge. In the years since the initial ISSMFE meeting, there has been less interest in unsaturated soil dynamics at research conferences. It is clear that the study efforts focused on the behavior of saturated soil have been easier and more fruitful, which has certainly had an impact on this. Given that numerous seepage problems have been empirically addressed as unrestricted flow, it was no longer primarily necessary to examine the area around the vadose, which is the area in which the pore-water pressure was doing negative work. It was easy to justify the important need to set aside time to study the vadose zone.

To gain a comprehensive understanding of the behavior of unsaturated soil within the traditional framework of saturated soil, research was conducted at Imperial College London in the 1950s (Bishop, Alpan, Blight, and Donald, 1960). This study focused on the shear strength of unsaturated soil and included extensive laboratory investigations. These findings seem to have served as a cornerstone for further research in many different countries. As time went on, it became more widely recognized that knowledge of unsaturated soil behavior could be used to better examine various geotechnical problems (Fredlund, 1993). Information on soil classified as "problem soil" was shared at specialized conferences. The first such conference series, now known as the Comprehensive Soil Series of conferences, was held on the topic of swelling and shrinking soil. There have been seven conferences until now, happening in different nations throughout the world. International conferences have also addressed other "problematic soil," such as residual and crumbling soil. Studying the behavior of compacted soil has also revealed that they fail to possess the same favorable theoretical framework as saturated soil. The pore-water phase stress condition has been identified as common throughout all of these "problematic soil". The pressures between the pore and the water are negative, and it is an eventual change in this pressure that results in unforeseeable outcomes. It's always been challenging to measure negative porewater pressures. Figuring out the manner in which this soil will respond can be difficult, in the end in particular, associated with the process by which laboratory testing are carried out. Before testing, submerging the specimen in water is frequently regarded as a valid procedure. In this process, the qualities that must be measured are drastically changed. To put it another way, controlled negative porewater pressure conditions cannot be used for laboratory testing with our current standard equipment. The fundamental theories pertaining to the majority of the traditional domains of unsaturated soil behavior were compiled in the 1970s and later (Fredlund, 1979). Their use has been hampered primarily by the challenges of measuring negative pore-water pressure in situ or matric suction. Although much remains to be learned about measuring matric suction, theories of unsaturated soil behavior are rapidly advancing. The problems that need to be solved for unsaturated soil are often the same as those that have been solved for saturated soil. The most important driving force for the use of saturated/unsaturated leakage analysis has been advances in the field of

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geophysics. It is now standard practice to use saturated/unsaturated computer models and follow established procedures to characterize the permeability function for unsaturated soil. Unsaturated soil formulas are often nonlinear, making their solution computationally demanding. This has not generally served as a deterrent due to the accessibility and power of microcomputers [1].

5. CATEGORIZATIONS FOR UNSATURATED SOIL

Figure 1 illustrates the general categories into which classical soil mechanics can be divided. This classification shows the specificity of the dynamics of unsaturated soil. Within the theoretical framework for unsaturated soil mechanics, saturated soil can be viewed as a specific example of the more general theories for unsaturated soil. Saturated soil mechanics and unsaturated soil mechanics are terms that indicate that the difference between these two groups is determined by the degree of saturation. This is accurate, yet it is challenging to quantify the degree of saturation and identify a number that can serve as a dividing line. The stress state in the water phase is now properly an indicator. For classification purposes. Unsaturated soil mechanics includes soil of any kind having a negative pore-water pressure. Additionally, it is known that soil with negative pore-water pressures can either be saturated or have occluding air bubbles.

A soil classification based on the characteristics of the air and water phases is depicted in Figure 1. Theoretically, the tiniest amount of air in a soil makes it unsaturated. The air bubbles will be occluded and the corresponding saturation level will be high. Occlused air bubbles can emerge in soil that are close to the ground or the water table. This category includes soil that have been compacted above their optimum water content. The pore fluid becomes compressible due to the occluded air bubbles. Encounters in this threshold category have not received much emphasis from study findings. The engineering and physics concepts that apply to dry soil are nearly identical to those that apply to saturated soil. A compressible pore fluid with air bubbles has taken the place of the incompressible water that was previously present in the voids of a saturated soil. The scenario in which water and air are continuous across the voids has received the majority of research focus. This is the main focus of this paper as well. The case that seems to have the greatest bearing on engineering practice is this one.

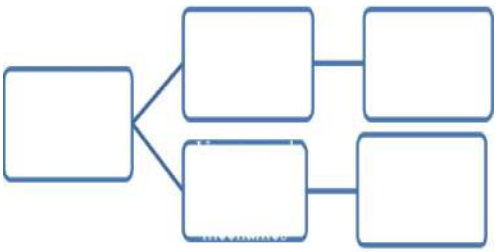


Fig. 1. General categorization of Soil Mechanics based on the state of stress in the pore-water

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6. THEORETICAL FRAMEWORK FOR UNSATURATED SOIL MECHANICS

The variables that can be used to describe the stress state of a soil must be defined before the relevant unsaturated soil parameters can be identified. These are the factors that will enable easy comparison of engineering experiences around the world. They will serve as a cornerstone on which a transportable science can be built. Compared to the empirical arts, geotechnical engineering is distinguished as a science on which the stress state is isolated. Therefore, it serves as the foundation or hypothesis on which engineers build their engineering formulas.

6.1 Stress state variables

Nowadays, there seems to be a broad consensus that two independent stress variables, with two independent normal stress parameters, should be used to describe the stress state for unsaturated soil (Friedlund and Morgenstern, 1977). These two properties are represented in Equation 1, which logically follows from the effective stress variable used for saturated soil. Net normal stress is the ($\sigma - u_a$) term, and matric suction is the ($u_a - u_w$) term. The Definition of Soil Terms provides terminology for more variables. The stress state at an occurrence can be defined by using two separate normal stresses, exhibited in Figure 2. The simplest way to understand the need for two independent stress state variables is to understand how differences in total stress and changes in pore-water pressure do not yield equal responses in unsaturated soil. This causes them to respond

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differently than saturated soil. Shear strength and dimensional change behavior are characterized by two factors.

$$\begin{bmatrix} (\sigma_x - u_a) & \tau_{yx} & \tau_{zx} & (\sigma_y - u_a) & \tau_{xy} & \tau_{zy} & (\sigma_z - u_a) & \tau_{xz} & \tau_{yz} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ (u_a - u_w) & 0 & 0 & (u_a - u_w) & 0 & 0 & (u_a - u_w) & 0 & 0 \end{bmatrix}$$

And

saturated state.

6.2 Volume change moduli

For an unsaturated soil, the constitutive relations can be formulated using the independent stress state variables. For isotropic loading, the constitutive equation for volume change can be expressed as a change in the void ratio.

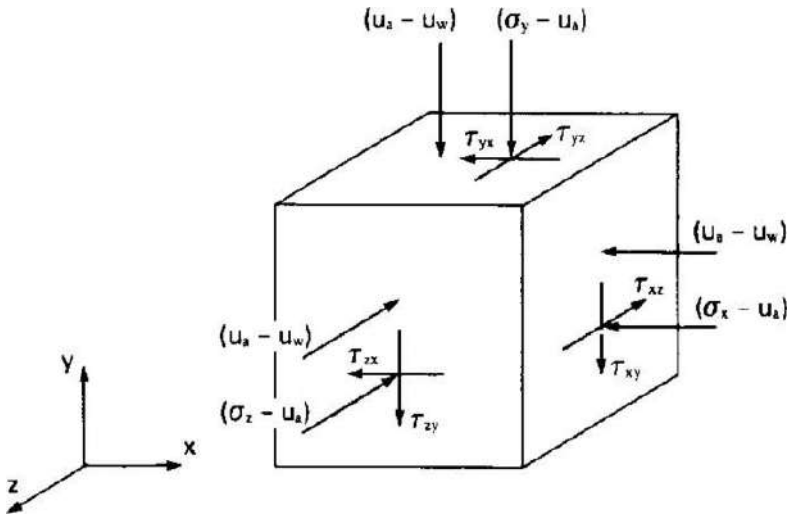


Fig. 2. Element showing the stress state at a point in an unsaturated soil

For most real geotechnical problems, the pore-air pressure is constant (i.e., atmospheric), so it makes sense to consider pore-air pressure separately from total stress and pore-water pressure. The stress state variables can now be used to refer to all descriptions of soil behavior, such as dimensional change and shear strength. Since the pore-air pressure is equal to the pore-water pressure as the soil becomes saturated, there is also a seamless transition from the unsaturated state to the

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$$de = a_t d(\sigma_c - u_a) + a_m d(u_s - u_w)$$ [1]

For a thorough volume-mass characterization of an unsaturated soil, multiple constitutive equations are needed since fluctuations in water content (or saturation level) are independent of changes in the void ratio. For an unsaturated soil, the second constitutive relationship has often been the water content constitutive equation.

$$d w = b_t d(\sigma_c - u_a) + b_m d(u_{aw})$$ [2]

The context of isotropic loading is represented by Equations 2 and 3, however comparable equations can be expressed for various loading scenarios. An illustration of the void ratio and water content constitutive surfaces in three dimensions is presented. When the soil's matric suction is zero, modifying the water content and influencing the void ratio react to changes in total stress in an analogous way.

It displays the constitutive surfaces for the void ratio loading and unloading of a stable structured soil. It illustrates the constitutive surface for the void ratio loading and unloading of a meta-stable-structured soil. The main difference in the volume change behavior is that lower soil volume results from both an increase and a decrease in matric suction. Consequently, a ridge line seems to develop across the constitutive surface. To fully describe the nature of the constitutive surface for unsaturated soil, more investigation is required. It should be mentioned, however, that meta-stable soil structures have been found in the soil utilized in a number of research programs to examine constitutive behavior.

Another important relationship in characterizing the behavior of unsaturated soil is the correlation between water content and matric suction. To quantify this relationship, an instrument known as the pressure plate apparatus has been developed in the field of soil research. It is called the "soil water characteristic curve" and it provides information about the relationship between matric suction and water content.

The behavior of unsaturated soil can be measured using soil water characteristic curves. Most unsaturated soil properties can generally be measured using soil water characteristic curves and saturated soil parameters. Currently, research is needed on how to approximate unsaturated soil properties. Given that the shape of the soil water characteristic curve has been shown to be affected by total pressure, it may be necessary to develop new pressure plate test equipment that is more suitable for geotechnical testing.

7. LABORATORY TESTING OF UNSATURATED SOIL

7.1 Triaxial testing

It can be considerably more relentlessly to do high-quality triaxial testing on unsaturated soil than on saturated samples. A way to check that is undrained is no longer a constant volume test, and the flow of water from the sample in a drained

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test cannot be used to determine the change in sample volume. Air diffusing through the membrane in purportedly undrained situations is another practical issue. In cases where air diffused through the membrane, Bishop and Donald (1961) discovered the pore air pressure declined by 28.8% over a 7-day timeframe. In order to address this issue, Bishop and Donald employed mercury as the cell fluid and oiled aluminum foil between two rubber membrane layers. At that time, the pore air pressure slumped by just 1.2% to the same extent

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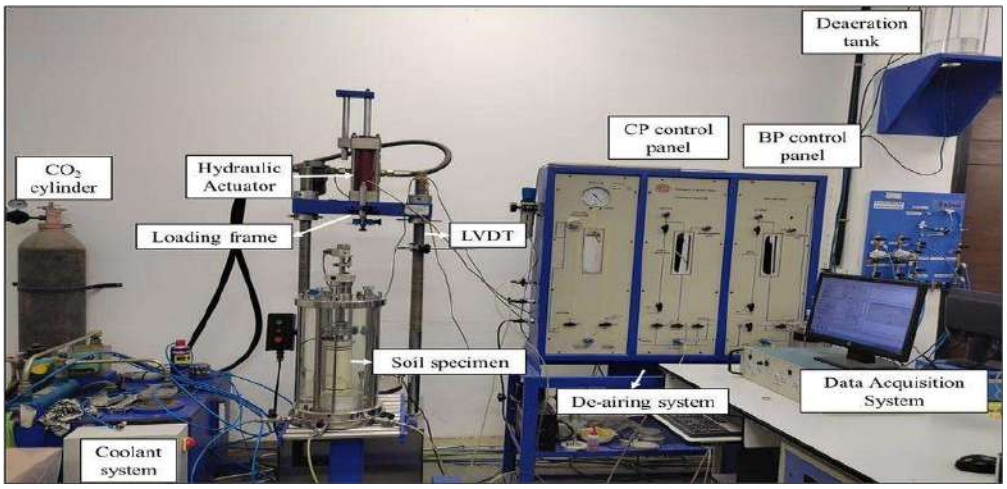


Fig.3. Set up of cyclic triaxial testing
(https://research.iitgn.ac.in/stl/wp/dynamictriaxial/)

Unsaturated soil has to endure triaxial testing to measure two types of volume change. The water volume change and the overall sample volume change are aforementioned. Using a burette or automatic volume change device attached to the sample's drainage line, the water volume change can be measured as usual. Axial and lateral strain measurements of the sample, which yield volumetric strain, or the flow of cell fluid into the cell can be used to estimate the overall sample variation in volume that results from fluctuation in both air and water volume. A modified triaxial cell was invented at Imperial College to evaluate unsaturated soil. The redesigned device was a double-walled cell with an inner cell wall made of an acrylic jacket.

The lower part of the inner cell contained mercury as the cell fluid. The upper part of the inner cell wall was perforated to maintain equal pressure between the inner and outer cells, which prevented the inner cells from expanding in response to pressure differences between the cells. Throughout the test, a stainless-steel ball hovered over the mercury in the inner cell to track the flow of the fluid inside. The cathetometer was used to track the movement of the stainless-steel ball, and the reading was translated into the sample's volume change. This apparatus's principal drawbacks were (a) the inability to observe the sample throughout the test, (b) the stress variation across the sample's height caused by the mercury's weight, and (c) the safety concerns associated with handling a large volume of mercury. Isotropic

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consolidation tests on undrained compacted kaolin were also successfully performed by different researchers.

To test unsaturated soil in a laboratory environment, Wheeler (1986) constructed a double-walled triaxial cell (Figure 2.9). The basic concept behind the double-walled triaxial cell was that the flow of water into or out of the inner cell could be used to measure the change in volume of the sample. To avoid any volume change in the inner cell due to the expansion of the inner acrylic cylinder, the inner and outer cells had to be subjected to the same cell pressure. Water leakage from the inner cell was prevented by a rolling diaphragm seal on the loading ram. The process continues to be desirable to calibrate the double-walled cell for any apparent volume change resulted on by the application of cell pressure (because the cell fluid was compressed, the top plate somewhat flexed, and the connecting tubes expanded), water absorption by the acrylic cell wall, and ram displacement.

The majority of laboratory studies involving triaxial testing of unsaturated soil have employed the axis translation technique. A low air entry filter deploys high pore air pressure values to one section of the sample boundary, whereas a high air entry filter implements or assesses lower (but still positive) pore water pressure values on another section of the sample border. Air entering the water drainage system is still a problem, despite the deployment of high air entrance filters. It continues to be possible for dissolved air in the pore water to diffuse through the porous stone and evacuate the solution in the drainage line underneath the stone. Fredlund (1975) and Bishop and Donald (1961) devised techniques to quantify and eliminate the quantity of dispersed air amassed beneath a high air entry filter. A device, like a bubble pump, was employed to remove the diffused air from the system. The air was then collected and its volume recorded in a calibrated container.

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7.2 Oedometer testing

It is more intuitive to figure out the volume change of an unsaturated soil sample with an oedometer than with a triaxial device since the soil sample is laterally constrained and any movement of the sample occurs vertically. In order to perform controlled suction one-dimensional consolidation tests on unsaturated compacted soil, Barden and Sides (1970) created a modified Rowe cell (Figure 2.10). The axis translation technique has been employed to measure or control the suction. Many others who have studied such as Fredlund and Morgenstern (1977) and Escario and Juca (1989), have utilized this kind of equipment with successful outcomes. Vicol (1990) (Vicol, 2024) monitored or assessed soil suction using a semi-permeable membrane as opposed to the axis translation technique

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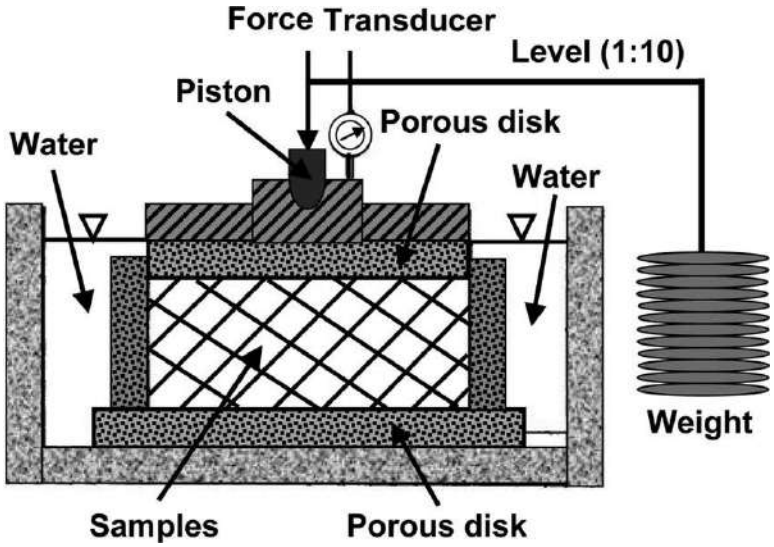


Fig.4. Photograph of Oedometer testing (Wang & Abriak, 2015).

7.3 Direct shear testing

A soil sample is sheared on a predetermined shear plane in the direct shear test, often under continuous normal stress. For lengthy periods of time, this device has been used to test both saturated and unsaturated soil. To evaluate unsaturated soil samples under controlled suction, Escario (1980) invented the direct shear apparatus (Figure.5). The pore air pressure was introduced to a high value in a container surrounding the entire apparatus using the axis translation technique. Then, the pore water pressure was delivered to the sample base or measured using a high air permeability filter. Because the drainage path was short, the direct shear apparatus was able to investigate much faster than triaxial instruments. This was its main advantage. Since complete consolidation can then take weeks in unsaturated fine-grained soil, test time is a major cause of concern.

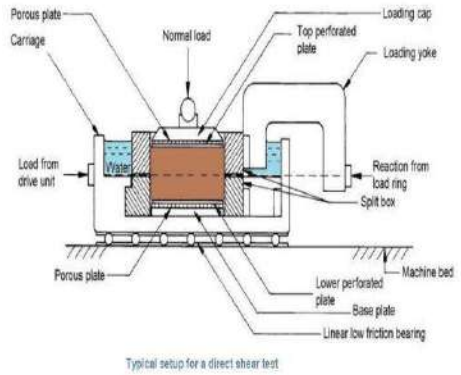


Fig. 5. Set up of direct shear test

Unsaturated soil exhibits complex hydraulic behavior due to the simultaneous presence of air and water in its pore spaces. The hydraulic properties

of unsaturated soil play a crucial role in geotechnical and environmental engineering applications, affecting water flow, strength, and stability.

ISBN: 978-93-343-2006-0

(https://www.geotechdata.info/geotest/direct-shear-test)

8. HYDRAULIC PROPERTIES

8.1 Water retention function

The soil water retention curve, $\theta(h)$, outlines the manner in which the energy status of water at a certain point in the soil is related to its water content, θ. Numerous other names, such as the pF curve, the capillary pressure–saturation relationship, and the soil moisture characteristic curve, can be retrieved from the literature. The negative logarithm (base 10) of the absolute value of the pressure head expressed in centimeters is called pF, and historically, retention curves were often expressed in this way. Both adsorption on solid-state surfaces and capillary forces in soil pores affect water in the unsaturated zone. Compared to free water, this results in positive suction or tension or negative values of pressure head (or matric head). The pressure head h is positive in a saturated system compared to an unsaturated soil. A more accurate description of the pressure head is the difference between the air and liquid phase pressures. The surface tension of the liquid phase, the contact angle between the solid and liquid phases, and the width of the pores are all components of the complex network of interactions that generate capillary forces.

Figuring out of $\theta(h)$ Energy density (potential) relates capacity (water content), making it important for hydraulic characterization of soil. Pressure or matric capacity (energy per unit volume of water, usually measured in pascals, Pa) is used in place of pressure head (energy per unit weight of water) in many agrophysical applications., $\varphi_m = \rho_w g h$, where ρ_w is the density of water (ML^{-3}) and g the acceleration of gravity ($L\ T^{-2}$). For soil of relatively coarse texture (such as sand and loamy sand), medium texture (such as loam and sandy loam), and fine texture (such as clay loam, silt loam, and clay), It emphasizes typical soil water retention curves. The equilibrium water content distribution at the appropriate depth of the water table, where the soil is completely saturated and the upper

ISBN: 978-93-343-2006-0

pressure is zero, can be derived from the curves. The plots show that fine-textured soil lose water much more slowly than coarse-textured soil, which lose water very quickly (above moderate negative pressure) and suddenly at the top of the water table. It indicates the distribution of particle or pore sizes in the medium.

Most pores in fine-textured soil do not drain unless very high stress (negative pressure) is applied, while most pores in coarse-textured soil have a larger diameter and drain with relatively moderate negative pressure. The with large surface areas. Typically, with minimal physical relevance.

plots show that the water content fluctuates between a high value, called the saturated water content, and a very small value, called the residual (or irreplaceable) water content, over the year. By the intuition and first approximation mentioned above, the year is zero and the saturated water content is equal to the porosity. Yet, due to trapped and dissolved air, the saturated water content, or θ_x, of soil is typically lower than the porosity. Owing of the adsorbed water, the residual water content year is probably going to be higher than zero, particularly for fine-textured soil θ_x and θ_r are regarded as fitting parameters

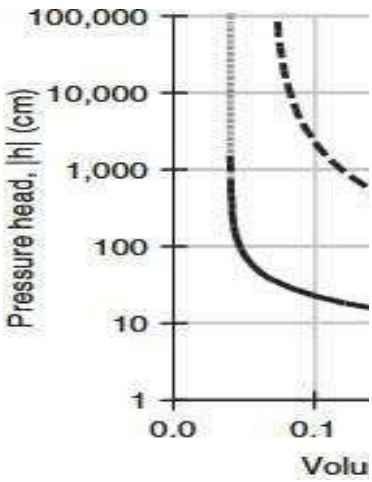


Fig.6. Typical soil water retention curves for relatively coarse- (solid line), medium- (dashed line), and fine-textured (dotted line)

Soil water retention curve that fails to be unique as opposed to depends on the wetting and drying history. In order to calculate the soil water retention curve, a primary drying curve is typically produced by gradually desaturating an initially wet soil by applying progressively greater suctions. Similar to this, a very dry sample could be gradually wetted in order to generate the primary wetting curve, which usually advances by a factor of 1.5–2.0 toward higher pressure heads near saturation. The presence of different wetting and drying curves, such as primary

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and secondary scanning curves, is a phenomenon known as hysteresis. Hysteresis results from the fact that larger pores in a particular pore sequence determine. wetting, while smaller pores in the same sequence determine drainage (an effect often referred to as the ink bottle effect). Other factors contributing to hysteresis are the entrainment of air during wetting, the existence of different liquid-solid contact angles for advancing and receding water menisci, and possible shrinkage-swelling processes in certain soil (D.R.Nielsen, 1986).

Hydraulic conductivity function

The capacity of a soil to transfer water is characterized by its hydraulic conductivity. The tortuosity, shape, roughness, and degree of interconnectivity of the pores, as well as the medium's pore-size distribution, all affect its value. considering that less pore space is filled with water, flow routes become more convoluted, and drag forces between the fluid and solid phases rise, the hydraulic conductivity significantly drops as soil becomes unsaturated. The dependence of hydraulic conductivity on water content is provided by the unsaturated hydraulic conductivity function, $K(y)$, or pressure head, $K(h)$. Figure 7 depicts instances that are widespread $K(y)$ and $K(h)$ collaborates with soil that are comparatively coarse, medium, and fine grained. It's likely that observe the fact coarse-textured soil have a significantly enhanced hydraulic conductivity at saturation than fine-textured soil.

This disparity is frequently several orders of magnitude. Additionally, observe that as the soil becomes unsaturated, the hydraulic conductivity drastically drops. For the coarse-textured soil, this decline is considerably more pronounced when plotted against the pressure head (Figure 7; right). Above a given pressure, the hydraulic conductivity of coarse-textured soil drops to a lower level than that of fine-textured soil due to the intensity of the decrease. The residual water content, yr, is often defined as the water content at which the conductivity drops asymptotically to zero (Figure 7; left).

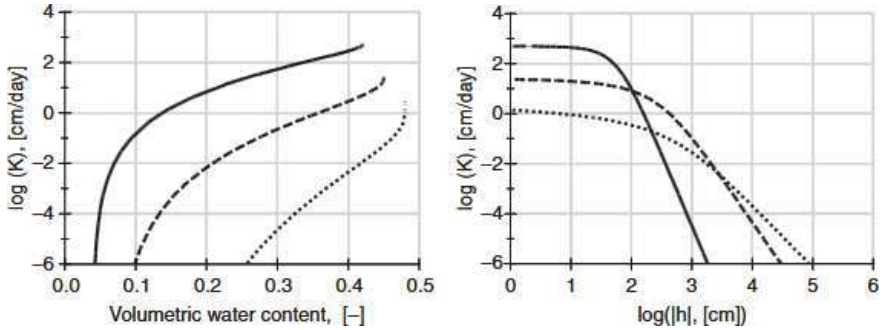


Fig.7. Typical curves of the hydraulic conductivity K, as a function of the pressure head (left) and water content (right) for coarse- (solid line), medium-

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(dashed line), and fine-textured (dotted line) soil

8.2 Soil water diffusivity

Soil water diffusion is an additional hydraulic function frequently used in the theoretical and managerial application of unsaturated flow theories $D(\theta)$,(L^2T^{-1}), which is defined as

$$D(\theta) = K(\theta)\left|\frac{dh}{d\theta}\right| \quad [3]$$

Equation 1 yields a water-content-based equation with y as the dependent variable, resulting in the appearance of this function.:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\theta)\frac{\partial h}{\partial z} - K(\theta)\right] \quad [4]$$

Particularly for modeling horizontal (without the $K(y)$ gravity factor) and vertical infiltration (e.g., Philip, 1969; Parlange, 1980), Equation 3 is highly appealing for approximate analytical modeling of unsaturated flow processes. For more thorough numerical modeling of flow in layered media, flow in partially saturated and partially unsaturated media, and extremely transient flow issues, the water-content-based equation is less appealing.

9. Summary

The behavior of unsaturated soils is a complex and essential topic in geotechnical and environmental engineering. The distinctive properties of unsaturated soils, influenced by the interaction of pore water, air, and soil particles, play a significant role in their mechanical, hydraulic, and volumetric behavior. Advances in modeling and experimental methods have improved our understanding of key factors such as shear strength, hydraulic conductivity, and volume changes under varying moisture conditions. However, challenges still exist in precisely characterizing and modeling the behavior of unsaturated soils due to the inherent variability of soils and environmental influences. Additional research is necessary to refine existing models, enhance predictive accuracy, and address external factors like climate change. Ongoing investigation into unsaturated soil mechanics is essential for improving the design and performance of civil and geotechnical infrastructure and for tackling environmental issues such as groundwater contamination and soil conservation. Overall, the review highlights the need to combine both theoretical and practical approaches in understanding unsaturated soil behavior for engineering applications, while emphasizing the importance of continuous innovation and collaboration in this critical area of study.

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ISBN: 978-93-343-2006-0

"FIBRE REINFORCED CONCRETE BY USING NYLON FIBRE"

Nikhil U. Jadhav[1]
P. G. Student of Structural Engineering
Dept. of Civil Engineering
K. J. College of Engineering
7&Management Research,
Pune, India
jadhaavnikhil15@gmail.com

Dr. Santosh K. Patil[2]
Head of Department
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
santosh68.patil@gmail.com

Dr. Atul B. Pujari[3]
Associate Professor
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
atulpujari.kjcoemr@kjei.edu.in

Abhijeet R. Undre[4]
Assistant Professor
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
abhijeetundre90@gmail.com

***Abstract*—** The usefulness of fiber reinforced concrete (FRC) in various civil engineering applications is indisputable. Fiber reinforced concrete has so far been successfully used in slabs on grade, architectural panels, precast products, thin and thick repairs, footings, hydraulic structures and many other applications. Fiber Reinforced Concrete (FRC) is gaining attention as an effective way to improve the performance of concrete. Fibers are currently being specified in tunneling, bridge decks, pavements, concrete pads, and concrete slabs. These applications of fiber reinforced concrete are becoming increasingly popular and are exhibiting excellent performance. Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include Synthetic fibers, glass fibers, synthetic fibers and natural fibers. This study presents understanding strength of fiber reinforced concrete with respect position of fibers placed in the concrete.

***Keywords*—** 1.ATM: Advanced technical material, 2.SEM:Scanning electron microscopy, 3.EDS:Elemental distribution sample, 4.NPP:Nuclear power plant concrete,

I. Introduction

Concrete is a construction material composed of cement as well as other cementitious materials such as fly ash and slag content, aggregate (generally a coarse aggregate such a gravel, limestone, or granite, plus a fine aggregate such as river sand) , water and chemical admixture concrete shows several desirable properties like high compressive strength, stiffness and durability.

Cement concrete is a mixture of coarse aggregates, fine aggregate, cement and water in a certain proportion so as to make a concrete of desired quality. Sometimes, special ingredients known as Admixture are also added to these so as to include or improves some property in concrete.

Concrete is the most important construction material because it is difficult to find out another material of such versatility and mouldability at such a cheap pice.

It has got good compressive strength, durability, impermeability, fire resistance, and abrasion value.

Its weakness in tensile strength can be made up by use of reinforcing and prestressing techniques and this has made the use of concrete widespread and now it is almost used everywhere

1.1 Durability of Concrete

The durability of concrete is its ability to withstand the environmental conditions to which it is exposed.

Main requirements of durability are :

An upper limit of w/c ration

A lowest limit of the cement concrete

A lower limit of the concrete cover to reinforcement

Good compaction

Adequate curing

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1.2 Water – Cement ratio

The ratio of weight of water to the weight of cement in a concrete mix is called water cement ratio. It is Usually expressed in liters of water required per bag of cement. The strength of concrete is controlled by the quantity and quality of its ingredients. Excess quantity of water creates segregation and bleeding whereas insufficient quantity of water makes the concrete harsh and unworkable. Therefore, it is necessary to add optimum quantity of water to allow hydration of cement completely and to make the mix workable.

Water is used for making concrete for three different purposes :

For mixing

For curing and

For washing

1.3 Workability of Fresh Concrete

1. Slump Cone Test:-

Concrete slump test or slump cone test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction.

The slump test is the most simple workability test for concrete, involves low cost and provides

immediate results. Due to this fact, it has been widely used for workability tests since 1922.

1.4 Equipment Required For Concrete Slump Test

Mould for slump test i.e. slump cone, non-porous base plate, measuring scale, temping rod. The mold for test is in the form of the frustum of a cone having height 30 cm, bottom diameter 20 cm and top diameter 10 cm. The tamping rod is of Synthetic 16 mm diameter and 60cm long and rounded at one end.

1.5 Procedure for Concrete Slump Cone Test

Clean the internal surface of the mould and apply oil.

Place the mould on a smooth horizontal non-porous base plate, Fill the mould with the prepared concrete mix in 4 approximately equal layers.

Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mould. For the subsequent layers, the tamping should penetrate into the underlying layer.

Remove the excess concrete and level the surface with a trowel.

Clean away the mortar or water leaked out between the mould and the base plate.

Raise the mould from the concrete immediately and slowly in vertical direction.

Measure the slump as the difference between the height of the mould and that of height point the specimen being tested.

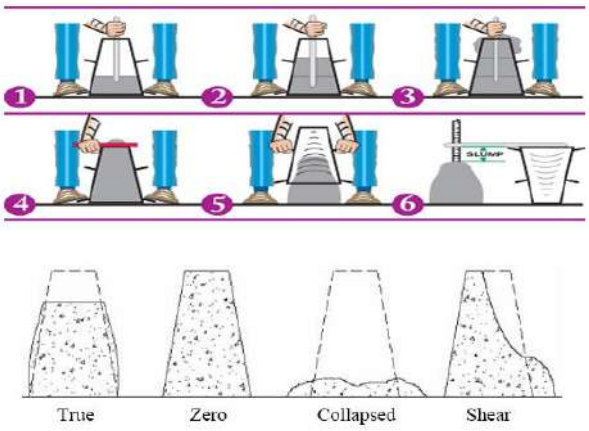


Figure No :- 1 Details Of Slump Condition

1.6 Compaction Factor Test:-

Compaction factor test is the workability test for concrete conducted in laboratory. The compaction factor is the ratio of weights of partially compacted to fully compacted concrete. It was developed by Road Research Laboratory in United Kingdom and is used to determine the workability of concrete.

The compaction factor test is used for concrete which have low workability for which slump test is not suitable.

Apparatus:-

Compaction factor apparatus consists of trowels, had scoop (15.2 cm long), a rod of synthetic or other suitable material (1.6 cm diameter, 61 cm long rounded at one end) and a balance.

Samling:-

Concrete mix is prepared as per mix design in the laboratory

1.7 Procedure of Compaction Factor Test on Concrete:-

Place the concrete sample gently in upper hopper to its brim using the hand scoop and level it.Cover the cylinder.

Open the trapdoor at the bottom of the upper hopper so that concrete fall into the lower hopper. Push the concrete sticking on its sides gently with the road.

Open the trapdoor of the lower hopper and allow the concrete to fall into the cylinder below.

Cut of the excess of concrete above the level of cylinder using trowels and level it.

Clean the outside of the cylinder.

Weight the cylinder with concrete to the nearest 10 g. This weight is known as the weight of partially compacted concrete (W1) .

Empty the cylinder and then refill it with the same concrete mix in layers approximately 5 cm deep, each layer being heavily rammed to obtain full compaction.

Level the top surface.

Weight the cylinder with fully compacted. This weight is known as the weight of fully compacted concrete (W2).

Find the weight of empty cylinder (W).



Figure No :- 2 Compaction Factor Test

1.8 Properties Of Hardened Concrete:-

Strength :-

The ability of concrete to resist force is called its strength. The hardened concrete should therefore, have sufficient strength to bear the load for which it is designed.

Compressive Strength:-

The most important property of concrete is its high strength, and therefore, it is used to resist compressive stresses. The strength of the concrete generally means compressive strength and is measured in N/ mm^2.

The resistive capacity of a concrete cube of 150 mm side after 28 days complete curing against compressive load is known as compressive strength of concrete and is measured in N/mm^2.

1.9 Fiber Reinforced Concrete (FRC) :-

It is a concrete in which small and discontinuous fibers are dispersed uniformly. Fiber reinforcement is one of the effective ways of improving the properties of concrete Addition of fibers to concrete makes it a homogenous and isotropic material.

The fibers used in FRC may be of different materials like Synthetic, G.I, synthetic fibers Carbon, Glass Asbestos, Polypropylene, and Jute etc.

In this study, an experimental investigation shall be conducted on strength of concrete containing synthetic fibers.

In this paper, studies shall be conducted on M20 mix and tests like compression test the usefulness of fiber reinforced concrete (FRC) in various civil engineering applications is indisputable. Fiber reinforced concrete has so far been successfully used in slabs on grade, architectural panels, precast products, thin and thick repairs, footings hydraulic structures and many other applications.

Fiber Reinforced Concrete (FRC) is gaining attention as an effective way to improve the performance of concrete. Fiber are currently being specified in tunneling, bridge decks, pavements, concrete pads, and concrete slabs. These applications of fiber reinforced concrete are becoming increasingly popular and are exhibiting excellent performance.

Fiber-Reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fiber that are uniformly distributed and randomly oriented. Fibers include Synthetic fiber, glass fiber, synthetic fibers and natural fibers. This study presents understanding strength of synthetic fiber reinforced concrete.

Finally, the results of fiber reinforced concrete shall be compared with the conventional concrete.



Figure No :- 3 Fiber Reinforced Concrete

ISBN: 978-93-343-2006-0

II. RESULTS

3 Days Compressive Strength of various positions of Nylon Fiber:-

Fiber Place In Concrete Block	Compressive Strength (in N/mm^2)	Average Compressive Strength (in N/mm^2)
Horizontal	16.7	14.21
	10.92	
	15.02	
Vertical	4	4.45
	4.4	
	4.96	
Random	8.8	7.53
	6.6	
	7.2	
Normal	10.2	10.53
	10.8	
	10.6	

Table No 1 :- Compressive Strength after 3 Days curing

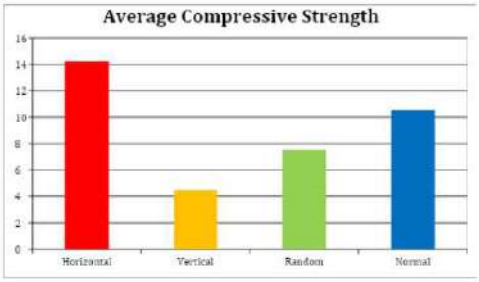


Table No 1 :- Compressive Strength after 3 Days curing

7 Days Compressive Strength of various positions of Nylon Fiber :-

Fiber Place In Concrete Block	Compressive Strength (in N/mm^2)	Average Compressive Strength (in N/mm^2)
Horizontal	13.86	13.90
	13.68	
	14.20	
Vertical	12.62	13.06
	14.30	
	12.26	
Random	7.46	6.00
	4.96	
	5.60	
Normal	13.40	13.80
	13.80	
	12.22	

Table No 1 :- Compressive Strength after 7 Days curing

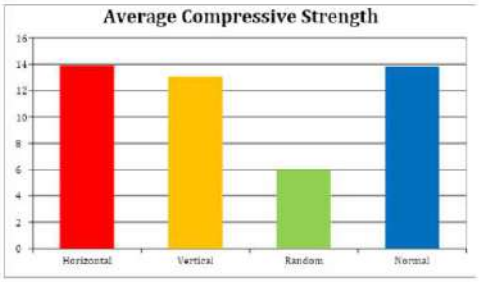


Table No 1 :- Compressive Strength after 7 Days curing

28 Days Compressive Strength of various positions of Nylon Fiber :-

Fiber Place In Concrete Block	Compressive Strength (in N/mm^2)	Average Compressive Strength (in N/mm^2)
Horizontal	17.80	17.60
	17.40	
	14.60	
Vertical	14.80	16.60
	17.50	
	17.52	
Random	14.56	16.28
	17.68	
	16.62	
Normal	23.10	17.10
	14.22	
	14.00	

Table No 1 :- Compressive Strength after 28 Days curing

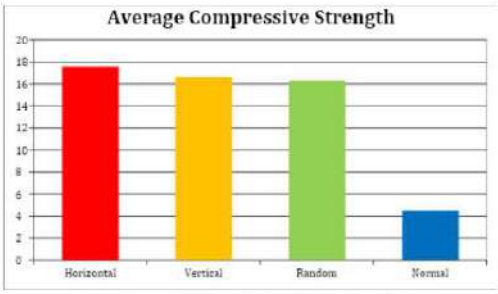


Table No 1 :- Compressive Strength after 28 Days curing

III. CONCLUSION

From the result, tabulated in the table No. 5 in chapter 4, it is concluded that compressive strength of cube casted with horizontal position of fiber have nearly equal strength as that of normal concrete cube. So, from the above test result we can conclude that we can partially replace cement with Nylon fiber. It is also observed that for horizontal position as compared to vertical and random position we get maximum strength.

So, by using Nylon fiber as partial replacement to cement we can achieve economy in concreting. Heat of hydration will be minimized which will result is less development of cracks.

#This study intends to fill this gap by analyzing and comparing the seismic performance of both systems on sloping ground, considering parameters like base shear, lateral displacement, and storey drift.

ACKNOWLEDGMENT

The authors are grateful to the Director, K. J. College of Engineering & Management Research, Pune, and the Head of Department, Civil Engineering for motivating and providing the required facilities in carrying out this study.

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Parametric Study and Comparison of Performance of Steel Frames with Different dampers (frictional and viscous) and Bracing (V shaped and X braced) in Seismic Zone IV

Anand Abhishek
PG Student, ME Structural Engineering, Dept . of Civil
KJ College of Engineering & Management Research
Pune, India
vickygoldsmith@gmail.com

Dr.S.K.Patil
HOD, Dept . of Civil
KJ College of Engineering & Management Research
Pune, India
santosh68patil@gmail.com

Dr. A.B. Pujari
Associate Professor, Dept . of Civil
KJ College of Engineering & Management Research
Pune, India
atulpujari.kjcoemr@kjei.edu.in

Prof. A.R.Undre
KJ College of Engineering & Management Research
Pune, India
abhijeetundre.kjcoemr@kjei.edu.in

***Abstract*—Steel frame structures' seismic flexibility is important, particularly in highly seismic active zones. Parametric study and performance This research focusses on the comparison for steel frame structures with varying dampers or bracing systems in earthquake pressures. It particularly studies the performance of frictional and viscous dampers coupled with V-shaped and X-bracing systems in buildings of different heights (G+7, G+14, and G+21) located in Seismic Zones IV. The seismic behavior of these structures is evaluated through time history analysis with special focus on major parameters like story displacement, story drift, and base shear. The research aims to identify the most effective combinations of bracing or damper configurations to improve the seismic response for steel structures. This is achieved by examining both distinct and combined configurations. Based on the results, X-bracing with frictional dampers always yields the lowest story drift and displacement, which means better lateral stiffness and overall structural stability. Viscous dampers, particularly when used in combination with X-bracing, enhance energy dissipation, reducing base shear and enhancing overall seismic performance. The study also investigates the influence of seismic zone and building heights on the performance of various configurations. Lastly, this research provides useful insights for the optimization of design of seismic-resistant steel frame structures.**

Keywords—Bracing systems, Dampers, Frictional dampers, Seismic analysis, Seismic performance, Steel frames, Structural resilience, Time history analysis, Viscous dampers, X-bracing, Zone IV

I. INTRODUCTION

Seismic analysis is increasingly significant in the assessment of the structural reliability and effectiveness of steel structures, particularly in seismically active regions. This study aims to conduct a comprehensive assessment of the seismic response of a steel structure by employing a variety of bracing configurations. In order to mitigate the impact of lateral forces produced during earthquakes and other seismic occurrences, bracing systems are essential parts of steel structures. Understanding the comparative effectiveness of different bracing configurations is essential for optimizing structural design and enhancing adaptability against seismic forces. Seismic analysis is essential for ensuring the safety of steel buildings during earthquakes. Steel's strength and ductility make it ideal for seismic-resistant structures. Various bracing systems, like diagonal, eccentric, concentric, and buckling-restrained bracing, are strategically placed in buildings to resist lateral forces. Researchers study these systems to enhance stability. For steel frame construction, seismic analysis is essential as the bracing selection has a major influence on a building's capacity to tolerate seismic pressures and safeguard people. However, under seismic stress, these structures are susceptible to excessive displacements, drifts, and vibrations, which may compromise structural integrity and occupant safety. Traditional reinforcing methods, such as bracing systems and modern damping devices, have shown potential in enhancing seismic performance. However, their individual and combined effects on dynamic behaviour, especially across different building heights and earthquake zones, remain inadequately understood. To evaluate and compare the reliability of steel frames with different bracing designs (V-braced and X-braced) along with dampers (frictional as well as viscous) across various building heights along with seismic zones, thorough parametric research is required. Identifying the most effective combination for reducing seismic response is crucial for improving structural performance and resilience in earthquake-prone areas. The parametric examination and effectiveness evaluation of steel frames with various bracing systems including dampers to improve seismic behaviour are the main objectives of this work. Three building models—G+7, G+14, and G+21— In accordance with pertinent IS regulations, time history analysis is employed to analyse the data for Seismic Zone IV. Story displacement, story slide, base shear, and time period are critical response parameters, and frequency are examined in the research, along with the effects of V-bracing and X-bracing configurations alone and

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in conjunction with frictional and viscous dampers. Engineers and designers in seismically active areas could gain significantly from the results of the study, which try to identify the optimum bracing and damper combinations for various building heights and seismic zones by examining the seismic performance of these models. The following are the objectives of this research: (1) To examine the seismic behaviour of G+7, G+14, and G+21 steel frames based on time history analysis for Seismic Zone IV ; (2) To compare and evaluate the structural behaviour of steel frames with different types of bracings (V-bracing and X-bracing) subjected to seismic loading; (3) To study the effectiveness of frictional and viscous dampers for improving seismic performance for different heights of buildings in seismic zone IV; and (4) To select the best combination of dampers and bracings for enhancing seismic performance by considering various frame models with combined configurations of bracing and dampers..

II. LITERATURE REVIEW

Literature Review

The literature review forms a good foundation for comprehending theoretical and empirical research on seismic behavior of steel structures, particularly those with bracing systems and damping devices. This section explores a range of studies and approaches that examine the efficacy of different bracing arrangements and types of dampers subjected to seismic stress. It provides a summary of recent research to improve the structural robustness of steel frames by minimizing lateral displacements, story drift, and base shear during earthquakes. Aparna Shiny Gottem et al. (2023) carried out an analytical study in an attempt to assess the seismic performance of the 50-story reinforced concrete building in various seismic zone scenarios.

The performance of buckling restrained braces was evaluated under the study. Based on the research, effectiveness in BRBs differs with respect to seismic zones, and particular configurations increase the story rigidity and decrease lateral displacement. Authors highlight the relevance of choosing a proper bracing configuration to suppress the P-delta effect for high-rise structures. In seismic zones II, III, IV, and V, T. Laya Sri et al. (2022) compared the performance of a G+15 reinforced concrete structure with and without steel reinforcement considering lateral displacement and story shear. The findings indicate that chevron bracing systems provide the best seismic performance in seismic zones II and III, while V-bracing performs better in seismic zones IV and V. This highlights the importance of choosing the right bracing system for a given seismic zone. Magdalini D. Titirla (2023) provides a thorough review of seismic safety systems employing passive energy dissipation, focusing on dampers in steel supports. The research evaluates the efficiency of more than 196 publications on a range of dampers, including friction (FD), metallic (MD), and viscous dampers (VD), in dissipating seismic energy and preventing deformation. The review emphasizes that no damper is optimal for every case, since every damper takes advantage of certain benefits, depending on cost, technical demands, and architectural necessities. In another study related to the topic, Wesam Al Agha and Dr. Nambiappan Umamaheswari (2020) analyze the seismic performance of FVD-equipped and -unequipped reinforced concrete structures. The research assesses the seismic performance effects of FVDs through the use of ETABS software and Equivalent Static, Response Spectrum, and Time History Analysis. Findings suggest that FVDs play a key role in minimizing lateral deflections, story shear, and base shear and enhancing story stiffness and overall structural stability.

III. METHEDOLOGY

The systematic procedure to perform parametric study and performance comparisons of steel frame structures having various bracing systems including dampers under seismic loading is time history analysis, which is a dynamic structural analysis technique. G+7, G+14, and G+21 steel frames are studied in Seismic Zone IV with the help of time history analysis to find out their dynamic response. The structural models are developed and solved with finite element software, with two bracing systems—V-bracing and X-bracing—and two types of dampers—frictional and viscous. Each frame is analyzed in combination configurations, to determine the best system for increasing seismic performance. To guarantee accuracy and compliance with safety requirements, the methodology follows the essential sections of Indian Standard (IS) norms for seismic analysis and structural design. Using a discretised record of synthetic time history as the basis motion, dynamic analysis using time history analysis computes the building's reactions at discrete time steps. Only the largest responses of the parameter of interest are chosen when three or more-time history analyses are conducted.

The examination of a structure's dynamic reaction at each additional time point when its base is subjected to a certain ground motion is known as time history analysis. In situations when higher mode effects are not significant, static approaches may be used. For short, regular structures, this is regularly valid. Therefore, a dynamic approach is required for tall structures, structures with torsional asymmetries, or structures without orthogonal frameworks.

A linear elastic stiffness matrix and an analogous viscous damping matrix are used to represent the structure as a multi-degree-of-freedom (MDOF) system in the linear dynamic approach. Time history analysis is used to simulate the seismic input, and linear elastic analysis is used to determine the displacements and internal forces. Similar to linear static procedures, the advantage of linear dynamic procedures is that higher modes may be considered.

By computing the buildings' reaction to ground motion in the time domain, linear dynamic analysis preserves all phase information. Only linear qualities are taken into account. If the external force or ground acceleration varies randomly over time, or if the system is nonlinear, the analytical answer of the equation of motion for a one degree of freedom system is often not possible. Numerical time-stepping methods for integrating differential equations might be used to address such problems.

IV. PROBLEM STATEMENT

The dynamic performance of steel frames under seismic stress is an important concern in structural engineering, especially in areas with varying seismicity. This study focuses on a parametric analysis and performance comparison of G+7, G+14, and G+21 steel frame models equipped with distinct energy dissipation systems namely

frictional and viscous dampers and bracing configurations (V-shaped and X-braced frames). The analysis is carried out for seismic zones 4 in accordance with the applicable IS rules, with structure reactions evaluated using time history analysis in ETABS. Each frame is evaluated in combination configurations such as X bracing with frictional dampers and V bracing with viscous dampers, to determine the most effective methods for maximum seismic adaptability. The purpose of this comparative study is to give insights into the synergistic effects of coupled systems and to suggest ways for improving the seismic performance of steel frame structures in varying seismic zones.

A. Input data of Building

In both the X and Y directions, the study examines a steel-framed building with plan dimensions of 30m × 30m, which is divided into five bays of 6m each. Analyzed are three distinct building heights: G+7 (8 stories), G+14 (15 stories), and G+21 (22 stories). The buildings are situated on medium soil and are designed for Seismic Zones IV, with seismic zone factors of 0.24, respectively. Considered are a response reduction factor of 5 and an importance factor of 1. The slab thickness is 200mm, and each floor is 3 meters in height. The structural system includes X-type and V-type reinforcement, as well as structural and viscous dampers installed along the Y vector. ISMB 400 and ISHB 450-2 are the beam and column sections, respectively.

The material properties consist of Fe345 steel and HYSD 500 for reinforcement, while M30 grade concrete is employed. A uniform floor load of 3 kN/m², a wall load of 14 kN/m, and self-weight (calculated automatically in ETABS) are the dead loads that define the loading conditions. Wind loads in the X and Y directions are considered at 1.5 kN/m2, while live loads are applied at 2 kN/m2. Accurate structural modeling and performance evaluation under seismic and wind loads are guaranteed by this comprehensive input data.

B. Model Detail

The study analyses 24 distinct steel frame models across three building heights—G+7, G+14, and G+21—in Seismic Zones IV. In both orientations, each model employs frictional or viscous dampers in conjunction with either X-bracing or V-bracing. In both seismic zones, four configurations are evaluated for each building height: (1) X-bracing with frictional dampers, (2) V-bracing with frictional dampers, (3) X-bracing with viscous dampers, and (4) V-bracing with viscous dampers. This comprehensive approach enables a comparative analysis of the impact of various bracing-damper combinations on seismic performance across varying seismic building heights in seismic zone IV intensity.

C. Value of Dampers

For G+7, G+14, and G+21 steel frame structures in Seismic Zones IV, the study considers both friction and viscous dampers. Across all configurations, the mass and weight of the dampers are constant at 61.8 kg and 606.258 kN, respectively. The effective stiffness values for Zone IV are 25,750 kN/m, while for Zone V they are 92,700 kN/m. The effective damping ranges from 36,024.12 kN·s/m to 113,347.2 kN·s/m, depending on the building height and zone. The stiffness values for nonlinear properties range from 10,815 kN/m to 64,890 kN/m, while the damping values range from 14,409.65 kN·s/m to 56,673.62 kN·s/m. In all cases, a constant damping coefficient of 0.3 is maintained, allowing for a comparative assessment of damper performance across various seismic intensities and building heights.

D. Modelling images

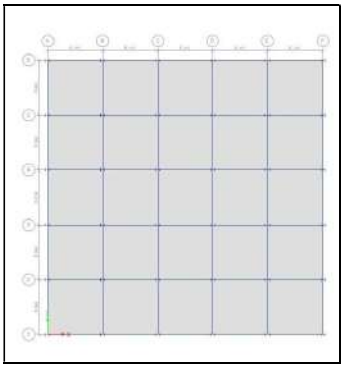


Fig:1 Plan view

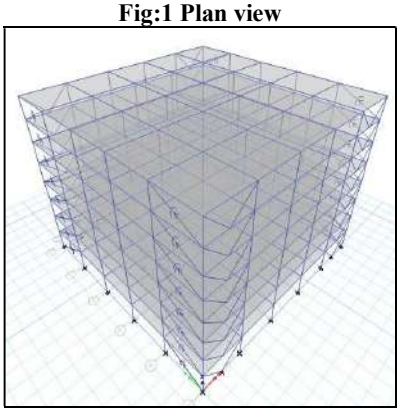


Fig:2 3D view G+7 building

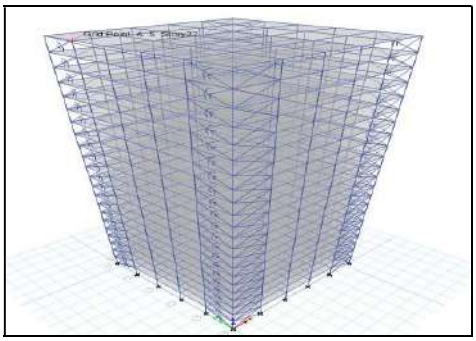


Fig:3 X bracing and friction damper in both directions

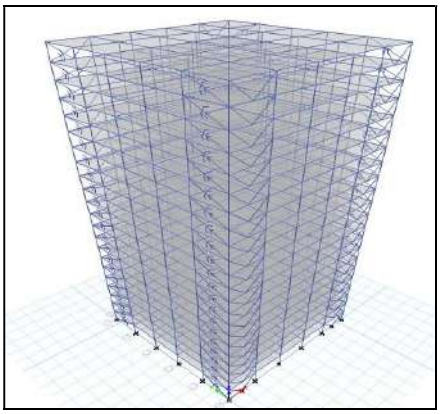


Fig:4 V bracing and friction damper in both directions

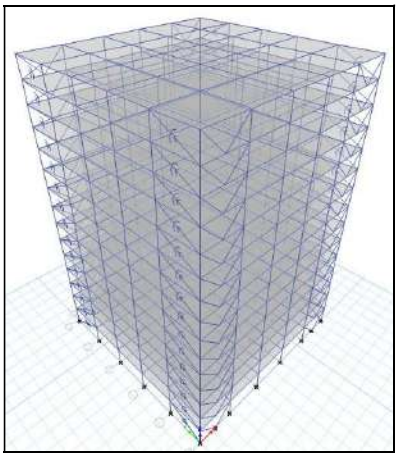
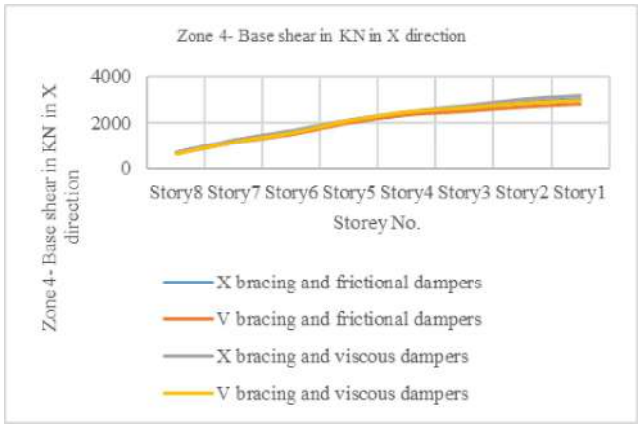


Fig:5 3D view G+14 building

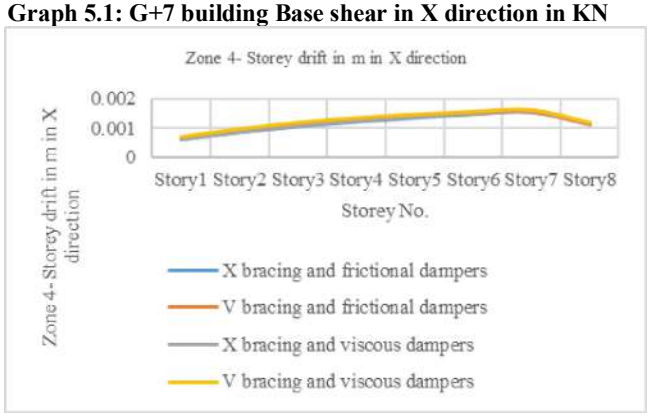
E. Result & Discussion

This section seeks to provide a clear understanding of how each parameter varies with variations in building height, seismic zone, and structural system. Parametric analysis of steel frames with various bracing systems (V-bracing and X-bracing) and dampers (frictional and viscous) under seismic loads for G+7, G+14, and G+21 structures. Time history analysis was used to examine Seismic Zone IV, paying particular attention to important factors such story displacement, story drift, base shear in both the X and Y directions, time period, and frequency. These parameters provide essential information about the frames' dynamic behavior and seismic performance. The results are compared across configurations to determine the effectiveness of various damping and bracing combinations. The discussion analyses these results, stressing the high-performance increases, structural stability, and choosing the best design for reducing seismic response and increasing structural resilience.

G+7 results

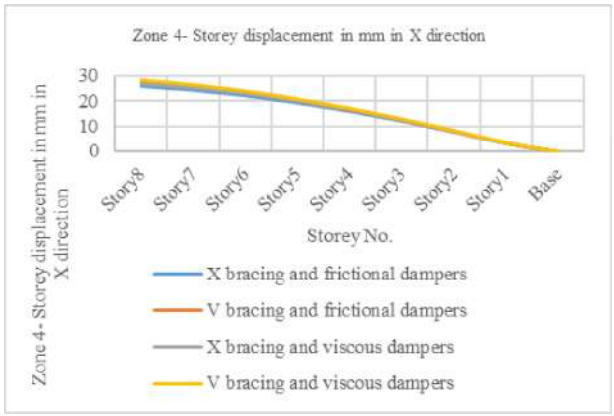


Graph 5.1: G+7 building Base shear in X direction in KN



Graph 5.2: G+7 building Storey drift in X direction in m

The X-direction storey drift values show that the biggest drift occurs between the middle and lower storeys, with a peak around Storey 3 and Storey 4. The difference between bracing and damper configurations is minimal, however X-bracing with relative low frictional dampers results in higher resistance to inter-storey distortion. The biggest drift is seen in V-bracing with viscous dampers, indicating lower rigidity.

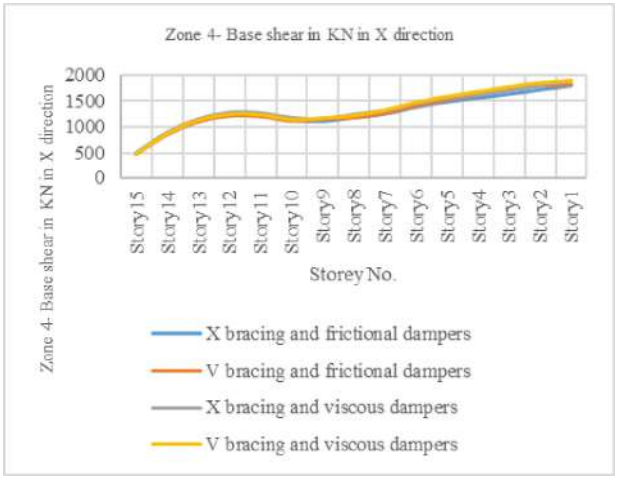


Graph 5.3: G+7 building Storey displacement in X direction in mm

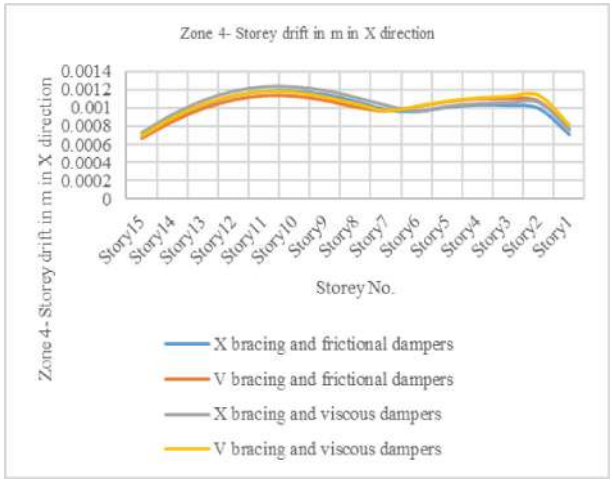
The storey displacement in the X direction shows that the highest displacement occurs at the topmost storey (Story 8) and progressively decreases towards the base. X-bracing with frictional dampers has the lowest displacement values,

whereas V-bracing with viscous dampers has the largest displacement across all stories. This suggests that X-bracing with frictional dampers offers more lateral stiffness and decreases total displacement more efficiently in seismic Zone IV.

G+14 results



Graph 5.4: G+14 building Base shear in X direction in KN



Graph 5.5: G+14 building Storey drift in X direction in m

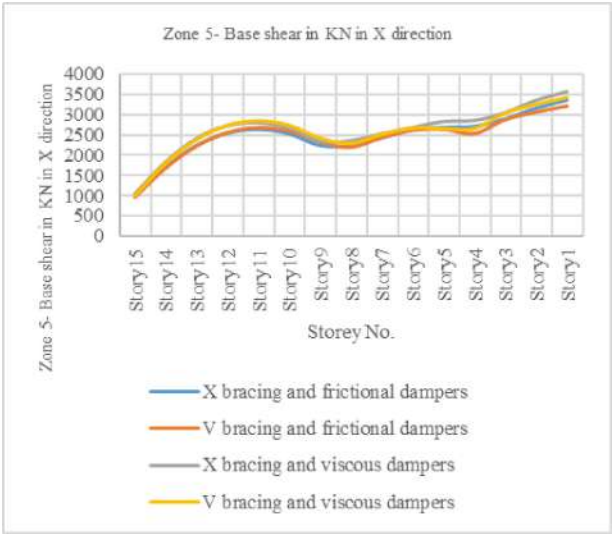
Storey drift analysis in the X direction reveals that the biggest drift occurs between Stories 12 and 14, with values reaching 0.00119 m for X bracing with frictional dampers and 0.001241 m for X bracing with viscous dampers. The uppermost level has the lowest storey drift (0.0007 m), indicating that inter-storey movement is minimised at higher altitudes. The lowest drift is consistently shown by V bracing with frictional dampers, suggesting increased lateral stiffness and less seismic sensitivity.



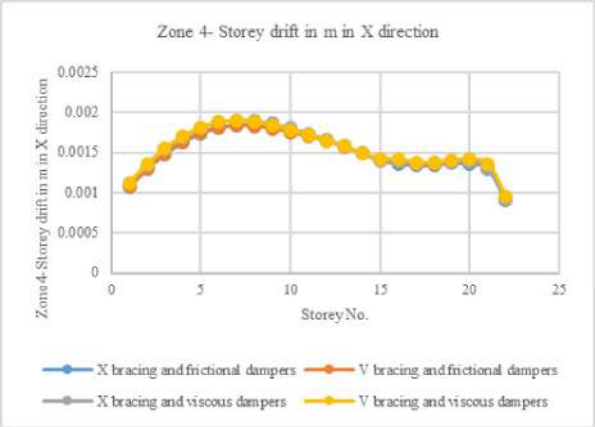
Graph 5.6: G+14 building Storey displacement in X direction in mm

The G+14 building in Zone IV demonstrates various storey displacements depending on the type of base bracing and damper system utilised. The X bracing with viscous dampers has the most displacement observed at the topmost storey (Story 15), whereas the V bracing with frictional dampers has the lowest displacement (36.265 mm). V bracing with frictional dampers gives the least displacement across all levels, indicating higher stiffness and better resistance to lateral stresses. The displacement values decrease towards the base, eventually reaching 0 mm at the foundation level, as anticipated.

G+21 results

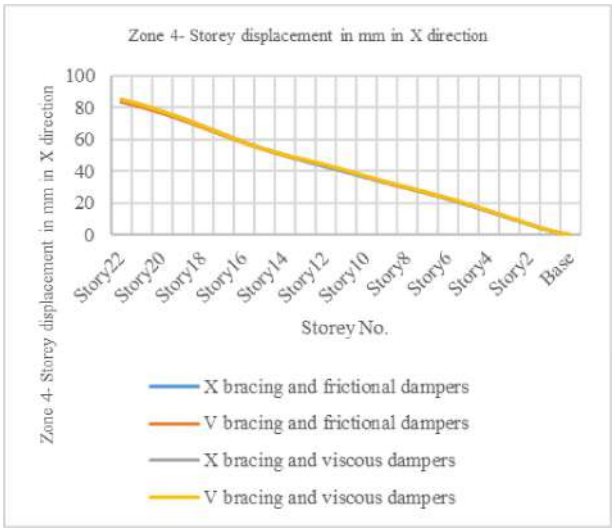


Graph 5.7: G+14 building Base shear in X direction in KN



Graph 5.8: G+21 building Storey drift in X direction in m

Both the X and V bracing configurations with frictional dampers keep drift below acceptable limits, exhibiting good lateral stability. Viscous dampers exhibit somewhat higher drift while being within acceptable structural safety limits.



Graph 5.9: G+21 building Storey displacement in X direction in mm

The storey displacement values show that displacement rises with height, peaking at the top level (Story 22). X and V bracing with frictional and viscous dampers provide variable degrees of displacement control, with X bracing and frictional dampers providing somewhat superior performance in terms of displacement reduction.

F. Conclusion

Steel frame buildings' seismic performance is essential to preserving building longevity and safety, particularly in seismically active regions. In order to cushion seismic in G+7, G+14, and G+21 steel frames, this research aimed to evaluate and compare the performance of steel frames with various damper types (frictional and viscous) and bracing configurations (V-shaped and X-braced). Time history analysis was used to evaluate structural characteristics such story displacement, base shear, story drift, and time period when the frames were subjected to seismic loads in Seismic Zones IV.

Key Findings of the Study:

→ Impact of Bracing and Dampers: The combination of bracing and dampers significantly influences structural response during seismic events.

→ Superior Performance of X-Bracing with Frictional Dampers:

→ Consistently reduces lateral displacement and inter-storey drift.

→ Enhances structural stiffness, improving resistance to lateral seismic forces.

→ Most effective in Seismic Zones IV for minimizing storey displacements.

→ Effective in reducing base shear but results in higher lateral displacements, especially in taller buildings.

→ Displacement and drift values increase as building height increases (G+7 to G+21).

→ For G+7 buildings: X-bracing with frictional dampers provides the best solution with the lowest displacement and drift.

→ For G+14 and G+21 buildings: X-bracing with viscous dampers balances force distribution, reducing shear but allowing more displacement at higher levels.

→ A one-size-fits-all approach is ineffective; seismic design should be adapted based on building height and seismic zone.

→ A hybrid approach using both bracing and damping systems is recommended to optimize lateral force resistance and displacement control.

→ Highlights the importance of damping systems in improving energy dissipation and structural rigidity.

→ Verifies frictional dampers as very effective in restricting displacement.

→ Highlights the function of viscous dampers to regulate base shear, maintaining structural stability under seismic activity.

In general, this study offers a comprehensive insight into the behavior of different damper and bracing systems under seismic loads, setting the stage for future developments in earthquake-resistant steel frame design. The results underscore the need for an advanced seismic design approach that addresses both material and rate issues to maximize building performance in diverse seismic zones. The long-term behavior of such systems, cost-effectiveness, and their implementation in actual structural design scenarios may all be investigated in subsequent studies to further advance this work.

For higher steel buildings (G+14 and G+21), friction dampers are efficient in minimizing story displacement and inter-story drift, particularly in seismic zones IV. Engineers should tailor seismic design by picking suitable bracing and dampers depending on the seismic zone—X-bracing with frictional dampers for Zone IV and X-bracing with viscous dampers for improved shear resistance in Zone V. Cost effectiveness must be balanced, as viscous dampers improve base shear resistance but may not always be economical for tall buildings. Hybrid systems, with varying bracing and

dampers, may achieve optimal structural performance in seismically high regions.

Additional studies on hybrid damping systems, such as viscoelastic dampers, may enhance seismic performance. Nonlinear dynamic analysis should be explored to better understand material behavior under extreme seismic forces. Studying soil-structure interaction (SSI) would enhance result.

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Earthquake behavior of Diagrid structure Subjected to different Soil types

Mandar D. Pawar[1]
P. G. Student of Structural Engineering
Dept. of Civil Engineering
K. J. College of Engineering
7&Management Research,
Pune, India
mandarpawar9146@gmail.com

Dr. Atul B. Pujari[2]
Associate Professor
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
atulpujari.kjcoemr@kjei.edu.in

Dr. Santosh K. Patil[3]
Head of Department
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
santosh68.patil@gmail.com

Associate Professor
Dept. of Civil Engineering
K. J. College of Engineering &
Management Research,
Pune, India
abhijeetundre90@gmail.com

***Abstract*— With the scarcity of flat land, construction on sloped terrain has become increasingly common. However, such conditions heighten the risk of structural and construction-related damage during seismic events. Diagrid structural systems have emerged as a promising alternative to conventional building frameworks, offering superior stability, especially for high-rise structures. Despite their potential, further investigation is needed to understand how variables like material type and loading conditions influence the seismic performance of Diagrid systems. This study examines the seismic response of Diagrid reinforced concrete (RC) buildings on both flat and inclined ground. A multi-storey structure was modeled and analyzed using the Response Spectrum Method in ETABS software, considering a flat ground. The evaluation was based on dynamic characteristics such as storey displacement, drift, shear, and stiffness. The comparative analysis reveals that Diagrid systems constructed on sloped terrain exhibit improved behavior in terms of lateral displacement, drift, shear forces, and ductility, suggesting enhanced suitability for earthquake-prone hilly regions compared to conventional structures on level surfaces.**

Keywords*— Diagrid structure, Response spectrum method, Sloping Ground, Level Ground, Story displacement, Story drift, Story shear, ETAB software.

I. INTRODUCTION

The development of tall skyscrapers is influenced by a combination of factors, including aesthetic considerations, technological advancements, political influences, and economic factors. Among these, economic considerations are paramount. However, the realization of high-rise building projects would not be feasible without the technological advancements that support them. A tall building's structure can be conceptualized as a vertical cantilever beam anchored to the earth. This design must be capable of withstanding not only vertical gravity forces but also lateral forces such as wind and earthquakes. Gravity loads, including permanent dead loads and variable live loads, contribute to the vertical forces. The primary threat to the building's integrity often arises from lateral loads, which can lead to structural failure. Therefore, the structure must provide adequate vertical support while also resisting shear and bending forces. Tall buildings, due to their increased height and vulnerability to lateral pressure, rely more on their perimeter design than any other type of building.

To enhance a skyscraper's structural stability and resistance to lateral forces, it is crucial to integrate as many lateral load-resisting systems into the perimeter as possible. A review of the history of diagrid systems in high-rise construction shows that these systems can be applied to various architectural styles, enhancing both the durability and visual appeal of the building. The primary purpose of these systems is to help the structure endure both lateral and vertical stresses.

A. Diagrid Structure

A diagrid is a structural framework composed of intersecting diagonal members, forming a single-layer grid that derives its strength through triangulation. This system can adopt various forms, including planar, crystalline, or curved shapes, with curvature often incorporated to enhance stiffness. Typically, the perimeter diagrids, which frame the edges of the floors, are responsible for supporting both lateral and vertical forces acting on the building. The diagonal elements of the system are essential in transferring shear forces and moments.The optimal angle for placing the diagonals is largely dependent on the building's height. Steel is the material that is most frequently and widely utilized to build diagrids. Wide flanges, rounded HSS and rectangular HSS are the most widely used sections. The sections are made strong to withstand strong bending stresses. They are easy to erect and labour cost is reasonable. Precast as well as cast in situ concrete diagrids can be used on site. Precast concrete sections can fit exactly in the geometry of the structure because of their flexibility. In addition, it guards against fire damage. However precast concrete diagrid contributes more to the structure's dead load. Timber as a

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diagrid material has many drawbacks as compared to concrete and steel. The only benefit of using timber is that the piece of timber can be found easily and of any shape. Low installation costs are involved. The main drawback is the lower material strength. Timber is vulnerable to weathering actions.

II. LITERATURE REVIEW

1) Analysis of Diagrid Structural System by E-Tab by U. A. Nawale and D. N. Kakade (2017)

The design of high-rise buildings is significantly influenced by lateral forces such as earthquakes and windstorms. Among various structural systems, the diagrid system has gained popularity due to its structural efficiency and aesthetic appeal. This study focuses on a 32-story building employing a diagrid structural system without vertical columns around the perimeter. The analysis, conducted using ETABS software, examines the building's behavior under seismic loads. Key parameters such as story displacement and story drift are evaluated to assess the structural performance of the diagrid system **Table 1.** Table captions should be placed above the tables.

2) Diagrid buildings for tall structures with complicated shapes by K. S. Moon (2011)

Tall buildings are increasingly adopting diagrid structural systems, and their durability is assessed alongside building forms within each complex form category. This study examines the impact of modifying key geometric combinations of tall, complex-shaped buildings, such as twisting rate and tilting angle. Design considerations are provided for the effective use of diagrid structures in complex-shaped tall buildings based on the study's findings. Multidisciplinary collaboration and further research into the potential structural systems of the numerous complex-shaped tall structures emerging worldwide are essential for designing more functional environments.

3) Study of Seismic Behavior of Multi-storied R.C.C. Buildings resting on sloping ground and bracing system by Nikhil Tamboli, Dr. Ajay Swarup (2017)

Buildings situated on hill slopes in earthquake-prone areas often exhibit irregularities and torsional coupling, making them susceptible to significant damage during seismic events. These structures typically have varying mass and stiffness along both vertical and horizontal planes, causing the centers of mass and rigidity to misalign across different floors. Dynamic analysis, utilizing the response spectrum method, has been conducted to assess the fundamental time period, story displacement, and base shear induced in columns for buildings of varying heights. The findings indicate that step-back and set-back building frames offer better performance compared to step-back frames alone. However, incorporating bracing into step-back frames enhances their seismic resilience, surpassing the performance of both step-back and set-back configurations. Three-dimensional space frame analysis has been performed on four building configurations—eight, ten, and twelve stories—situated on sloping ground. These models were analyzed using ETABS software to evaluate the effects of time period, story displacement, and base shear.

4) Seismic Analysis of building resting on sloping ground by B.G. Birajdar, S.S. Nalawade (2004)

In this paper researcher studied on the dynamic response properties developed in column on 24 RC building resting on sloping ground with three different configuration. like, Step back building, Step back Set back building and Set back building are presented. 3 –D analysis including torsional effect has been carried out by using response spectrum method. The dynamic response properties i.e. fundamental time period, top story displacement and, the base shear action induced in columns have been studied with reference to the suitability of a building configuration on sloping ground. It is observed that Step back Set back buildings are found to be more suitable on sloping ground. They confirmed that Step back Set back building are found to be more suitable on sloping surface.

5) Seismic analysis of Multi story Building on Sloping Ground and Flat Ground by using ETABS by K Veera Babu, S Siva Rama Krishna, Venu Malagavelli (2023)

Rapid urbanization and industrial growth in emerging nations like India have led to the development of tall, multi-story buildings on mountainous terrains due to limited flat land availability. Structures built on sloping ground differ significantly from those on level ground, exhibiting irregularities and asymmetries in both vertical and horizontal planes. These buildings are more susceptible to seismic forces when situated on inclined surfaces. This study aims to examine the seismic behavior of structures on both level and sloping terrains. Buildings on hilly terrains are characterized by torsional coupling, irregularities, and asymmetries, making them prone to severe damage during earthquakes. The research focuses on a multi-story building with two distinct slope angles, comparing its performance with that of a building on level ground, considering Earthquake Zone II. The models are developed using ETABS software, and response spectrum analysis is employed to assess dynamic responses such as story shear, story drift, moments, and displacement.

6) Estimation of Storey Stiffness in multi-storey buildings by A. R. Vijayanarayanan, Prof. Rupen Goswami (2017)

The presence of stiffness irregularity, when combined with strength irregularity, along the height of a building can lead to undesirable behavior during severe earthquake shaking, such as localized lateral deformations in specific stories and the initiation of storey collapse mechanisms. Seismic design codes recommend a simple quantitative check using storey stiffness to identify the presence of stiffness irregularity along the building height. However, the procedure to estimate storey stiffness is not specified in design codes. Consequently, several methods are used in practice to estimate storey stiffness. In theory, there exists a unique value of stiffness for a given storey in a multi-storey

building, but estimates using different methods yield different results due to the inherent assumptions in each method. Therefore, there is a need to compare and ascertain a method that can estimate storey stiffness with adequate accuracy. A comparison of seven available methods for estimating storey stiffness reveals that the Fundamental Lateral Translational Mode Shape Method is the most accurate, as it does not entail any simplifying assumptions.

7) Study on the diagrid structure of a multistory building by E-Tab by Ravi sorathiya, Asst. prof. pradeep pandey (2017)

This research proposes a stiffness-based design methodology to estimate the preliminary dimensions of reinforced concrete (RCC) diagrid structural elements for tall buildings. The study focuses on RCC buildings with varying heights G+24, G+36, G+48, and G+60 stories located in Surat, each with a plan dimension of 18 m × 18 m. Structural modeling and analysis are conducted using STAAD.Pro software. All structural components are designed in accordance with IS 456:2000, and seismic load combinations are applied as per IS 1893 (Part 1):2002. Comparative analyses are performed to assess beam displacement, story drift, and bending moments across different building configurations. The findings indicate that the diagrid structural system offers a more costeffective solution compared to conventional structural systems.

8) Diagrid structural system for R.C.Framed multistory buildings by Harshita Tripathi, Dr. Sarita Singla(2016)

In tall buildings, lateral loads, rather than gravitational forces, predominantly influence the structural design. Consequently, systems that efficiently provide stiffness against lateral loads are preferred for such structures. The diagrid system stands out as a highly effective lateral load-resisting system due to its triangular configuration. This structural system has gained popularity in modern tall buildings, offering both structural efficiency and aesthetic appeal through its unique geometric design. This paper introduces a stiffness-based design approach to determine the preliminary member sizes of reinforced concrete (RCC) diagrid structures for highrise buildings. The methodology is applied to diagrid systems of varying heights and grid geometries to identify the optimal grid configuration within a specified height range. The design approach is implemented on diagrid structures comprising 24, 36, and 48 stories. Dynamic analysis of these buildings, featuring perimeter diagrids with different story modules, is conducted using the response spectrum method. Comparative analysis of results, including top story displacement, story drift, story shear, time period, diagrid angle, spectral acceleration coefficients, and base reactions under seismic and wind forces, is performed within the same story height across different story modules and building heights.

9) Seismic Analysis and Design of G+10 Story building in different Sloping ground conditions by Dhruv Sharma, Dr. Praveen Kumar, Dr. Abhay Kumar jha, Barun Kumar (2022)

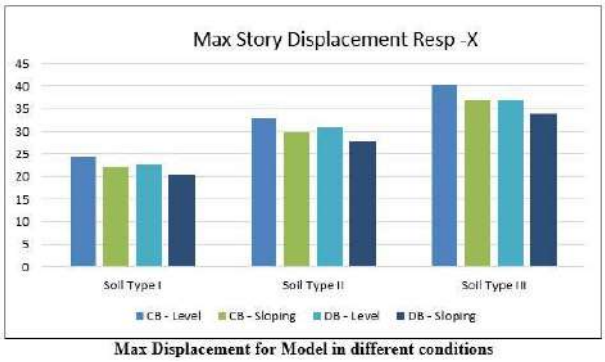
In mountainous regions, the scarcity of flat land often leads to the construction of buildings on sloping terrains, resulting in irregular structural layouts and foundations at varying elevations. These structures face unique challenges, particularly when subjected to seismic activity. The effects of step-like inclined geology on buildings have not been extensively studied, especially when compared to the more commonly studied slopes and ravines. The non-symmetric geometry of step-like inclines complicates structural design and often necessitates site-specific numerical simulations. A primary concern for structural engineers is the seismic vulnerability of buildings situated on such sloping terrains.

10) Comparative Study on Seismic Behavior of RC Structure with diagrid & X- steel bracing for Different Stories by Pushkaraj S. Mane, Pramod B. Salgar (2023)

This study compares the seismic performance of reinforced concrete (RC) buildings equipped with diagrid and X-bracing structural systems across various building heights. Utilizing ETABS software, the analysis evaluates the structural response to seismic and wind loads. The findings suggest that diagrid structures may serve as a viable alternative for tall buildings in seismically active regions. Key recommendations include ensuring that diagrid systems possess adequate stiffness and strength to prevent excessive deformation and failure. Additionally, further research is necessary to explore the impacts of factors such as soil-structure interaction, material properties, and loading patterns on the seismic behavior of these structures. The analysis encompasses buildings with 36, 40, 50, and 60 stories, each with a plan area of 1296 m² (36m x 36m). Comparative evaluations of story displacements, story drift, base shear, and structural ductility indicate that diagrid structures outperform X-bracing systems in terms of seismic resistance.

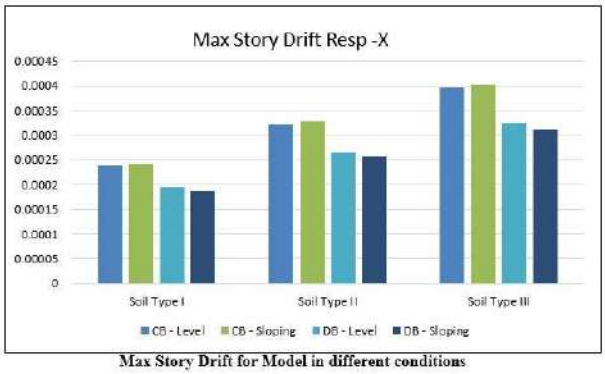
III. RESULTS

*A) **Displacement:** Indian regulations limit the maximum displacement in a multistory building for seismic H/250 and for wind is H/500*



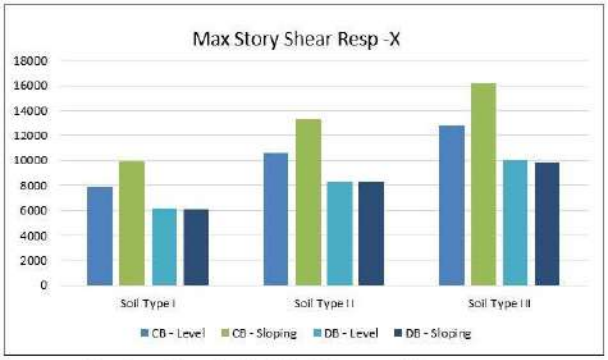
Max Displacement for Model in different conditions

*B) **Story Drift:** The Horizontal displacement of a floor in relation to the floor below, caused by outside forces like wind or earthquake is known as story drift.*



Max Story Drift for Model in different conditions

C) ***Story Shear:*** *The maximum projected lateral force on the base of a structure as a result of seismic activity is estimated as base shear.*



Max. Story Shear for Model in different conditions

IV. CONCLUSION

The seismic analysis of reinforced concrete (RC) buildings with diagrid and conventional frame structures across various soil types reveals the following key observations:

Diagrid structural systems are highly effective for high-rise buildings, offering better lateral stiffness, reduced material usage, and architectural flexibility.

Previous studies confirm that diagrids outperform conventional systems in terms of lateral displacement, storey drift, and base shear under lateral loads.

Buildings on sloping ground face additional challenges such as irregular geometry, unequal load distribution, and increased seismic vulnerability.

Most existing research on sloping ground focuses on conventional RCC or steel framed structures, with limited work on diagrid systems.

There is a lack of studies combining diagrid structures with sloping ground conditions, especially under seismic and soil interaction effects.

A research gap exists in the comparative performance analysis of diagrid vs. conventional systems on inclined sites.

#This study intends to fill this gap by analyzing and comparing the seismic performance of both systems on sloping ground, considering parameters like base shear, lateral displacement, and storey drift.

ACKNOWLEDGMENT

The authors are grateful to the Director, K. J. College of Engineering & Management Research, Pune, and the Head of Department, Civil Engineering for motivating and providing the required facilities in carrying out this study.

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DAMAGE INDEX ESTIMATION FROM MEASURED RESPONSE FOR NONLINEAR SYSTEMS UNDER SEISMIC EXCITATION

Vijay kishor Marathe

PG Student

Department of Civil Engineering,

K.J. College of engineering and management research

Pune, India

Vijaymarathe8446@gmail.com

Dr. Santosh K. Patil

Head of Department,

Department of Civil Engineering,

K.J. College of engineering and management research

Pune, India

santosh68.patil@gmail.com

Dr. Atul B. Pujari

Professor

Department of Civil Engineering

K.J. College of engineering and management research

Pune, India

atulpujari.kjcoemr@kjei.edu.in

Prof. Abhijeet R. Undre

Assistant Professor,

Department of Civil Engineering,

K. J. College of Engineering & Management Research,

Pune, India

abhijeetundre.kjcoemr@*kjei*.edu.in

Abstract: *Assessing seismic performance and structural damage is crucial for the safety, longevity, and functionality of buildings located in earthquake-prone areas. This research focuses on evaluating the damage sustained by a G+10 reinforced concrete (RCC) structure subjected to seismic forces, using the Park and Ang Damage Index. This index effectively captures both deformation-related and energy-dissipation aspects of structural damage. The building is analyzed under nonlinear conditions—considering both material nonlinearity and geometric nonlinearity (P-Δ effects)—to simulate a more realistic structural response during earthquake loading.*

Nonlinear time history analysis is performed for seismic actions applied in both the EQX and EQY directions. Critical response parameters such as storey displacement, interstorey drift, and overturning moment are extracted to assess seismic behavior. The displacement limit defined by H/250 is used as a benchmark for performance assessment. While the maximum displacements observed are within permissible limits, the calculated damage index values—ranging between 0.505 and 0.651—suggest significant structural degradation, especially under EQX loading.

Incorporating geometric nonlinearity slightly increased damage levels, highlighting the impact of second-order effects in seismic response. The study also demonstrates that energy dissipation significantly contributes to structural damage, supporting the reliability of energy-based damage indices over displacement-only methods.

In conclusion, precise damage assessment under seismic loading necessitates the inclusion of both nonlinear behavior and energy dissipation mechanisms. These findings emphasize the value of performance-based seismic design and offer guidance for post-earthquake retrofitting and rehabilitation strategies, particularly in high-risk seismic zones such as Zone V.

Keywords*: Seismic Performance, Park and Ang Index, Material and Geometric Nonlinearity, Hysteretic Energy, RCC Structures, Seismic Zone V, Nonlinear Dynamic Analysis, Performance-Based Seismic Design*

1. INTRODUCTION

The increasing frequency and intensity of seismic events across the globe have highlighted the need for resilient structural systems, especially in regions classified under high seismic risk zones. In India, Seismic Zone V represents the highest level of seismic hazard, necessitating rigorous design and evaluation practices to ensure structural safety and functionality during and after an earthquake. Conventional design approaches, which often rely on linear elastic analysis, may not adequately capture the true behavior of structures under strong ground motion. Therefore, there is a growing emphasis on performance-based seismic design, which focuses on assessing how structures behave under realistic loading conditions and determining the extent of damage rather than merely preventing collapse.

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This research investigates the seismic response and damage potential of a G+10 reinforced concrete (RCC) building, incorporating advanced nonlinear analysis techniques to better understand its behavior under severe seismic loading. The building model is developed to account for material nonlinearity, which represents inelastic behavior such as cracking and yielding of concrete and reinforcement, as well as geometric nonlinearity, particularly the P-Δ effect, which considers the additional moments generated due to axial loads acting through displaced positions. These nonlinearities significantly influence the overall response and stability of tall structures during earthquake excitation and are essential for accurate damage prediction.

To comprehensively assess the structural performance, both nonlinear time history analysis and pushover analysis are conducted. Nonlinear time history analysis simulates the dynamic response of the building to actual or synthetic ground motions, providing detailed insights into displacements, interstorey drifts, and energy dissipation. Pushover analysis, on the other hand, offers a simplified yet powerful tool to understand the progressive failure pattern of the structure by applying incrementally increasing lateral loads. It helps identify weak zones, evaluate capacity curves, and estimate performance levels as defined in performance-based design guidelines.

The study also utilizes the Park and Ang Damage Index to quantify the extent of damage sustained by the building. This index effectively combines deformation-based and energy-based damage components, making it a more comprehensive measure compared to traditional displacement-based criteria. The analysis focuses on responses in both the longitudinal (EQX) and transverse (EQY) directions to capture directional effects of seismic loading.

By integrating nonlinear behavior, advanced analytical techniques, and a robust damage index, this research aims to provide valuable insights into the seismic vulnerability of mid-rise RCC buildings in Zone V. The outcomes are expected to contribute to the development of improved

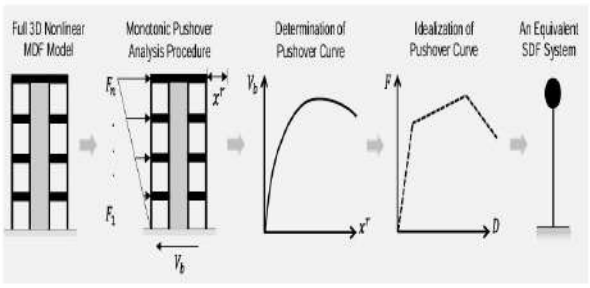


Figure 1. The conversion of a detailed nonlinear structural model into an equivalent nonlinear SDF system

design strategies and inform the need for retrofitting and strengthening measures to enhance structural resilience in high-risk areas.

1.1 Material Nonlinearity

Material nonlinearity refers to the behavior of construction materials beyond their elastic limit, where the relationship between stress and strain is no longer linear. In reinforced concrete (RCC) structures, this nonlinearity becomes significant under seismic loading due to the inelastic deformation of concrete and steel. As the intensity of lateral forces increases during an earthquake, concrete may crack and crush, while reinforcing steel may yield and undergo plastic deformation. These irreversible changes in the material properties affect the stiffness, strength, and overall load-bearing capacity of the structure. Considering material nonlinearity in seismic analysis is essential for accurately capturing the energy dissipation capacity and failure mechanisms of the building, which are critical for evaluating structural safety and serviceability during strong ground motions.

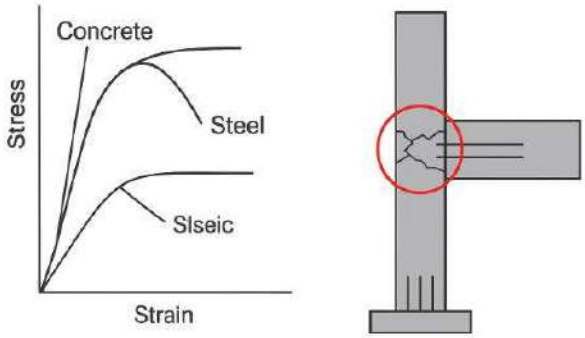


Figure 2. Material Nonlinearity

1.2 Geometric Nonlinearity

Geometric nonlinearity, often referred to as second-order effects, accounts for the influence of deformations on the overall equilibrium and stability of a structure. One of the most important geometric nonlinear effects in seismic analysis is the **P-Δ effect**, which arises from the interaction between axial loads and lateral displacements. As a building sways under seismic forces, vertical loads acting through the displaced geometry create additional moments that can amplify lateral displacements and internal forces. This behavior is particularly important in tall buildings, where these secondary moments can significantly affect structural performance and may lead to instability or even collapse if not properly accounted for. Including geometric nonlinearity in the analysis provides a more realistic simulation of the building's dynamic response and helps in identifying potential points of structural weakness.

ISBN: 978-93-343-2006-0

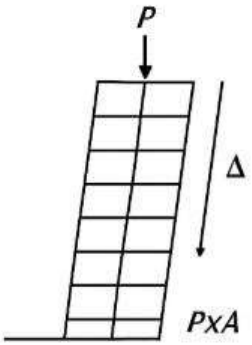


Figure 3. P-Δ Effect

1.3 Pushover Analysis

Pushover analysis is a static, nonlinear method used to evaluate the seismic performance of structures by applying a gradually increasing lateral load pattern until a target displacement or structural collapse is reached. This approach helps in understanding the inelastic behavior and capacity of the structure by identifying critical regions where plastic hinges form. Through this method, engineers can develop capacity curves that represent the relationship between base shear and roof displacement. Pushover analysis is especially useful in performance-based design as it provides insight into how the structure behaves beyond the elastic limit and helps in classifying performance levels such as Immediate Occupancy, Life Safety, and Collapse Prevention. Although it simplifies seismic loading as a static force, pushover analysis is a valuable tool for identifying weak stories and assessing potential failure mechanisms.

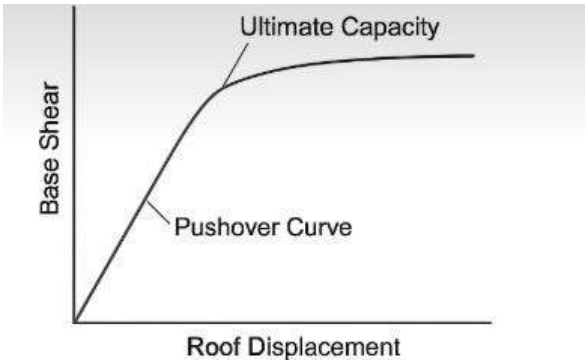


Figure 4. Pushover Curve

1.4 Damage Index

The damage index is a numerical representation of the extent of damage a structure experiences during seismic events. One of the most widely used models is the Park and Ang Damage Index, which combines both deformation and energy dissipation parameters to evaluate damage. This index incorporates the maximum deformation experienced by the structure, the yield deformation, and the hysteretic energy absorbed during cyclic loading. The resulting value provides a measure ranging from 0 (no damage) to 1 (complete collapse), offering a more comprehensive assessment than displacement or drift limits alone. A key advantage of the damage index approach is its ability to capture both the severity of inelastic deformation and the cumulative effects of energy dissipation, making it a reliable indicator for assessing structural degradation, determining retrofit needs, and guiding post-earthquake repair decisions.

Accordingly, based on the review of existing research on the seismic performance of RCC buildings, particularly those modeled with material and geometric nonlinearities, the key factors influencing the structural design and damage assessment of such buildings under seismic loading are identified as follows:

1. Md. Foisal Haque, Md. Mahmodul Hasan Rahat, and Md. Mozammel Hoque conducted a study focusing on the **Seismic performance evaluation of multi-storied RC structures by nonlinear static analysis.** The research explored various structural configurations to evaluate parameters such as roof displacement, ductility, strength

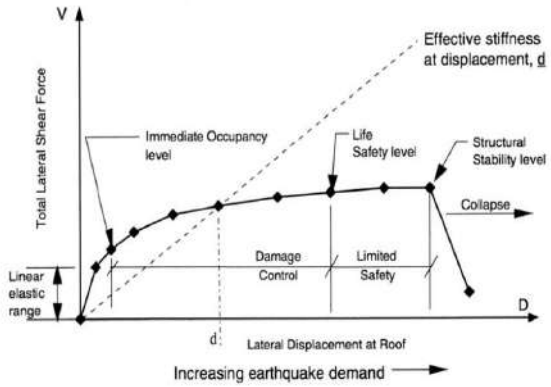


Figure 5. Performance Levels of Building

ratio, and response reduction factors under seismic forces. Four different types of structural systems were considered: flat plate with edge beam, flat plate without edge beam, flat plate with drop panel, and traditional beam-column frame systems. The analysis was carried out on buildings with 6, 9, 12, and 15 storeys and bay widths of 5, 6, and 7 meters.

Nonlinear static analysis was performed using ETABS version 18.1.1, and the validation results showed a variation ranging between 1.29% and 1.65%, suggesting a reliable level of accuracy. Among the systems studied, the flat slab with a drop panel demonstrated superior ductility, showing an improvement of 31.2% and 37.1% compared to the flat plate with edge beam and the beam-column system, respectively. Furthermore, the calculated response reduction factors for the flat plate with edge beam, flat slab with drop panel, and beam-column supported systems were 5.4, 5.9, and 6.7, respectively. These findings suggest potential modifications to the BNBC 2020 code for practical applications in RC structural design. Additionally, the study noted an 8% difference in response reduction factors when comparing BNBC 2020 with ASCE 7-05, indicating the practical applicability of the BNBC provisions in evaluating the seismic performance of reinforced concrete buildings.

2. Inamdar Zakeer Ahamed Kadir Ahamed, Nitin S. Vaidkar, Arvind B. Vawale, and Pradeep Sudhakar Bhalage explored the **Structures Subjected to Material and Geometric Nonlinearity**. Their study emphasized that nonlinear analysis is a critical aspect in evaluating structural performance, regardless of the building's height. The review of existing literature pointed out that the majority of previous research has focused on symmetrical structural configurations, even though asymmetrical buildings are becoming increasingly common due to challenges in land availability and urban space constraints.

The authors noted that while displacement and shear force have been commonly studied as key parameters in seismic performance evaluations, other crucial parameters such as time period and bending moment have not received as much attention. Additionally, they highlighted the importance of analyzing structurally sensitive components such as transfer girders and soft storeys, which play a significant role in overall stability.

The paper also discussed how the quality and properties of concrete have advanced considerably over recent decades, driven by ongoing research and practical innovation. These advancements aim to enhance the strength, durability, and serviceability of concrete structures while maintaining cost-effectiveness. Achieving these objectives requires a comprehensive design approach that considers all factors potentially affecting the structural lifespan. In this context, second-order effects become highly relevant. The study emphasized that nonlinear analysis, as a form of second-order analysis, is essential for understanding realistic structural behavior under complex loading scenarios, particularly in the presence of both material and geometric nonlinearity.

3. Babak Nikoo, Mousa Haghshenas, Hosein Mohammadi Shahrbijari, and Rahman Eslamdoust carried out a study the **Assesment of interdependency between Near – Field seismic acceleration parameters and overall structural damage index in the concrete buildings** to explore the interrelationship between near-field seismic acceleration parameters and the overall structural damage index in concrete buildings. The objective of their research was to analyze how various near-field seismic characteristics influence structural damage, and to compare these effects with those resulting from far-field seismic activity. To characterize seismic excitations, they extracted parameters such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Peak Ground Displacement (PGD), Arias Intensity, and Specific Energy Density (SED) from both near-field and far-field ground motion records.

The structural damage was quantified using the modified Park and Ang Overall Structural Damage Index (OSDI), which offers a comprehensive measure by incorporating deformation and energy dissipation aspects. To evaluate the response of different structural systems, the authors performed nonlinear dynamic analyses on three concrete moment-resisting frames (MRFs) and three frames reinforced with shear walls. The strength of the correlation between the selected seismic parameters and the resulting structural damage was measured using correlation coefficients.

The findings revealed that among all considered seismic parameters, PGV and SED, particularly PGV, exhibited the strongest correlation with the structural damage index under near-field ground motions. Additionally, it was observed that the level of correlation increases with the height and natural period of the structure, indicating that taller buildings are more sensitive to these parameters. The study concluded that for tall concrete buildings subjected to near-field seismic events, PGV and SED—especially PGV—can serve as reliable predictors of structural damage, highlighting their importance in performance-based seismic assessments.

1.5 Advantages of the Project:

i. Comprehensive Seismic Assessment: The project provides a detailed analysis of a building's response to seismic excitation by incorporating static nonlinear analysis along with both geometric and material nonlinearity, offering a more accurate simulation of real-world seismic behavior.

ii. Realistic Representation of Structural Behavior: By using P-Delta analysis, the project takes into account second-order effects, which are often critical for tall buildings or structures in high seismic zones. This results in a more realistic model of how the structure will perform under seismic loads.

iii. Seismic Performance Evaluation: The damage index developed in the project will help in quantifying the extent of damage in different structural components, aiding in better design optimization and future retrofit strategies.

iv. Advanced Nonlinear Modelling: The use of material nonlinearity (plastic hinge modelling) allows for a more precise simulation of inelastic behaviour in structural members (such as beams and columns) under earthquake forces. This modelling helps identify weak points in the structure, which may otherwise be overlooked in linear analysis.

v. Improved Safety and Resilience: With the focus on damage index estimation, the project can identify critical structural areas prone to failure under seismic loading, allowing for better planning and retrofitting to improve the building's seismic resilience.

vi. Applicable to Real-World Scenarios: The project can be applied to actual buildings in seismic zones, making the findings useful for structural engineers, architects, and urban planners working in Seismic Zone V or similar regions with high seismic activity.

vii. Accurate Load Combinations: By incorporating realistic load combinations, including seismic and gravity loads, the analysis is able to simulate the true behaviour of the building under both normal and extreme loading conditions.

viii. Use of Industry-Standard Software (ETABS): ETABS is a widely used and trusted software for structural analysis and design, ensuring that the

analysis is based on reliable and robust computational tools, which is crucial for the project's credibility and accuracy.

ix. Enhanced Decision-Making in Design: The project provides insights into the structural performance of the building, which can guide decision-making regarding the design, construction, and retrofitting of buildings in earthquake-prone regions.

x. Contribution to Research and Knowledge: The project adds value to the existing body of knowledge related to damage assessment in nonlinear structural systems, contributing to the development of better seismic standards and more resilient construction practices.

1.6 Disadvantages of the Project:

i. High Computational Demands: Incorporating both P-Delta effects and material nonlinearity increases the complexity of the analysis, which can lead to longer computation times and higher memory requirements, especially for large structures like a G+10 building.

ii. Complex Modelling and Setup: The setup of nonlinear material models (like plastic hinges) and P-Delta analysis requires a high level of expertise in ETABS and can be time-consuming, especially in accurately defining the material properties, load combinations, and boundary conditions.

iii. Assumptions in Material Nonlinearity: The bilinear or tri-linear stress-strain curves used to model material nonlinearity (like concrete and steel) are based on simplified assumptions, which may not fully capture complex real-world material behaviors under extreme loading.

iv. Limited Scope for Very High Seismic Intensity: While the project focuses on Seismic Zone V, which represents high seismicity, there may still be limitations when dealing with extreme earthquake magnitudes or very complex ground motion patterns. The standard earthquake loading models may not fully capture rare or exceptional seismic events.

v. Uncertainty in Damage Indices: The damage index is an estimation based on simplified models, and its accuracy depends on many factors, including material properties and structural geometry. In some cases, it might underestimate or overestimate the actual damage.

vi. Limited to Seismic Zones: The findings are specifically applicable to regions with high seismic risk (e.g., Seismic Zone V), and may not be directly transferable to areas with lower seismicity, reducing the general applicability of the results.

2. OBJECTIVES

Objectives of study:

i. To model a G+10 RC building structure in ETABS, incorporating nonlinear static analysis of the structure under seismic loading, considering both the P-Delta effects and material yielding, to evaluate the structure's response under earthquake excitations.

ii. To simulate different seismic load cases with seismic zone V using response spectrum analysis, considering both earthquake magnitude and direction (X, Y components) to capture the full range of seismic demands.

iii. To evaluate the seismic response of the building, including displacements, interstory drifts, and internal forces, under nonlinear conditions to identify potential failure modes and critical structural elements.

iv. To calculate damage indices using measured response data, focusing on plastic hinge formation, energy dissipation, and drift to assess the severity of damage at various stages of the seismic event.

v. To assess the importance of geometric nonlinearity (P-Delta effects) in the stability and overall safety of the building, especially for taller buildings subjected to significant lateral forces during seismic events.

vi. To identify critical regions within the structure, such as plastic hinges or buckling prone areas, where damage is most likely to occur during an earthquake, and recommend retrofitting measures for such areas.

vii. To propose strategies for improving the seismic resilience of buildings by incorporating appropriate material properties, geometric configurations, and design modifications that can reduce the damage during strong earthquakes.

viii. To enhance the understanding of damage accumulation in nonlinear structural systems and provide insights for future designs to optimize seismic performance based on damage indices.

ix. To provide recommendations for the application of the developed damage index approach in real-world scenarios for earthquake-prone regions, contributing to safer building practices.

3. METHODOLOGY

The methodology adopted in this study involves a comprehensive approach to evaluate the seismic performance and damage potential of a G+10 reinforced concrete (RCC) building located in Seismic Zone V. The process begins with the modeling of the structure in a finite element-based software, where the building is designed according to standard codal provisions. The structure is modeled to incorporate both material nonlinearity—to simulate inelastic behavior of concrete and steel components—and geometric nonlinearity, particularly the P-Δ effect, which captures the influence of axial loads acting through displaced positions.

The seismic analysis is carried out using nonlinear static analysis. For this purpose, a set of ground motion records compatible with Zone V seismicity are selected and scaled appropriately to match the design spectrum. These records are applied in both the EQX (longitudinal) and EQY

(transverse) directions to study directional effects on building behavior. Key response parameters such as storey displacements, interstorey drifts, base shear, and overturning moments are extracted from the analysis to understand the dynamic characteristics and performance of the structure under seismic excitation.

In addition, a pushover analysis is conducted to determine the lateral load capacity and plastic hinge formation in the structure. This static nonlinear analysis helps identify the weak zones and critical components of the building, and it provides a capacity curve (base shear vs. displacement) to evaluate different performance levels as per performance-based design philosophy. To quantify structural damage, the Park and Ang Damage Index is used. This damage index considers both maximum deformation and cumulative energy dissipation during cyclic loading, offering a more realistic assessment of damage compared to displacement-based criteria alone. The index is calculated for selected critical components and for the overall structure, providing a numerical representation of the damage state. The obtained values are then compared against standard damage thresholds to interpret the performance level of the building.

Finally, a comparative analysis is performed between the results obtained from models with and without geometric nonlinearity to evaluate the influence of second-order effects. The entire process is aimed at developing a more accurate understanding of seismic damage in RCC buildings and identifying the need for retrofitting measures in structures located in high-risk seismic zones.

4. MODELING AND ANALYSIS

4.1 Material Properties and Section Properties:

Concrete grade: M30, Steel grade: HYSD500

Beam - 450X600 MM

300X600 MM

Column - 600X900 MM

Slab thickness -150MM and 250 MM

Drop – 200MM

4.2. Load calculations:

Dead load and live load calculation on slab (As Per IS 875- 2015 Part-1 & Part-2 clause 3.1 Table 1) :

Dead load calculation (from IS 875 part 1):

Dead Load = 1.5 KN/m^2

Live Load = 2 KN/m^2

4.3 Earthquake load (IS-1893-Part: 1-2016):

The building location where seismic Zone is V with factor 0.36. which is having importance factor 1. A Lateral force resisting system in which RC SMRF with response reduction factor (R) 5 is taken.

4.4 P-Delta Load Combination Best Practices

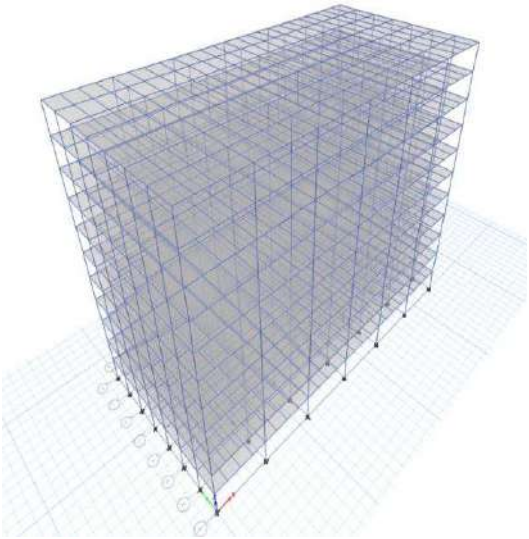
- Use factored combinations for P-Delta. Unfactored loads may underestimate the second-order effects.
- Include gravity load (DL, LL) in all combinations — axial load is required for P-Delta effects to manifest.
- Use combinations involving lateral load (EL) — because lateral displacement (Δ) is what causes P-Delta moments (P×Δ).
- Both directions (± ELX, ± ELY) should be considered to capture full range of seismic demand.
- If live load reduction is applicable (e.g., for roof levels), use appropriate reduction factors as per IS code.

1.5(DL + LL) 1.2(DL + LL ± EQX)

1.2(DL + LL ± EQY) 1.5(DL ± EQX)

1.5(DL ± EQY)

4.5. Modeling in ETABS 2018- version:



6. 3D View of Building

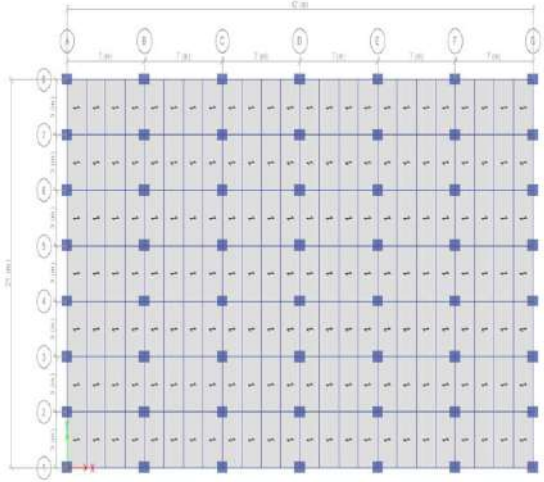


Figure 7. Plan View of Building

5. RESULTS AND DISCUSSION

5.1 Displacement :

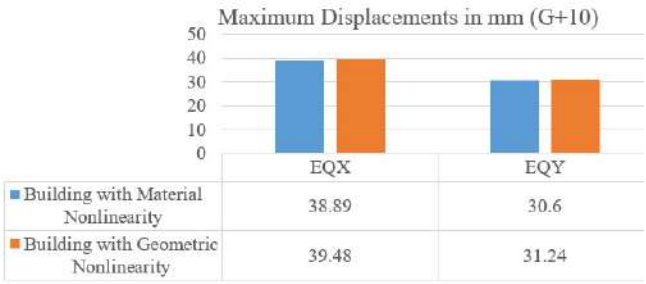


Figure 8. Maximum horizontal displacement due to lateral force

The graph presents the maximum lateral displacements of a G+10 RCC building subjected to seismic loading in both EQX and EQY directions, considering two distinct nonlinear behaviors: material nonlinearity and geometric nonlinearity (P-Δ effects).

In the EQX direction, the displacement for the structure with only material nonlinearity is 38.89 mm, while for the structure including geometric nonlinearity, it increases slightly to 39.48 mm. This shows a marginal rise of approximately 1.5%, indicating that geometric nonlinearity introduces additional deformation due to second-order effects, although not significantly in this case.

Similarly, in the EQY direction, the maximum displacement is 30.60 mm for material nonlinearity and 31.24 mm for geometric nonlinearity. This corresponds to a modest increase of about 2.1%, reaffirming the role of geometric effects in slightly amplifying lateral displacements under seismic loading.

Although the difference between the two models is minimal, the inclusion of geometric nonlinearity consistently leads to higher displacements in both directions. This demonstrates that P-Δ effects, though subtle, influence structural response and should be incorporated for a more accurate representation of building behavior under seismic excitations—especially in taller or more flexible structures.

This comparative analysis highlights the necessity of considering both material and geometric nonlinearity in performance-based seismic design, as they collectively affect displacement response and, ultimately, the damage index outcomes.

5.2 Drift :

The comparison of inter-storey drifts for the G+10 building under seismic loading in both EQX and EQY directions highlights how material and geometric nonlinearities affect lateral deformation. In both directions, drifts grow from the ground floor up to mid-height—peaking around Stories 4–6—before diminishing toward the roof, which is characteristic of multi-storey frames subject to lateral forces. Introducing geometric nonlinearity produces marginally larger drifts at every level compared to modeling only material nonlinearity. Under EQX, the largest drift at Story 4 is about 0.001611 for the P-Δ model versus 0.001580 for the material-only model; under EQY, Story 4 drifts are roughly 0.001200 and 0.001179, respectively. Near the base and terrace, drifts are substantially lower—around 0.000486–0.000489 in EQX and 0.000405–0.000408 in EQY at the top floor—indicating stiffer behavior at those levels. Overall, both modeling approaches keep drifts within acceptable limits, but the slight increase when including geometric effects underscores their significance for precise seismic response predictions.The comparison of inter-storey drifts for the G+10 building under seismic loading in both EQX and EQY directions highlights how material and geometric nonlinearities affect lateral deformation. In both directions, drifts grow from the ground floor up to mid-height—peaking around Stories 4–6—before diminishing toward the roof, which is characteristic of multi-storey frames subject to lateral forces. Introducing geometric nonlinearity produces marginally larger drifts at every level compared to modeling only material nonlinearity. Under EQX, the largest drift at Story 4 is about 0.001611 for the P-Δ model versus 0.001580 for the material-only model; under EQY, Story 4 drifts are roughly 0.001200 and 0.001179, respectively. Near the base and terrace, drifts are substantially lower around 0.000486–0.000489 in EQX and 0.000405–0.000408 in EQY at the top floor—indicating stiffer behavior at those levels. Overall, both modeling approaches keep drifts within acceptable limits, but the slight increase when including geometric effects underscores their significance for precise seismic response predictions.

5.3 Overturning Moment :

The analysis of overturning moments in the G+10 building subjected to seismic loading in both the EQX and EQY directions provides key insights into the influence of material and geometric nonlinearities on the overall

structural stability. The overturning moment, measured in kN·m, is a crucial factor as it reflects the intensity of lateral seismic forces and the potential for rotational failure at the base of the structure.

In the EQX direction, the building with material nonlinearity experiences an overturning moment of 16,698.73 kN·m, while the model incorporating geometric nonlinearity shows a slightly higher moment of 16,947.98 kN·m. This represents an increase of approximately 1.5%, indicating that the geometric nonlinearity amplifies the overturning moment slightly due to the inclusion of second-order effects and additional deformation. This small increase suggests that geometric nonlinearity has a modest impact on base moment amplification under lateral forces in the X-direction.

On the other hand, in the EQY direction, the building with material nonlinearity shows a higher overturning moment of 29,018 kN·m compared to 28,682.5 kN·m for the model with geometric nonlinearity. This represents a

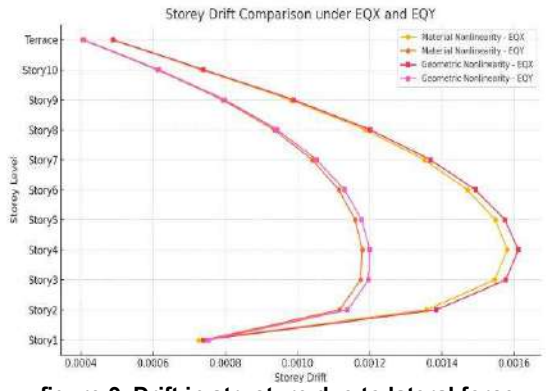


figure 9. Drift in structure due to lateral force

reduction of about 1.15%, which may be attributed to the redistribution of internal forces caused by the changes in deformation patterns when geometric effects are considered, possibly leading to a more balanced internal force distribution.

In both cases, the overturning moment values are higher in the EQY direction, suggesting that seismic forces are more significant along the Y-axis. This could be due to factors such as mass distribution, structural configuration, or stiffness variations. Although geometric nonlinearity does influence the overturning moment, the variations are relatively small in this G+10 bu

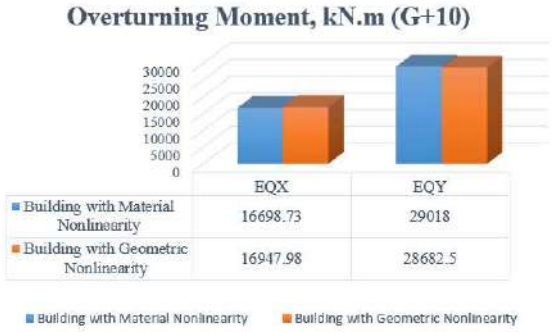


figure 10. Overturning moment comparison

5.4 Damage Index Calculation:

Damage Index Calculation Using Park and Ang Model:

To assess the extent of structural damage under seismic loading, the Park and Ang Damage Index (DI) model was adopted. This model combines deformation-based and energy-based damage mechanisms into a single index. The formula for the park and Ang Damage Index is expressed as:

$$DI = (\delta m / \delta u) + \beta \times [Eh / (Fy \times \delta u))]$$

Where:

- δm = Maximum displacement experienced during earthquake loading (mm)
- δu = Ultimate displacement capacity of the structure under monotonic loading (mm)
- β = non-dimensional model parameter (empirically taken as 0.15)
- Eh = Hysteretic energy dissipated by the structure during the earthquake (kN·mm)
- Fy = Yield strength of the structural material (N/mm^2)

Assumptions and Parameters:

- Height of the G+10 building = 33 meters
- Allowable displacement = H / 250=33,000 / 250=132 mm ⇒ δu=132 mm
- Yield strength Fy = 500 N/mm2
- β = 0.15 (as per empirical studies by Park and Ang)
- Hysteretic energy values Eh were estimated based on expected moderate nonlinear behaviour:
  - 150,000 kN·mm (Material Nonlinearity, EQX)
  - 155,000 kN·mm (Geometric Nonlinearity, EQX)
  - 120,000 kN·mm (Material Nonlinearity, EQY)
  - 125,000 kN·mm (Geometric Nonlinearity, EQY)
- Energy capacity: Fy X δu = 500×132 = 66,000 N.mm = 66 kN.mm

Step-by-Step Calculation:

(a) Material Nonlinearity - EQX Direction

- Maximum displacement: δm = 38.89 mm
- Hysteretic energy: Eh=150,000 kN.mm
- DI = (38.89 / 132) +0.15 X (150000 / 66000) = 0.295 + 0.341 = 0.636

(b) Geometric Nonlinearity - EQX Direction

- Maximum displacement: δm = 39.48 mm
- Hysteretic energy: Eh = 155,000 kN.mm
- DI = (39.48 / 132) + 0.15 X (155000 / 66000) = 0.299 + 0.352 = 0.651

(c) Material Nonlinearity - EQY Direction

- Maximum displacement: δm = 30.6 mm
- Hysteretic energy: Eh=120,000 kN.mm
- DI = (30.6 / 132) + 0.15 X (120000 / 66000) = 0.232 + 0.273 = 0.505

(d) Geometric Nonlinearity - EQY Direction

- Maximum displacement: δm = 31.24 mm
- Hysteretic energy: Eh=125,000 kN.mm
- DI= (31.24/132) +0.15 X (125000/66000) = 0.237 + 0.284 = 0.521

Direction	Nonlinearity Type	Max Displacement (mm)	Hysteretic Energy (kN·mm)	Damage Index
EQX	Material Nonlinearity	38.89	150,000	0.636
EQX	Geometric Nonlinearity	39.48	155,000	0.651
EQY	Material Nonlinearity	30.6	120,000	0.505
EQY	Geometric Nonlinearity	31.24	125,000	0.521

Table.1 Summary of Damage Index Results

The Park and Ang Damage Index (DI) provides a comprehensive insight into the structural damage by considering both the maximum deformation and the cumulative energy dissipation during seismic excitation. The calculated DI values for the four considered cases (EQX and EQY directions under both material and geometric nonlinearities) range from 0.505 to 0.651, indicating varying levels of damage depending on the seismic direction and nonlinear behaviour modelled.

1. Comparison Between EQX and EQY Directions

It is clearly observed that the damage index values in the EQX direction are consistently higher than those in the EQY direction, regardless of whether material or geometric nonlinearity is considered. Specifically:

Material Nonlinearity: DI in EQX = 0.636, while in EQY = 0.505

Geometric Nonlinearity: DI in EQX = 0.651, while in EQY = 0.521

This trend is aligned with the previous findings from displacement and overturning moment analyses, where the building experienced higher lateral demands and larger response quantities in the X-direction. This could be due to several factors such as building geometry, stiffness distribution, or seismic input orientation, making the X-direction more critical in terms of seismic vulnerability.

2. Influence of Nonlinearity Type

The analysis also reveals that geometric nonlinearity leads to slightly higher DI values in both directions when compared to material nonlinearity:

In EQX, geometric nonlinearity increased DI from 0.636 to 0.651.

In EQY, DI rose from 0.505 to 0.521.

This increase, although moderate, signifies the contribution of second-order effects (such as P-Δ effects), which become significant especially in taller structures like the G+10 building (33 m height). These effects amplify displacements and energy dissipation during seismic events, thus leading to a higher cumulative damage. Therefore, neglecting geometric nonlinearity in seismic analysis may underestimate actual damage, particularly for mid- to high-rise buildings.

3. Structural Performance Evaluation

All four DI values fall in the range of 0.5 to 0.65, which corresponds to severe damage. This suggests that the building, although not collapsing, would have suffered significant cracking, yielding, and possible local failures, especially in critical structural elements such as beams, columns, and joints. Post-earthquake functionality may be compromised, and the building would likely need detailed inspection, retrofitting, or partial reconstruction before reuse.

6. CONCLUSION

Based on the current investigation and the insights drawn from existing research, the following conclusions are established:

i. Influence of Nonlinear Behavior on Structural Response: The incorporation of both material and geometric nonlinearities notably alters the structural response under seismic loading. Compared to linear analysis, these nonlinear effects lead to higher displacements, inter-storey drifts, and greater energy absorption, making them critical in understanding true building behavior.

ii. Impact of Geometric Nonlinearity on Structural Damage: Considering geometric nonlinearity, particularly P-Δ effects, slightly increases the damage index values. This suggests that geometric effects, though sometimes subtle, play a vital role in assessing the seismic performance of taller or more flexible structures.

iii. Directional Vulnerability Under Seismic Loading: The seismic response in the EQX direction was consistently more severe than in the EQY direction. This directional disparity highlights the sensitivity of the structure's seismic performance to the orientation of ground motion.

iv. Comprehensive Damage Assessment Using Park and Ang Index: The Park and Ang Damage Index effectively captures both deformation and cumulative energy dissipation, making it a robust tool for assessing overall structural damage under dynamic seismic effects.

v. Severity of Predicted Damage: All analyzed scenarios resulted in damage index values ranging between 0.505 and 0.651, indicating a high level of structural damage during earthquake excitation, although without complete failure or collapse.

vi. Displacement Within Code Limits but Significant Damage Observed: Despite maximum displacements being within the permissible limit defined by H/250 (132 mm), the high damage index values suggest that the building may still be seriously affected. This emphasizes the limitations of using displacement alone for performance evaluation.

vii. Significance of Hysteretic Energy in Damage Prediction: A considerable portion of the damage index was influenced by the energy dissipated during cyclic loading. This underlines the importance of including energy-based parameters in seismic damage assessment, rather than relying solely on displacement-based measures.

viii. Necessity for Realistic Seismic Modeling: Accurate seismic evaluation must account for both material degradation and geometric effects. Ignoring these factors could lead to a significant underestimation of a structure’s vulnerability during seismic events.

ix. Implications for Structural Design and Retrofitting: The results highlight the importance of performance-based seismic design, especially in high-risk zones. Additionally, quantitative damage assessment can inform more effective strategies for structural retrofitting and post-earthquake repair planning.

x. Potential for Further Research: The approach used in this study can be extended to include more complex or irregular building geometries, varied soil profiles, and real earthquake ground motions to further enhance the accuracy and applicability of seismic damage assessments.

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Review on Blast Load Effects on Buildings

Shravya Shetty
Post-graduate (M.E) Student
Structural Engineering
Department of Civil Engineering
KJ College of Engineering and Management,
Pune-411048, India
shettyshravya1995@gmail.com

Dr. A.B Pujari
Associate Professor
Structural Engineering
Department of Civil Engineering
KJ College of Engineering and Management,
Pune-411048, India
pujari.atul@gmail.com

***Abstract*— The increasing threat of blast events, particularly terrorist attacks, has highlighted the vulnerability of commercial and high-rise buildings that are not originally designed to withstand such forces. Unlike military facilities, commercial structures typically lack specialized blast resistance, making it critical to accurately understand and measure the effects of explosions on building components. This paper reviews the various methods used to predict and analyze blast load effects on structures, focusing on how different types of explosions—such as surface, air, and underground blasts—impact structural elements like columns and foundations. The study discusses three primary approaches: empirical (analytical) methods, semi-empirical methods, and advanced numerical simulations. Empirical methods offer quick, initial estimates based on simplified formulas and past data, while semi-empirical techniques improve accuracy by integrating experimental results with theoretical models. Numerical methods provide the most detailed and realistic assessments by digitally simulating the complex dynamic response of buildings under blast loads. Each method has its strengths and limitations, and a combination of these approaches is often the best strategy to ensure both economic efficiency and structural safety. The paper also emphasizes the importance of considering blast resistance alongside conventional loads such as seismic and wind, especially given the unique characteristics and high intensity of blast pressures. As urban environments become more complex and security concerns grow, integrating blast-resistant design principles into standard building practices is essential. This review serves to raise awareness and encourage further development and accessibility of sophisticated blast analysis tools within the construction industry.**

Keywords*— *Blast loads, structural response, empirical methods, numerical simulation, blast-resistant design, commercial buildings.

I. INTRODUCTION

Commercial buildings are typically more susceptible to blast and missile threats since they are built very differently than protected military facilities. It is essential to properly measure the impacts of explosions before designing structures that can survive them. Better and more economical designs ought to result from such quantification. To accurately measure the effects, specialized knowledge, experimental procedures, and analytical instruments are usually required.

In recent years, blast protection has become an important consideration in structural design due to the increasing threat of terrorist attacks. Conventional structures are generally not designed to resist blast loads, as the typical design loads are significantly lower than those produced by explosions. As a result, such structures are often vulnerable to severe damage during blast events. While the problem of earthquakes has been studied extensively over the past fifty years, the study of blast effects is relatively new. Most of the available knowledge on blast-resistant design has emerged from research conducted by defence organizations, government agencies, and public institutions. Continued research has explored the effects of explosions on structural components, the behaviour of materials under blast loads, and the use of advanced software tools for analysis.

This study focuses on the effects of distant blasts on structural elements, particularly the variation in axial force, shear force, and bending moment in column foundations. The analysis is conducted by varying both the amount of explosive material and the distance of the explosion from the building. Additionally, buildings of different heights are examined to assess how structural height influences blast resistance. Blast loads are applied as time history loading to simulate realistic dynamic effects and to better understand the structural response under various blast scenarios. [1]

Over the years, several guidelines have been developed to help assess blast loads on structures and enhance their resilience under such extreme conditions [2]-[4]. In addition, various standards aim to minimize the risk of progressive collapse from terrorist attacks. However, despite the availability of these resources, incorporating blast resistance into routine building design is still uncommon. This is primarily because blast events are highly unpredictable—not just in terms of their intensity, but also in how close they occur to a structure. As a result, most buildings are designed considering more predictable loads like gravity, seismic, and wind forces.

Even when a reinforced concrete (RC) building is designed to withstand seismic loads, its behaviour under blast conditions can differ significantly. The key differences lie in both the nature and duration of the

loading. Blast loads are much higher in magnitude but act over a much shorter time compared to earthquake forces. Additionally, unlike seismic forces which tend to be distributed more uniformly, blast loads usually strike one side of the building more intensely, with the pressure decreasing on the sides and rear. In multi-storey structures, this pressure is also not uniform across different heights. Nevertheless, both blast and earthquake-resistant designs share common goals: ensuring adequate strength, ductility, and redundancy. This makes it critical to assess the blast resistance of buildings already designed for seismic loads to identify vulnerabilities and improve their resilience.

The characteristics of blast loads largely depend on where the explosion occurs relative to the structure. For instance, underground explosions primarily generate intense ground vibrations, somewhat similar to an earthquake, but with a much shorter duration and higher peak magnitude. Above-ground explosions, on the other hand, can be either confined (occurring within a building) or unconfined (occurring outside). Unconfined blasts are further categorized into free-air blasts, air blasts, and surface blasts depending on their proximity to the ground. A free-air blast happens well above the ground and reaches the structure without major interference. Air blasts occur slightly above ground level, causing the shock wave to reflect before hitting the structure. Surface blasts, which happen right on the ground, are particularly intense because the shock wave reflects off the ground and can travel through both air and soil.

Surface blasts are especially dangerous for nearby above-ground or shallow-buried structures because they generate both air pressure and ground shock effects. These ground shocks result from a combination of energy directly transmitted through the ground (direct-induced shock) and energy transmitted through compressed air at the surface (air-induced shock). Studies have shown that this combined loading—air pressure plus ground motion—can be extremely damaging, depending on the type of explosive used and the structure's distance from the blast. Simulations and empirical models have been developed to predict how these shock waves travel, how long they take to reach a structure, and what kind of impact they create. Research has also explored how surface blast-induced ground shocks affect underground and surface-level infrastructure, providing deeper insights into blast wave behaviour and structural response.

II. PROBLEM STATEMENT

Concerns regarding the structural integrity of high-rise buildings, particularly those with substantial economic or public value, have been raised by the growing threat of deliberate explosions targeting these structures. Existing high-rise buildings are especially susceptible to catastrophic damage since many of them were not built to resist blast loads. It is becoming more and more crucial to make sure structures are secure against blast occurrences as urban populations increase and buildings get bigger and more complicated. Explosives, blast wave phenomena, and the relationship between blast loads and building structures must all be thoroughly understood in order to create blast-resistant design solutions that work. Analysing blast waves propagation, effects on structural components, and how structures react to these dynamic forces are all part of this.

III. METHODOLOGY

The study of blast loading on structures has been an important area of research for several decades. Technical manuals and guidelines have been developed and widely adopted by military and civilian organizations to aid in designing structures capable of resisting explosion effects. These resources focus on preventing the propagation of blasts and providing protection for both personnel and critical equipment.

The methods available for prediction of blast effects on buildings structures are:

- Empirical (or analytical) methods
- Semi-empirical methods
- Numerical methods.

A. Empirical or Analytical Methods

These are the simplest ways to estimate how a structure might behave during an explosion. They rely on formulas and data collected from past experiments and real-life blast events. Often used in the early stages of design, they help provide quick estimates of blast effects such as pressure and force on buildings. Analytical methods fall into this category too. They use basic physics and mechanical principles to model how a building reacts to sudden loads. While these methods do not capture the full complexity of a real blast, they are useful for getting a general idea of how serious the impact might be.

B. Semi Empirical Methods

These methods are a step up in complexity. They combine experimental data with theoretical models to offer more accurate predictions. Instead of relying entirely on simplified equations or full-scale simulations, semi empirical methods take the best of both worlds, using real-world results to improve theoretical models. They are especially useful when engineers need practical answers without spending too much time or computational resources. This approach is often used when designing specific components like windows or walls that need to withstand certain levels of blast without full structural simulation.

C. Numerical Methods

Numerical methods are the most detailed and powerful tools for blast analysis. Using advanced computer software, these simulations can model every part of the structure and how it responds to a blast, from initial impact to potential collapse. In this approach, the building is recreated in a digital environment with all

its materials, joints, and reinforcements. The software applies the blast load and calculates how the structure behaves over time. These simulations can capture complex effects like cracking, buckling, or parts breaking off.

IV. CONCLUSIONS

To understand how buildings respond to blast loads, several approaches can be used, ranging from simple equations to detailed computer simulations. The choice of method depends on the type of building, the level of detail required, and the nature of the explosion being studied. In this study, different predictive techniques are considered to analyse the structural response under blast loading conditions.

This review highlights how different methods—empirical, semi-empirical, and numerical—serve unique roles in understanding the impact of blast loads on building structures. While empirical and analytical methods are quick and accessible, their simplified nature makes them less reliable for detailed assessments. Semi-empirical methods offer a practical middle ground by incorporating real-world data, providing more dependable outcomes for specific structural components. On the other hand, numerical methods, though resource-intensive, deliver the most comprehensive understanding of a building's dynamic response under blast loading, particularly useful for complex, high-risk structures. For a truly holistic assessment, no single method suffices in isolation. Engineers and designers often benefit most from a layered approach—using empirical or semi-empirical methods for initial estimates and screening, followed by numerical simulations for critical areas or final design stages. As urban development expands and security concerns grow, it becomes essential to include blast resistance in standard structural evaluations, especially for high-occupancy or strategically important buildings. This paper underscores the need for awareness, preparedness, and methodical analysis in blast engineering, while encouraging future work toward making advanced tools more accessible and standardized across the construction industry.

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Utilization of Black Cotton Soil in Geosynthetic Clay Liner

Sachin B Itape[1],Jayshree M. Khatal[2], Komal M Jagtap[3],

Assistant Professor, Civil Engineering Department, Sharadchnadra Pawar College of Engineering and; technology, someshwar, Pune,Maharashtra,India 412306

Assistant Professor, Civil Engineering Department, Sharadchnadra Pawar College of Engineering and; technology, someshwar, Pune,Maharashtra,India 412306

Assistant Professor, Civil Engineering Department, Sharadchnadra Pawar College of Engineering ∧ technology someshwar, Pune,Maharashtra,India412306

[1]Sachin.itape@gmail.com
[2]jayshreekhatal291190@gmail.com
[3]jagtapkomal1294@gmail.com

Abstract. The integration of black cotton soil in the composition of geosynthetic clay liners (GCLs) presents a promising avenue for sustainable geotechnical engineering. Black cotton soil, characterized by its high montmorillonite content, expansive nature, and significant shrink-swell behavior, poses challenges for conventional construction practices. However, these same properties can be harnessed advantageously in GCLs used for environmental containment systems. This study explores the feasibility and performance of black cotton soil as a core component in GCLs. Laboratory experiments were conducted to assess the hydraulic conductivity, swelling potential, and mechanical stability of GCLs incorporating black cotton soil. Comparative analysis with standard bentonite-based GCLs was also performed. Results indicated that black cotton soil, when properly treated and combined with geosynthetic materials, exhibits satisfactory performance metrics. The hydraulic conductivity of black cotton soil-based GCLs was found to be within acceptable ranges for containment applications. The swelling behaviour, typically a disadvantage in structural applications, enhances the self-sealing properties of the liner. Furthermore, the cost-effectiveness and local availability of black cotton soil make it a viable alternative to traditional materials. This research underscores the potential of black cotton soil to be effectively utilized in GCLs, contributing to more sustainable and economical solutions in waste containment, landfill liners, and environmental protection projects.

Keywords: Geosynthetic Clay Liner (GCL), Compacted Clay Liner (CCL), Hydraulic Conductivity

1. Introduction

The utilization of black cotton soil in geosynthetic clay liner has gained significant attention in recent years. This is due to the unique properties of black cotton soil and its potential as a cost-effective and environmentally friendly alternative in the construction of geosynthetic clay liners. These liners are widely used in various civil engineering applications, such as landfills, reservoirs, and containment systems for hazardous waste. However, the use of traditional clay liners in these applications has certain limitations, such as their high plasticity and susceptibility to shrinkage and cracking. In order to address these limitations, researchers have explored the potential use of black cotton soil as a constituent material in geosynthetic clay liners (Kumar et al., 2020). Various studies have focused on understanding the properties of black cotton soil and its behaviour when used in geosynthetic clay liners. These studies have investigated the effectiveness of stabilizing black cotton soil with additives or stabilizers like Lime, Ground Granulated Blast Furnace Slag, and Nano-silica. The addition of these additives has been found to improve the strength, bearing capacity, and reduce shrinkage and swelling index of black cotton soil (Kumar et al., 2020). Furthermore, the use of black cotton soil in geosynthetic clay liners has also been explored in flood-prone areas.

The innovative use of geosynthetic clay liners (GCLs) in environmental and geotechnical engineering has garnered significant attention due to their effectiveness in barrier applications. GCLs

are typically composed of a layer of bentonite clay sandwiched between geotextiles or bonded to geomembranes. They are widely employed for their low permeability and ability to serve as hydraulic barriers in a variety of settings, including landfills, canals, and containment ponds. Black cotton soil, a type of expansive soil prevalent in tropical and subtropical regions, presents both challenges and opportunities in construction and engineering

projects. Known for its high shrink-swell potential, black cotton soil's behaviour can be problematic for conventional construction but also holds potential for innovative applications when stabilized or modified.
This study investigates the feasibility of using black cotton soil as a component in GCLs, potentially substituting for bentonite. By incorporating black cotton soil, the study aims to evaluate the geotechnical properties, performance under different conditions, and overall effectiveness as a hydraulic barrier. The

findings could lead to cost-effective and sustainable solutions in geotechnical engineering by utilizing locally available materials and reducing reliance on imported bentonite.

2. Hydraulic conductivity of Black Cotton Soil and Bentonite

Hydraulic conductivity, often denoted ask, is a measure of a soil's ability to transmit water. It is a critical property in geotechnical engineering, especially for applications involving barriers and liners, such as those used in landfills and containment systems. Both black cotton soil and bentonite are used in these applications, though their hydraulic conductivities differ significantly due to their distinct properties.

The Permeability of black cotton soil and Bentonite is 2.33108 X 10^{-7} cm/sec and 2.1167 X 10^{-8} cm/sec respectively. The hydraulic conductivity of untreated black cotton soil generally ranges from 10^{-6} to 10^{-8} cm/s. However, this value can vary widely based on factors such as soil composition, moisture content, and compaction. The hydraulic conductivity of bentonite is very low, typically ranging from 10^{-8} to 10^{-12} cm/s. This low permeability makes it an excellent material for liners and barriers. Black cotton soil and bentonite both have their uses in geotechnical engineering, their hydraulic conductivities differ significantly. Bentonite's consistently low hydraulic conductivity makes it ideal for use in GCLs and other containment applications. Black cotton soil, with proper treatment and compaction, can serve as a viable alternative, offering economic and environmental benefits, particularly in regions where bentonite is not readily available. Understanding the hydraulic properties and behavior of these soils under various conditions is essential for their effective application in environmental containment systems.

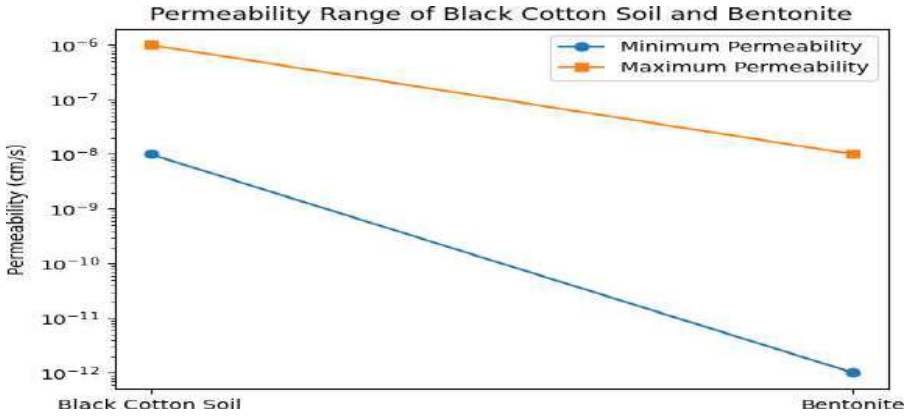


Fig.1 Permeability range of Black Cotton Soil and Bentonite

3. Liquid limit of Black Cotton Soil and Bentonite

The liquid limit of a soil is a critical property in geotechnical engineering, representing the water content at which the soil transitions from a plastic state to a liquid state. This parameter is essential for understanding the behavior and suitability of soils for various engineering applications. Bentonite generally has a much higher liquid limit compared to black cotton soil due to its higher montmorillonite content and greater swelling capacity. Soils with high liquid limits like bentonite are more plastic and have greater water retention and swelling capabilities. The liquid limit of black cotton soil generally ranges from 40% to 100%. However, it can vary significantly based on the specific mineralogical composition and the degree of weathering of the soil The liquid limit of bentonite is typically very high, ranging from 100% to 450%. This high value is due to the significant water absorption capacity of montmorillonite.

ISBN: 978-93-343-2006-0

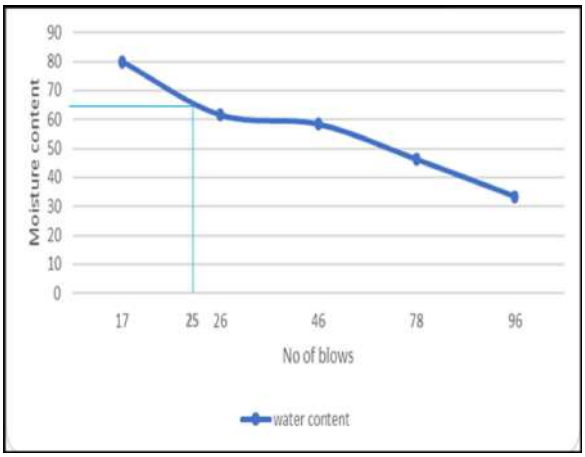


Fig 2. Liquid limit of Black Cotton Soil

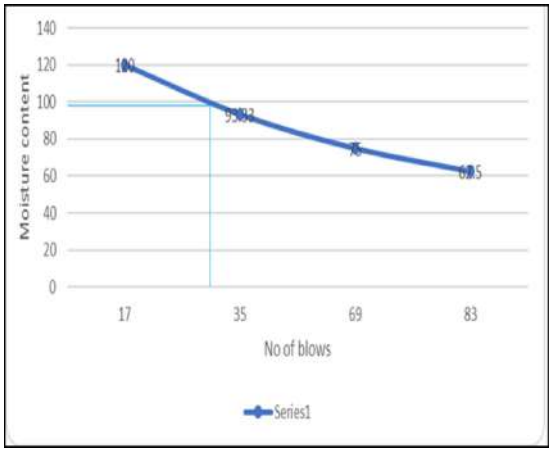


Fig 3. Liquid limit of Bentonite

4. Plastic Limit of Black Cotton Soil and Bentonite

The plastic limit of a soil is the water content at which the soil changes from a plastic state to a semi- solid state. This property, along with the liquid limit, helps define the plasticity characteristics of soils, which are crucial for understanding their behavior in various engineering applications. The plastic limit of black cotton soil typically ranges from 20% to 35%. This range can vary based on the specific mineralogical composition and the degree of weathering of the soil. The plastic limit of bentonite is around 50% to 70%. This high value is due to the significant water absorption capacity of montmorillonite. Bentonite generally has a higher plastic limit compared to black cotton soil due to its higher montmorillonite content and greater water retention capacity.

5. Comparison of Black Cotton Soil and Bentonite

Table 1: Comparison of GCL and CCL

Property	Black Cotton Soil	**Bentonite**
Mineralogy	Montmorillonite, kaolinite, illite	Primarily montmorillonite
Plasticity	Moderate to high	Very high
Swelling Potential	High	Extremely high
Hydraulic Conductivity	10^{-6} to 10^{-8} cm/s	10^{-8} to 10^{-12} cm/s
Shrink-Swell Behavior	Significant	Very pronounced
Common Uses	Road construction, natural liners (with treatment)	GCLs, waste containment, drilling muds

6. Conclusions

- Permeability: Bentonite is significantly less permeable than black cotton soil. Black cotton soil's permeability is low to moderate, while bentonite's is very low.
- Both soils swell when wet, but bentonite swells more dramatically, contributing to its lower permeability.
- Bentonite requires a higher optimal moisture content compared to black cotton soil. Black cotton soil generally achieves a higher maximum dry density than bentonite

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Evaluation of moisture content in Dendrocalamus Strictus bamboo specimens using standardized oven drying technique

Prof. Prajwal Gaikwad[1], Dr. Santosh Patil[2], Dr. Atul Pujari[3], Prof. Seham Khaleel[4,] Prof. Babasaheb Thore[5]

[1,4,5] Assistant Professor, Department of Engineering Science, K. J. College of Engineering and Management Research (KJCOEMR), Pune, Maharashtra, India

[3]Professor, Department of Civil Engineering, K. J. College of Engineering and Management Research, Pune, Maharashtra, India

[3]Associate Professor, Department of Civil Engineering, K. J. College of Engineering and Management Research, Pune, Maharashtra, India

[1] prajwalgaikwad707@gmail.com

Abstract

This paper presents a study on the moisture content determination of Dendrocalamus strictus bamboo using the oven-drying method, as per IS 287 (Part 1): 1986. The experimental investigation was conducted in the Civil Engineering Laboratory of K. J. College of Engineering and Management Research (KJCOEMR), Pune, India. The bamboo specimens used were exposed to rainfall for seven consecutive days prior to testing, simulating naturally wetted field conditions. Three specimens were taken from a single bamboo culm at different heights: Specimen 1 from the bottom (thickest), Specimen 2 from the middle, and Specimen 3 from the top (thinnest) of average 18 feet bamboo. Initial weights were recorded before drying the samples in an oven at 103 ± 2°C for 48 hours.

Keywords: Bamboo moisture content, Oven drying method, Dendrocalamus Strictus

Introduction

Bamboo is a versatile, sustainable, and fast-growing natural resource that plays an important role in the construction, rural housing, and handicraft industries. Among various species of bamboo, Dendrocalamus strictus (also called Manvel bamboo) has wide availability in India because of its strong culms, straight structure, and dense fiber configuration, making it an ideal candidate to be used in temporary structures, to be used in scaffolding, for fencing, and an alternative to light structural qualities instead of steel. According to these specific characteristics if moisture content for bamboo is adequate, it will have a plausible mechanical performance and durability. The moisture content governs dimensional stability, bio-decay resistance and mechanical performance in bamboo. High moisture content can cause fungal decay, distortion, and contact mechanical performance (compressive or tensile) to be reduced. Low moisture content can make bamboo be brittle. It is crucial to determine moisture content therefore allow to determine structural efficiency and suitable drying and preservation methods. Measuring the moisture content of Dendrocalamus Strictus using gravimetric method - weighing specimen pre- oven dry and post - oven dry is suitable for measuring moisture content. The study offers a unique perspective of this species by examining the variability in moisture content of untreated samples.

Methodology

1. Sample Collection and Preparation (As per IS 6874:2008)

The bamboo specimens used in this research were collected from Mahude Kh. village, Bhor, Pune located in the western part of Maharashtra, India (Coordinates: *approx. 17.805°N, 73.944°E*). This region is known for

naturally growing stands of Dendrocalamus Strictus, a widely used bamboo species for structural and construction applications. The bamboo specimens were subjected to rainfall for seven days before to testing, replicating naturally wet field conditions as shown in *Fig. 01*. Mature bamboo culms were selected based on uniformity in diameter, straightness, and absence of visual defects such as cracks or insect damage.



Fig. 01. Dendrocalamus Strictus bamboo

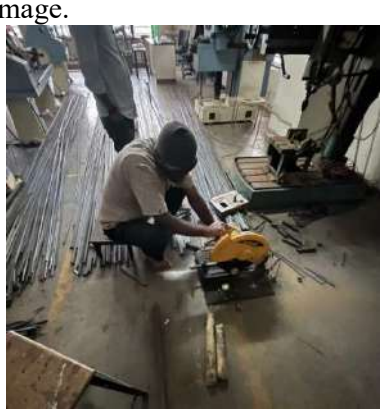


Fig. 02. Cutting of bamboo specimens using an abrasive chop saw (DEWALT) at KJCOEMR.

Bamboo specimen were cut into test specimens using a DEWALT abrasive cutting machine shown in *Fig. 02.* The cutting was done under supervision, and all safety measures (PPE) were taken during the process.

2. Initial Weighing (Wet Weight Measurement)

Each bamboo sample was weighed using a digital precision balance (Model: Contech CA 223, capacity: 220 g, readability: 0.001 g) in its natural (wet) state before drying. The measured initial (wet) weights are as follows



Sample 1: 164.064 g



Sample 1: 154.816 g



Sample 1: 141.016 g

Fig 03. Initial weight of bamboo specimens

3. Oven Drying Process

After recording the wet weights, all three samples were placed in a laboratory oven at a constant temperature of 103°C for 48 hours as pe IS code provision. The oven-drying method is considered the most accurate and standardized technique for determining the moisture content (MC) in bamboo and timber. It is a gravimetric method in which the loss in weight of a specimen due to moisture evaporation upon

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drying is used to calculate the moisture content. In tropical or humid conditions or for thick-walled bamboo like Dendrocalamus strictus**,** 48 hours at 103°C is practically necessary to ensure complete evaporation of bound and free water.



Fig 04. Oven drying process

4. Final Weighing (Dry Weight Measurement)

After cooling, samples are weighed immediately to record the oven-dry weight. weighing must be done swiftly to avoid reabsorption of moisture from the atmosphere. The samples were cooled in a desiccator and then reweighed using the same digital balance. The final dry weights are given below



Sample 1: 141.595 g



Sample 1: 133.065 g



Sample 1: 121.197 g

Fig 05. Final weight of bamboo specimens

5. Moisture Content Calculation

Moisture content on a wet basis calculated using the following formula:

Moisture Content (%) = ((Wet Weight - Dry Weight) / Wet Weight) × 100

Table 01. Moisture Content Calculation

Sample	**Initial Weight (g)**	**Final Weight (g)**	**Moisture content (%) (Weight loss ÷ Final Weight) × 100**	Average **Moisture Content (%)**
Sample 1	164.064	141.595	(22.469 ÷ 141.595) × 100 = **15.86%**	Average M.C = (15.86+16.34+16.36)/3 = **16.19**
Sample 2	154.816	133.065	(21.751 ÷ 133.065) × 100 = **16.34%**	
Sample 3	141.016	121.197	(19.819 ÷ 121.197) × 100 = **16.36%**	

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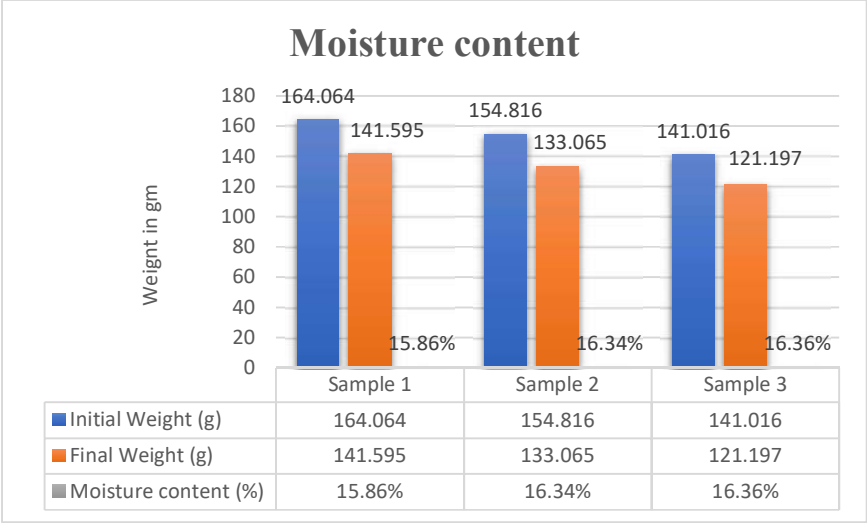


Fig 06. Moisture content calculation

6. Observations

The initial weights of the bamboo specimens ranged from 141.016 g to 164.064 g, while the final oven-dried weights ranged from 121.197 g to 141.595 g, indicating a clear loss of moisture during the drying process. The weight loss, varying between approximately 19.82 g and 22.47 g, reflects the amount of water removed from each sample through oven drying at 103°C for 48 hours, following IS code standards. The calculated moisture content percentages for the three samples were closely grouped between 15.86% and 16.36%, with an average of 16.19%, demonstrating consistency in the drying procedure and uniform moisture distribution across specimens.

Results

These moisture content values fall well within the acceptable range of 10% to 20% for structural bamboo as per IS specifications, confirming that the drying process effectively conditioned the bamboo for further use. The accuracy of measurements, ensured by precise weighing and controlled drying conditions, validates the reliability of the results. Moisture content around 16% maintains an optimal balance between strength and flexibility, minimizing risks of brittleness or deformation, which can occur if moisture levels are too low or too high. Overall, these observations indicate that the bamboo samples have been satisfactorily dried, making them suitable for structural applications, although periodic moisture monitoring is advisable to ensure long-term material performance in varying environmental conditions.

Discussion

In the current study, the moisture content of three bamboo specimens was calculated as 15.86%, 16.34%, and 16.36%, respectively, with an average moisture content of 16.19%. These values fall comfortably within the acceptable range of 10% to 20% moisture content typically recommended for bamboo used in construction and structural applications. Maintaining moisture content within this range is essential to prevent problems such as fungal decay, shrinkage, and loss of mechanical strength, which are common when bamboo is either too wet or excessively dry.

From a practical standpoint, the moisture content around 16% is ideal for preserving the balance between strength and flexibility of bamboo. At this level, bamboo is less likely to warp, crack, or suffer biological degradation when exposed to typical environmental conditions. This moisture

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level ensures that the bamboo retains its mechanical properties necessary for its intended structural uses, providing confidence in its performance and longevity.

Conclusion

The moisture content analysis of the bamboo specimens using the oven-drying method at 103°C for 48 hours, as prescribed by IS 287 (Part 1): 1986, yielded moisture contents ranging between 15.86% and 16.36%, with an average of 16.19%. These values lie well within the recommended range for structural bamboo, indicating effective moisture removal without compromising material integrity. The consistent results across samples confirm the reliability of the drying process and measurement technique. Maintaining moisture content at this level ensures optimal mechanical performance, dimensional stability, and durability of bamboo when used in construction and other engineering applications. Thus, the drying procedure and subsequent moisture content determination conform to Indian Standards and support the suitability of the bamboo specimens for further mechanical testing and structural use.

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Amrita Burungale amritaburungale6396@gmail.com

ABSTRACT

Earthquake constitutes one of the greatest hazards of life and property on the earth. Due to suddenness of their occurrence, they are least understood and most dreaded. The earthquake resistance construction is considered to be very important to mitigate their effects. The design of residential building is followed by the design requirements as per IS 456:2000 code.

However, as the recent earthquakes have shown, the performance of normal structures during past Indian earthquakes has been less satisfactory. This is mainly due to the lack of awareness amongst most practicing engineers of the special provisions that need to be followed in earthquake resistant design and thereafter in construction.

1. Introduction

Earthquakes are one of the most devastating natural disasters, capable of causing widespread destruction. As the global population continues to grow and urbanize, the construction of earthquake-resistant buildings becomes increasingly important to ensure the safety and stability of human settlements. Earthquake-resistant buildings are designed to withstand seismic forces by incorporating flexible structures, ductile materials, and innovative technologies. This project aims to investigate and apply various techniques used in earthquake-resistant building design.

Earthquakes are one of the most devastating forces on the planet. The seismic waves that travel through the ground can demolish buildings, kill people, and cost billions of dollars in damage and restoration. According to the National Earthquake Information Centre, there are over 20,000

ISBN: 978-93-343-2006-0

earthquakes every year on average, including 16 major disasters. The damage was caused by the collapse of buildings with people inside, as in previous earthquakes, prompting the development of earthquake-resistant constructions. Constructions intended to withstand earthquakes are known as earthquake-resistant structures. While no structure can be completely safe from earthquake damage, earthquake-resistant construction aims to build structures that perform better than their conventional equivalents during seismic activity.

2. Theoretical Content-

2.1 Earthquake-

Earthquakes are among the most devastating natural disasters, capable of causing significant loss of life, property damage, and disruptions to society. Advanced Earthquake Engineering is a multidisciplinary field dedicated to understanding seismic phenomena and designing solutions to mitigate their effects on structures and infrastructure. It builds upon fundamental principles of geophysics, structural engineering, and materials science to enhance the safety and functionality of buildings and systems in seismically active regions.

Indian standards dealing with Earthquake resistant construction are:

IS 1893 (Part 1): 2002 'Criteria for Earthquake Resistant Design of Structures : Part 1 General provisions and Buildings'

IS 1893 (Part 4): 2005 'Criteria for Earthquake Resistant Design of Structures : Part 4 Industrial Structures Including Stack Like Structures'

IS 4326:1993 Earthquake Resistant Design and Construction of Buildings - Code of Practice

IS 13827:1993 Improving Earthquake Resistance of Earthen Buildings - Guidelines

IS 13828:1993 Improving Earthquake Resistance of Low Strength Masonry Buildings - Guidelines

IS 13920:1993 Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice

IS 13935:1993 Repair and Seismic Strengthening of Buildings - Guidelines

2.2 Strategies For Earthquake Resistant Construction

In accumulation to the earthquake design code 1893 the Bureau of Indian Standards has distributed to applicable earthquake design codes for earthquake

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resistant construction Masonry structures (IS-13828 1993).

Delivering vertical reinforcement at significant locations such as internal corners, and external wall junctions as per code.

Horizontal bands should be provided at lintel, plinth and roof levels as per code

proper workmanship and Quality assurance must be guaranteed for all cost without any concession In RCC framed structures (IS-13920)

Grade of mortar should be as per codes definite for dissimilar earthquake zones.

2.3 Modern Construction Methods For Earthquake Resistant Buildings

A. Shape-memory alloys

This demonstrate exceptional characteristics desirable in a seismic risk resistant building. They have a capability to disintegrate considerable energy without permanent deformation or considerable destruction. Generally common shape memory alloys are makeup of metal blends comprising, nickel titanium, copper-aluminum-nickel and copper-zinc-aluminum-nickel. This is more suitable for extensive applications.

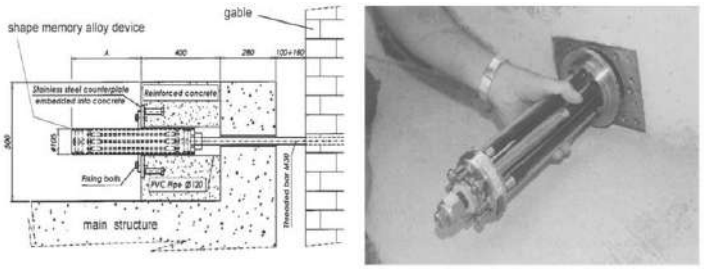


Fig. No.2.3.1- **Shape-memory alloys**

B. Seismic Dampers

In Seismic Dampers are the diagonal braces in a moment resisting frame which is used for efficient lateral load resisting scheme. In modern area the structural seismic retort to control have taken the lead to the alternative of these bracings with seismic dampers.

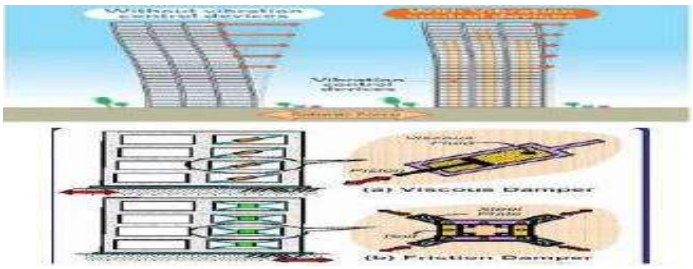


Fig.No.2.3.2-**Seismic Damper**

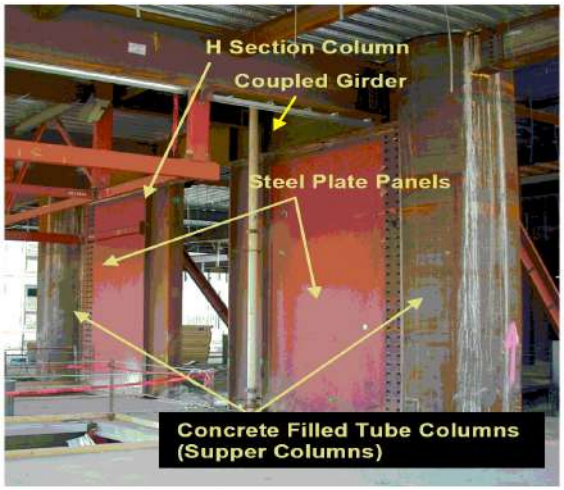
C. Shear Walls

Shear walls are deemed as an important component of a lateral load resisting systems and steel is known for its flexible behavior.

Types of shear wall

- Simply rectangular type (Barbell wall):
- Coupled shear wall:
- Rigid frame shear wall and in fill walls:
- Column supported shear wall:
- Core type shear wall:

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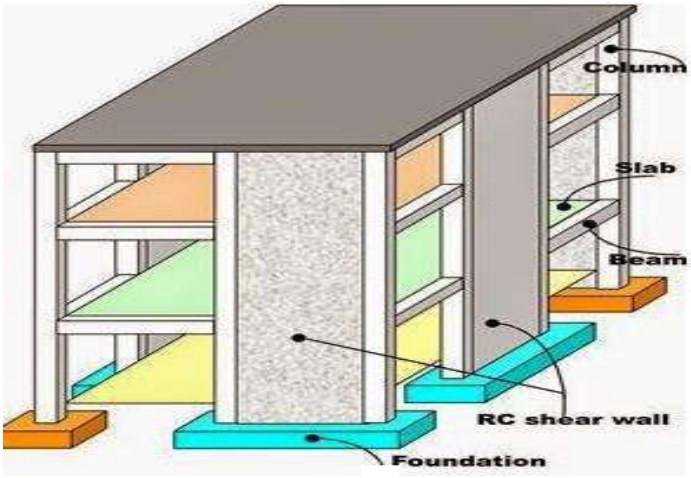


Fig. No.2.3.3- **Shear Wall**

D. Carbon Fibers

The tensile features and the constant nature of a spider web was studied by many researchers in Japan. This is the world's first seismic reinforcement structure made of carbon fiber material. A seismic risk Resistant Building Rendered with Carbon Fabric and it is redolent of a giant spider web has been erected in Nomi City of Ishikawa Prefecture in Japan.



Fig. No.2.3.4- **Carbon Fibers**

E. Ecological Ductile Cementations Composite (EDCC) Spray

A many researchers from the University of British Columbia (Vancouver, Canada) has established a new extreme method to make up the buildings resist against seismic risks. EDCC blends the fly ash, cement with polymer-based fibers, and other extracts in making it ecological and has been provided the molecular level to be malleable and strong at the same time.

F. Blue mussels

It is found sea decks and clinging to rocks all laterally the coast of New England. They are affixed in place by a gristly outcrop of cabling that occurs from among their twin shells. Generally, the most ferocious of high tides Can't pry them very loose.

G. Seismic Invisibility Cloak

A sequence of the borehole is mined about the periphery of the structure that needs to be endangered. **Symmetry, Diaphragms, and Cross-Bracing**

ISBN: 978-93-343-2006-0

Symmetry is a typical criterion used in seismic design. Asymmetrical designs have a higher seismic risk.



Fig. No.2.3.5- **Cross Bracing**

Technological Advancements in Earthquake Engineering

Technological advancements in earthquake engineering have significantly improved the ability to design and construct buildings and infrastructure that can withstand seismic events. Some key advancements include:

Base Isolation Technology

• Base isolators, such as lead-rubber bearings and elastomeric bearings, decouple buildings from ground motion, reducing seismic forces transmitted to the structure. This technology is increasingly used in both new constructions and retrofitting of existing buildings.

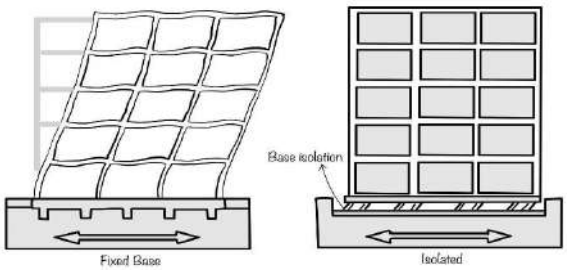


Fig. No.2.3.6- **Base Isolation**

Seismic Sensors and Monitoring Systems

• Seismic sensors and real-time monitoring systems provide immediate data on ground motion and building response.

Computer Modeling and Simulation

• Advanced finite element modeling (FEM) and structural simulation software enable engineers to analyze how buildings respond to different earthquake scenarios. These tools help optimize designs and predict structural performance under seismic loading.

Shake Tables and Testing Technologies

Indian standards dealing with Earthquake resistant construction are:

IS 1893 (Part 1): 2002 'Criteria for Earthquake Resistant Design of Structures : Part 1 General provisions and Buildings'

IS 1893 (Part 4): 2005 'Criteria for Earthquake Resistant Design of Structures : Part 4 Industrial Structures Including Stack Like Structures'

IS 4326:1993 Earthquake Resistant Design and Construction of Buildings - Code of Practice

IS 13827:1993 Improving Earthquake Resistance of Earthen Buildings

IS 13828:1993 Improving Earthquake Resistance of Low Strength Masonry Buildings

IS 13920:1993 Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice

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IS 13935:1993 Repair and Seismic Strengthening of Buildings

3.Conclusion

Different techniques are currently available for improving seismic resistance of structure which improves stiffness, strength and/or ductility. These techniques include the use of shear wall, base isolation system, energy dissipation system or use of composite materials. Seismic resistance RC structures can successfully improve with use of concealed steel profiles, by using advanced techniques or composite materials. The addition of shear walls can be suitably done as per requirement to improve strength, stiffness and ductility of structures. FRP composites can be used effectively for improvement of seismic behavior of structure which helps to increase ductility, control opening and widening of cracks and to reduce stiffness and strength degradation. Energy dissipaters dissipate energy of seismic wave thereby reducing seismic effect on structure. Base isolator reduces stiffness of structures which controls damage during earthquake.

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"PARAMETRIC STUDY AND COMPARISON OF PERFORMANCE OF STEEL FRAMES WITH DIFFERENT DAMPERS (FRICTIONAL and VISCOUS) AND BRACING (V SHAPED and X BRACED)

Mr. Anand Abhishek[1], Dr. S.K. Patil [2], Dr. A.B. Pujari [3] & Prof. A.R. Undre[4]

[1]PG Student, Department of Civil Engineering,

KJ College of Engineering & Management Research

[2]HOD, Department of Civil Engineering,

KJ College of Engineering & Management Research

[3]Associate Professor, Department of Civil Engineering,

KJ College of Engineering & Management Research

[4]Assistant Professor, Department of Civil Engineering,

KJ College of Engineering & Management Research

ABSTRACT

Seismic resilience of steel frame structures is crucial, especially in areas high seismic prone. This research concentrates on the parametric analysis and performance comparison of steel frame buildings with various damper and bracing configurations under seismic loads. It specifically investigates the effectiveness of frictional and viscous dampers in combination with V-shaped and X-bracing systems in buildings of varied heights (G+7, G+14, and G+21) situated Throughout Seismic Districts IV and V. The seismic performance of these structures is assessed using time history analysis, with an emphasis on key variables include time duration, storey displacement, frequency, base shear, and storey drift. The study's objective is to determine the best combinations for enhancing steel frames' earthquake response by examining individual and combined configurations of bracing and dampers. According to the findings, X-bracing paired with frictional dampers consistently results in the lowest storey displacement and drift, indicating superior lateral stiffness and overall structural stability. In contrast, viscous dampers, especially when combined with X-bracing, improve energy dissipation, lowering base shear and improving overall seismic performance. The study also examines the impact of seismic zone and high building height on the performance of different configurations. Finally, this research gives useful insights for optimising the design of seismic-resistant steel frame structures, as well as practical advice for improving the security and durability of structures in seismically active areas.

Keywords: Bracing systems, Dampers, Frictional dampers, Seismic analysis, Seismic performance, Steel frames, Structural resilience, Time history analysis, Viscous dampers, X-bracing, Zone IV, Zone V.

I. INTRODUCTION

It is more important to use seismic analysis to check the strength and performance of steel buildings, especially in places where earthquakes are common. The main goal of this study is to look at how a steel building with different kinds of bracing systems reacts to earthquakes. Bracing systems are

ISBN: 978-93-343-2006-0

important parts of steel buildings that are meant to lessen the damage caused by the side forces that happen during earthquakes and other seismic events. To make structures stronger against earthquakes and improve their design, it is important to know how different support systems compare in terms of how well they work.

To make sure that steel buildings are safe during earthquakes, seismic research is needed. Steel is great for building structures that can withstand earthquakes because it is strong and flexible. To keep buildings from coming apart, different kinds of bracing systems are used. These include diagonal, eccentric, circle, and buckling-restrained bracing. To make these systems more stable, researchers study them. earthquake analysis is very important for steel frame construction because the choice of bracing has a big effect on how well a building can protect its people and survive earthquake forces. Steel building construction is commonly used because of its adaptability, strength, and durability. It entails constructing structural frames made mostly of steel elements such as columns, beams, and braces. The process usually starts with comprehensive engineering and design, followed by the manufacturing of steel components off-site in controlled settings. These prefabricated parts are then delivered to the building site and assembled, allowing for shorter construction deadlines. The high strength-to-weight ratio of steel buildings lets them be taller and have more open floor plans. They are also resistant to rust, vermin, and fire, which improves their durability and safety. Steel structures find use in a variety of industries, including commercial, industrial, and residential construction. Furthermore, advances in design technology and construction processes continue to increase steel building systems' efficiency, sustainability, and seismic resistance, making them the ideal material for contemporary construction projects.

When it comes to layer drift and movement, the support system works better. With the same amount of material cost, it is more inexpensive than the other structural system, therefore it is the best alternative based on economic factors. Better seismic performance may be accomplished by installing diagonals between floors that function as truss members. The basic function of diagonals is to transfer axial loads to columns and transport lateral loads, resulting in an efficient natural structural system. Bracing systems are parts of buildings and structures that keep them stable, support them, and protect them from different forces, like wind, earthquakes, and other loads. These systems successfully spread out loads, stop swaying, and help buildings handle bad weather, which protects people and extends the life of buildings and structures.

Many mid-rise and high-rise buildings use steel frame designs because they are strong and can be bent in many ways. However, under seismic stress, these structures are susceptible to excessive displacements, drifts, and vibrations, which may compromise structural integrity and occupant safety. Traditional reinforcing methods, such as bracing systems and modern damping devices, have shown potential in enhancing seismic performance. However, their individual and combined effects on dynamic behavior, especially across different building heights and earthquake zones, remain inadequately understood. A parametric research is needed to determine how well steel frames perform with V-braced and X-braced bracing and frictional and viscous dampers at various building heights and seismic zones. Identifying the most effective combination for reducing seismic response is crucial for improving structural performance and resilience in earthquake-prone areas.

ISBN: 978-93-343-2006-0

This work parametrically analyses and evaluates steel frames using alternative bracing methods and dampers to improve seismic behaviour. Three building models for the Seismic Zones IV or V are looked at using time history analysis in line with the rules set by IS. Plus 7, 14, and 21. The research examines how V- and X-bracing designs effect storey movement, drift, frequency alone, time period, base shear, and when coupled with frictional. The study looks at how well these models handle earthquakes to find the best mix of bracing and dampers for each building height and seismic zone. This will help engineers and designers make buildings more resistant to shaking in areas that are prone to earthquakes.

The study's goals are: (1) To look at how well G+7, G+14, and G+21 steel frames handle earthquakes in Seismic Zone IV and Zone V by using time history analysis; The second goal is to study and compare how steel frames with V-brace and X-bracing bracing configurations hold up against earthquake loads. (3) To find out how well frictional and viscous dampers work to improve earthquake performance for buildings of different heights and in different seismic zones; and (4) To identify the optimal combination of dampers and bracing for improved seismic performance by analyzing different frame models with mixed configurations of bracing and dampers.

II. LITERATURE REVIEW

The literature review part gives a good foundation for understanding both theory and actual work on how steel buildings, especially those with damping devices and supporting systems, behave during earthquakes.

The chapter dives into a variety of studies and methodologies that investigate the effectiveness of various bracing configurations and damper types under seismic stress. It presents an overview of current research aimed at enhancing the structural resilience of steel frames by reducing lateral displacements, Storey drift, and base shear during earthquakes. This chapter brings together findings from numerous sources to provide insights into the various approaches employed in seismic analysis and to emphasize the key factors that determine the size of steel structures in seismic zones and their performance.

In their 2024 study, Sumon Islam et al. look at how different kinds of steel concentrically braced frames (CBF) affect the basic lengths of reinforced concrete (RC) buildings, focussing on how well they do in earthquakes. Using ETABS 2021 computer modelling, the study looks into how RC buildings with diagonal, cross, and reversed V-bracing systems change over time. The results suggest that bracing systems have a substantial impact on seismic performance, creating new predictive equations that can more accurately estimate the fundamental period based on the bracing configuration than traditional guidelines such as BNBC 2020. In a similar vein, Reza Siami Kaleybar and Payam Tehrani (2021) investigate the effectiveness of a variety of passive dampers, such as viscous, viscoelastic, and friction dampers, in enhancing intermediate steel moment frames' seismic performance. The study concludes that structures with dampers demonstrate superior seismic performance, with toggle arrangements of viscous dampers performing best, in accordance with nonlinear time history analyses conducted in Open Sees software with various ground motion recordings. Friction dampers are the most advantageous for seismic resilience among the dampers that have been examined. Aparna Shiny Gottem et al. (2023) did a mathematical study to check how well a 50-story reinforced concrete building would hold up in different types of earthquakes. The study looked at what effect buckling restricted braces (BRBs) have. According to the study, BRBs' effectiveness varies across

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seismic zones, with specific configurations enhancing Storey rigidity and reducing lateral displacement. The writers stress how important it is to pick the right bracing arrangement to lessen the P-delta effect in tall buildings. A study by T. Laya Sri et al. (2022) looks at how well a G+15 reinforced concrete building works in earthquake zones II, III, IV, and V. They examine how the building handles sideways motions and story shear with or without steel reinforcement. In zones II and III, chevron bracing systems perform best seismically, whereas V-bracing is better in zones IV and V. This underscores the significance of selecting the appropriate bracing system for each seismic zone. Magdalini D. Titirla (2023) provides an in-depth examination of passive dissipating systems with an emphasis on steel dampers supports for seismic safety. The study assesses the effectiveness of over 196 publications on a variety of dampers, such as friction (FD), metallic (MD), and viscous dampers (VD), in absorbing seismic energy and averting deformation. The review underscores that no single damper is universally optimal, as each has unique advantages that are contingent upon cost, technical requirements, and architectural considerations. In a related study, Wesam Al Agha and Dr. Researchers Nambiappan Umamaheswari and others (2020) looked at how reinforced concrete buildings responded to earthquakes with and without fluid viscous dampers (FVD). Scientists are using ETABS tools or Equivalent Static, Response Spectrum, as well as Time History Analysis to study how FVDs change how earthquakes work. Results indicate that FVDs significantly reduce lateral deflections, story shear, and base shear while improving story stiffness and overall structural integrity.

The seismic performance of steel structures fitted with viscous, friction, or yield dampers, amongst other types of dampers, is assessed by Vahid Saberi et al. (2022). Structural changes, base stress, & energy loss are compared for 3, 6, and 12 storey structures. According to the data, buildings with viscous dampers work better than those with yield for friction dampers at lowering story errors and base stress. This information is valuable for the selection of dampers for buildings of varying heights. Siami Kaleybar, Payam Tehrani (2021) How does an eight-story intermediate steel moment framework with various passive control systems perform in earthquakes. Using nonlinear time history analysis in Open Sees, the article simulates 10 frames with both viscous, viscoelastic, and Pall friction dampers In terms of maximum displacement, base shear, & energy dissipation, toggle-arranged viscous dampers improve seismic performance the greatest. Zeinab A. Alhello & Ihab Sabri Saleh (2024) use diagonal, chevron, or upper toggle friction dampers to examine a ten-story steel building's seismic performance. The study, which was conducted using ETABS software, reveals that the damper is most effectively placed in the mid-story, resulting in a maximal displacement reduction of 37%. This is notably true for the upper toggle friction damper configuration. The effectiveness of viscoelastic dampers in reducing lateral displacements brought on by seismic forces is highlighted in this. In the same vein, Prashant Gangwani and Aakash Suthar (2021) concentrate on the utilization of high-rise buildings' fluid viscosity dampers (FVD) (G+30, G+40, & G+50 storeys) with irregular L and C-shaped plans. The study assesses seismic performance with various FVD placements using ETABS software, demonstrating that the optimal placement substantially reduces narrative displacement, drift, and time periods during seismic events. The results show that where the dampers are placed has an effect on how the whole structure responds to earthquakes. Placing them strategically makes them work better.

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Yongwei Wang et al. (2020) investigate the creation of a Energy dissipation characteristics of friction dampers are integrated with the focussing on yourself behaviour of focussing on yourself varied friction damper (SC-VFD) braces. pretensioned obsidian fiber-reinforced plastic (BFRP) tendons. SC-VFD supports outperform conventional friction dampers in terms of energy dissipation, post-yield rigidity, and diminished residual displacement, as demonstrated by the study's theoretical analysis and experimental validation. Deepak Kumar et al. (2024) compare regular framed buildings to T-shaped buildings that have viscosity dampers to see how well they handle aftershocks. The study finds that viscosity dampers greatly improve seismic resistance by reducing torsional effects and lateral displacements. This makes the structure more stable during earthquakes by looking at base shear, story drift, and overturning moments under seismic loads, especially in areas with soft soil and a lot of earthquakes.

Dario De Domenico or Iman Hajirasouliha develop a layered planning method in 2021 for making nonlinear viscous dampers (NVDs) in steel frames.

The study optimizes damping distribution to attain homogeneous damage distribution across structures during seismic events by employing a performance-based design philosophy. By looking at the nonlinear time histories of steel frames with three, seven, or twelve stories beneath different earthquake excitations, we can see that the optimal damping distribution was a good way to upgrade buildings in high-risk seismic zones. This strategy significantly reduces inter-story deviations, local damage, and global damage indices. Finally, the performance of friction and viscous dampers in lofty steel structures under seismic stresses is evaluated by Rushikesh Vijaykumar Bandal and Sagar Gopalrao Solanke (2021). The study uses nonlinear dynamic analysis to look at a tall building in an earthquake zone and its base stress, inter-story drift, and movement. The results indicate that both friction and viscous dampers effectively reduce structural response. Friction dampers are superior in energy dissipation, while viscous dampers are superior in reducing displacement and drift during seismic events.

A lot of study has been done on how well steel frames work in earthquakes, but there are still many things we don't know about the best ways to set up damping and support systems for different types of earthquakes. While several studies have investigated the individual impacts of V-bracing, X-bracing, frictional dampers, and viscous dampers, there has been little research into the synergistic effects of combining multiple types of bracing with dampers in structures ranging from mid-rise to high-rise. Also, not many studies look at how well these systems work in more than one seismic zone, especially Zones IV and V, and how that affects important seismic reaction factors like base shear, floor displacement, and drift. A lot of research has been done on how well steel frames work with different types of support and dampers. These gaps need to be filled in, and this will give engineers important information they can use to make steel buildings in earthquake-prone places safer.

III. METHODOLOGY

The Methodology section teaches how to undertake parametric research to compare steel frame structures with different support systems and dampers under seismic stress. Using time history analysis, this research investigates the dynamic behavior of G+7, G+14, and G+21 steel frames in seismic zones IV & V. The use of finite element software to generate and evaluate the structural models, which include two kinds of bracing systems (V-bracing and X-bracing) and two types of dampers (viscosity and

ISBN: 978-93-343-2006-0

friction). To identify the optimal solution for improving seismic performance, each frame is examined independently with bracing and dampers, as well as in combination configurations. To guarantee accuracy and compliance with safety requirements, the methodology follows the essential sections of Indian Standard (IS) norms for seismic analysis and structural design. This chapter gives a full overview of the modelling process, material parameters, loading conditions, and analysis techniques employed to meet the study goals.



Fig 3.1: Flow process

Dynamic analysis that uses time history analysis figures out how the building reacts at specific time steps by starting with a discretized record of fake time history. After three or more-time history studies, only the biggest reactions of the important measure are picked out.

Time history analysis studies how a building grows under ground motion. These modifications take place at various points throughout time. When higher mode effects are not significant, static approaches may be used. Most of the time, this is true for short, standard arrangements. Because of this, a dynamic method is needed for systems that are tall, have rotational imbalances, or don't have straight frames.

Using the linear dynamic method, the structure is shown as an MDOF system including a linearly variable stiffness matrix and a viscous damper matrixUsing linear elastic analysis, internal forces as well as displacements are determined, while time history analysis generates earthquake input. As with linear static procedures, the advantage of linear dynamic approaches is that they permit the study of higher modesThe structures' reaction to ground motion is calculated via linear dynamic Analysis within the time domains while keeping phase information. We solely consider linear properties. A system with a single degree of freedom is nonlinear with the ground acceleration and external force fluctuates arbitrarily, it may be difficult to solve the equation of motion analytically. Numerical time-stepping may assist solve differential equation integration difficulties.

3.1 Case study

The time history is the set of values of any variable that changes over time, like a measurement of ground motion, that were taken at certain times. You could think of this as a record of the past. Alternatively known as time series. That the record might not have done a good job of catching the earth's high-frequency waves because of the soil-structure interaction that happened between the huge base and the soft soil nearby. Several individuals believe that The most accurate technique for carrying out nonlinear analysis is time history analysis as compared to other approaches.

3.2.1 About Bhuj earthquake

On January 26, 2001, a large earthquake struck the Indian state of Gujarat, which is next to Pakistan. It was referred to as the Bhuj earthquake of 2001. India's Republic Day, as commemorates the 1950 establishment of the nation, was marked by the Bhuj earthquake.It affected parts of Pakistan and much of northwest India. The earthquake reached 7.7 on the Richter scale at the time, meaning it

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was quite powerful. More than 20,000 people were killed and more than 150,000 were hurt. The earthquake also destroyed or damaged more than a million houses and made hundreds of thousands of people homeless. A lot of the crops grown in the area were also destroyed. Even after a year, many people were still living in homemade homes.

Fig 3.2 shows Bhuj earthquake data in acceleration – time graph.

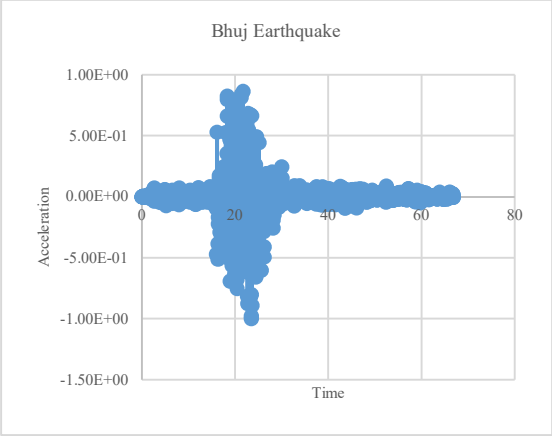


Figure 3.2: Bhuj earthquake data (PGA-3627.7 mm/s²)

IV. PROBLEM STATEMENT

4.1 General

The dynamic performance of steel frames under seismic stress is an important concern in structural engineering, especially in areas with varying seismicity. This study focuses on a parametric analysis and performance comparison of G+7, G+14, and G+21 steel frame models equipped with distinct energy dissipation systems—namely frictional and viscous dampers—and bracing configurations (V-shaped and X-braced frames). The analysis is carried out for seismic zones 2 and 5 in accordance with the applicable IS rules, with structure reactions evaluated using time history analysis in ETABS. To find the best ways to make buildings more resistant to earthquakes, each frame is tested on its own with and without dampers and bracing, as well as in different combinations, like X bracing with frictional dampers and V bracing with viscous dampers. This comparative research shows how connected systems improve things and how to make steel frame structures more earthquake-resistant in various seismic zones.

4.1.1 Input Data of Building:

The research analyses a 30m × 30m steel-framed structure with five 6-meter bays in both X and Y directions. Three building heights are examined: G+7 (8 stories), G+14 (15 stories), and G+21 (22 stories). The buildings are on medium-density soil and are made for Seismic Zones IV and V, which have significance levels of 0.24 and 0.36, respectively. Five reaction lowering factors and one important factor are taken into account. Every level is 3 meters tall and has a 200mm slab. The structural system includes X-type and V-type reinforcement, as well as structural and viscous dampers installed along the Y vector. ISMB 400 and ISHB 450-2 are the beam and column sections, respectively.

Material features include Fe345 steel and HYSD 500 for support, and M30 grade concrete is used. Three dead loads—a 3 kN/m² floor load, a 14 kN/m wall load, and the building's own weight (estimated automatically in ETABS)—set the conditions for loading. 2.5 kN/m2 are used for wind loads 2 kN/m2 are in the X, Y directions, with used for live loads. Accurate structural modeling and performance evaluation under seismic and wind loads are guaranteed by this comprehensive input data.

4.2 Model details

The study analyzes 24 distinct steel frame models across three building heights—G+7, G+14, and G+21—in Seismic Zones IV and V. In both orientations, each model employs frictional or viscous dampers in conjunction with either X-bracing or V-bracing. In both seismic zones, four configurations are evaluated for each building height: (1) X-bracing with frictional dampers, (2) V-

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bracing with frictional dampers, (3) X-bracing with viscous dampers, and (4) V-bracing with viscous dampers. This exhaustive approach enables a comparative analysis of the impact of various bracing-damper combinations on seismic performance across varying seismic building heights and intensities.

4.3 Values for dampers

For G+7, G+14, and G+21 steel frame structures in Seismic Zones IV and V, the study considers both friction and viscous dampers. Across all configurations, the mass and weight of the dampers are constant at 61.8 kg and 606.258 kN, respectively. The effective stiffness values for Zone IV are 25,750 kN/m, while for Zone V they are 92,700 kN/m. The effective damping ranges from 36,024.12 kN·s/m to 113,347.2 kN·s/m, depending on the building height and zone. The stiffness values for nonlinear properties range from 10,815 kN/m to 64,890 kN/m, while the damping values range from 14,409.65 kN·s/m to 56,673.62 kN·s/m. In all cases, a constant damping coefficient of 0.3 is maintained, allowing for a comparative assessment of damper performance across various seismic intensities and building heights.

4.4 Modelling images

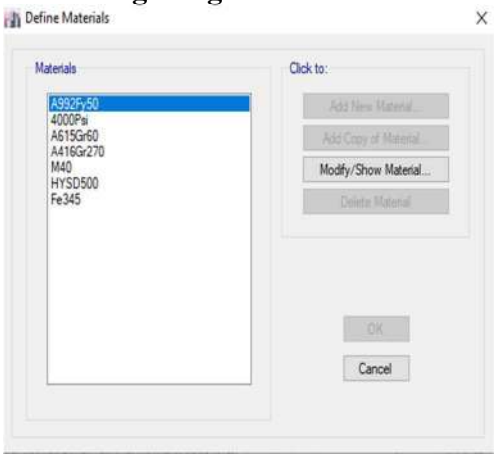


Fig: Material Properties

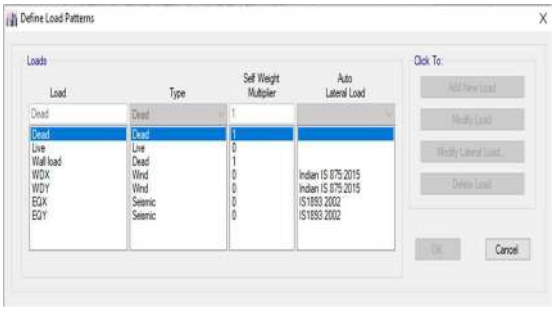


Fig: Defining load patters

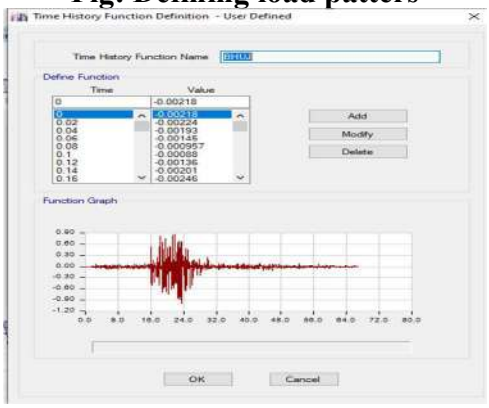


Fig: Defining time history



Fig: Define load cases

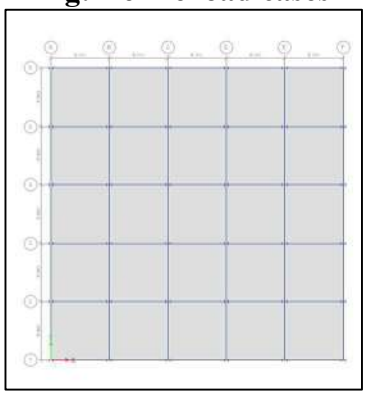


Fig: Plan view

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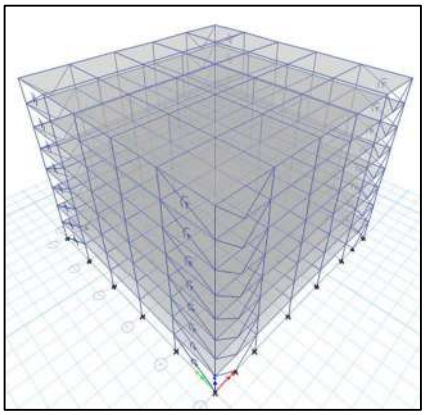


Fig: 3D view G+7 building

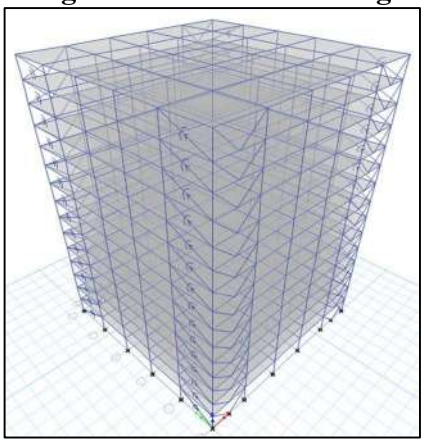


Fig: 3D view G+14 building

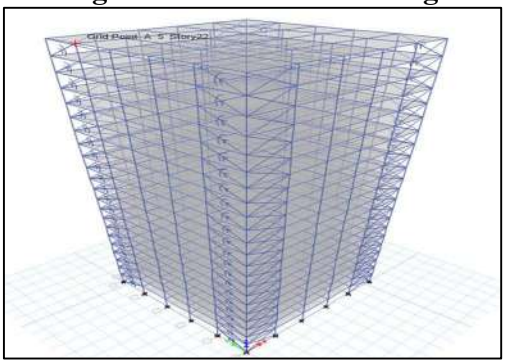


Fig: X bracing and friction damper in both directions

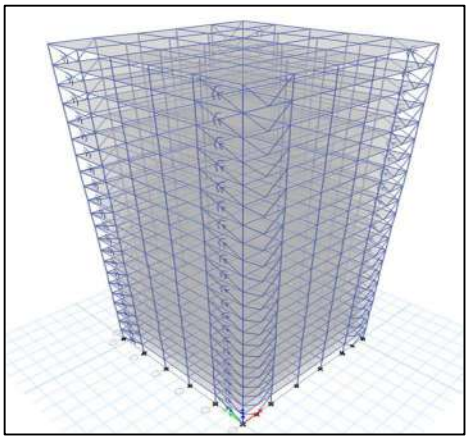


Fig: V bracing and friction damper in both directions

V. RESULT AND DISCUSSION

5.1 General

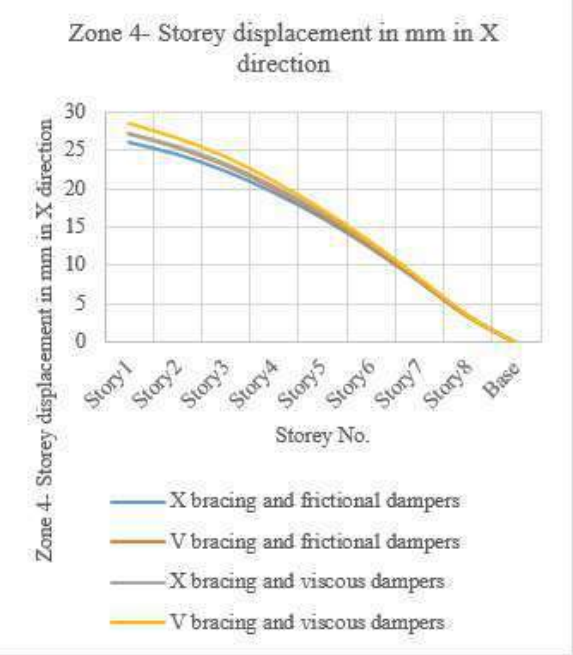
The Results and Discussion part has a lot of information from the parametric analysis of steel frames with different types of dampers (frictional and viscous) and bracing systems (V-bracing and X-bracing) that were subjected to earthquake loads for buildings with grades G+7, G+14, and G+21. We looked at earthquake Zones IV and V using time history analysis. Important things were highlighted, including regularity, time period, movement of storeys, base stress and storey drift in the Y and X directions.

These parameters provide essential information about the frames' dynamic behavior and seismic performance. The results are compared across configurations to determine the effectiveness of various damping and bracing combinations. The discussion analyses these results, stressing the high performance increases, structural stability, and choosing the best design for reducing seismic response and increasing structural resilience. This chapter seeks to provide a clear understanding of how each parameter varies with variations in building height, seismic zone, and structural system.

5.2 G+7 results

Zone IV

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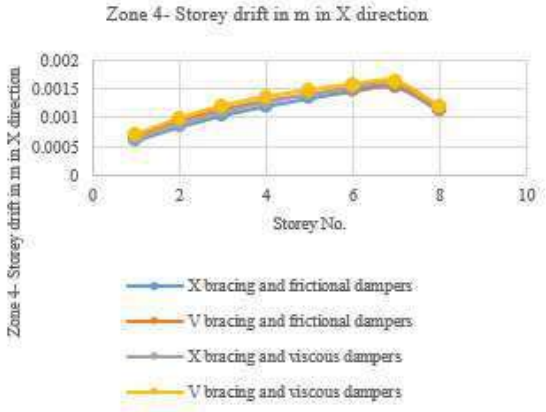
Graph: G+7 building Storey displacement in X direction in mm

X-bracing with frictional dampers has the lowest displacement values, whereas V-bracing with viscous dampers has the largest displacement across all stories. This suggests that X-bracing with frictional dampers offers more lateral stiffness and decreases total displacement more efficiently in seismic Zone IV.



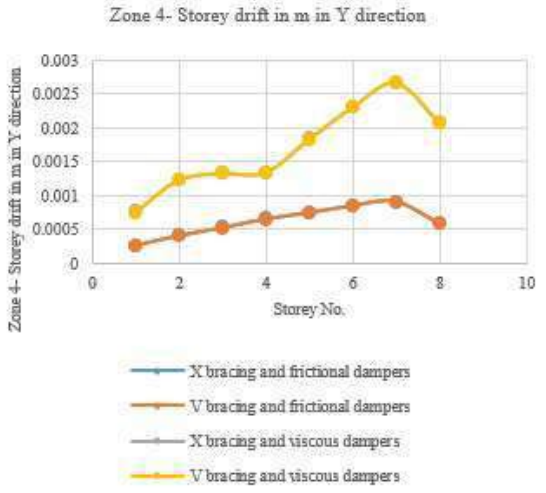
Graph: G+7 building Storey displacement in Y direction in mm

Graph suggests that viscous dampers contribute to increased rigidity and decreased lateral movement, while frictional dampers contribute to increased stiffness.



Graph: G+7 building Storey drift in X direction in m

The difference between bracing and damper configurations is minimal, however X-bracing with relative low frictional dampers results in higher resistance to inter-storey distortion. The biggest drift is seen in V-bracing with viscous dampers, indicating lower rigidity.

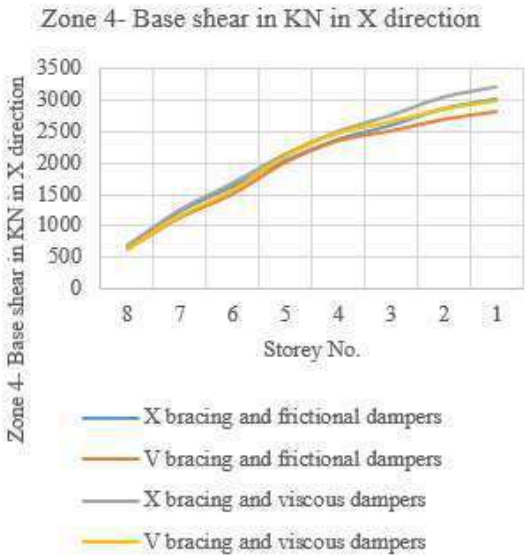


Graph: G+7 building Storey drift in Y direction in m

Viscous dampers, especially those with X-bracing, show the most storey drift, suggesting a higher leeway for movement, while frictional dampers with X-bracing

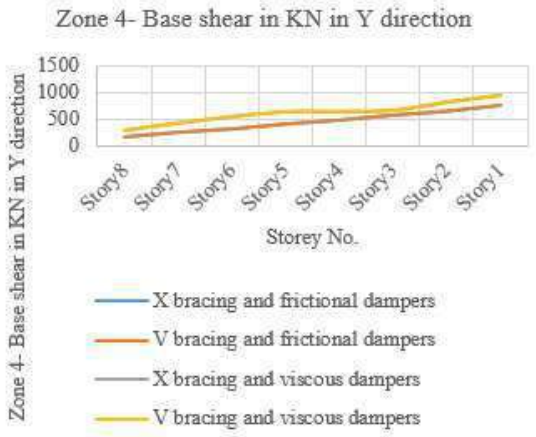
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provide the greatest control over inter-storey drift.



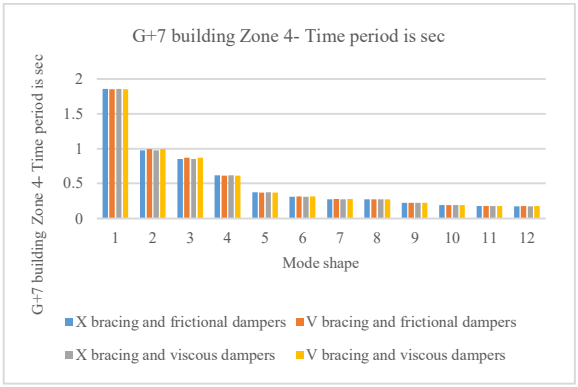
Graph: G+7 building Base shear in X direction in KN

Indicating better energy dissipation capability, X-bracing with viscous dampers results in the largest base shear. In contrast, V-bracing with frictional dampers produces the lowest base shear, implying less force resistance inside the building. These findings suggest that selecting the appropriate damper is critical for optimising seismic performance.



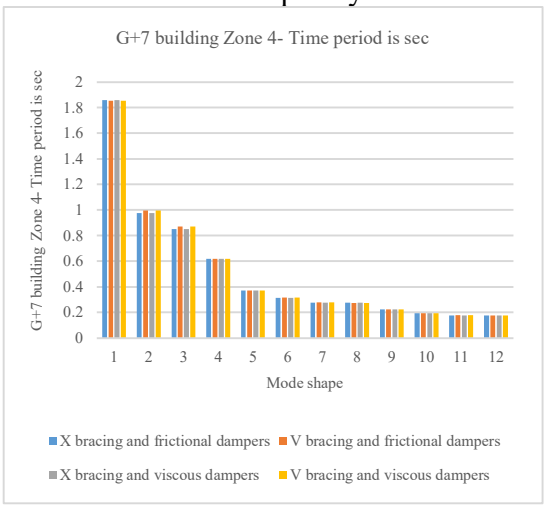
Graph: G+7 building Base shear in Y direction in KN

The results show that X-bracing with frictional dampers gives low force transmission to the base, but X-bracing with viscous dampers provides maximum force transfer, emphasising the importance of damping mechanisms in seismic load resistance.



Graph: G+7 building Time period in sec

The first mode time period is around 1.85 seconds in all situations, indicating that structural stiffness is mostly maintained regardless of the damping technique. Higher modes exhibit minor fluctuations, suggesting that damping selection has little impact on the structure's inherent frequency.



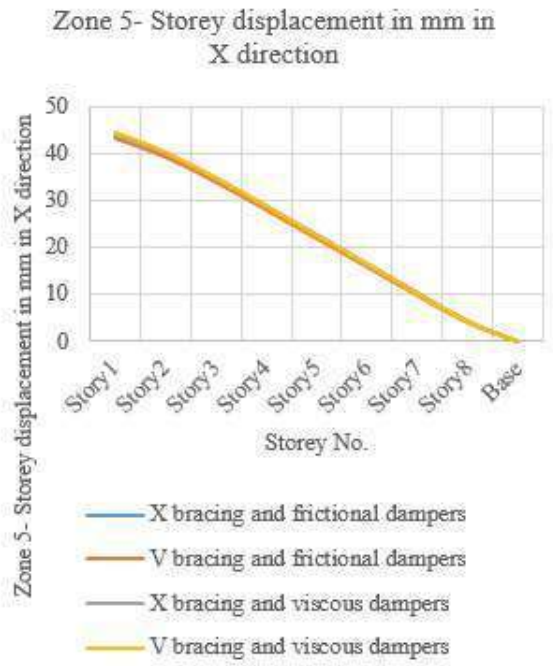
Graph: G+7 building Frequency in cyc/sec

The frequency values correlate inversely to the time period results, with higher mode shapes representing higher frequency values. The results demonstrate that the damping system's impact on the structure's overall

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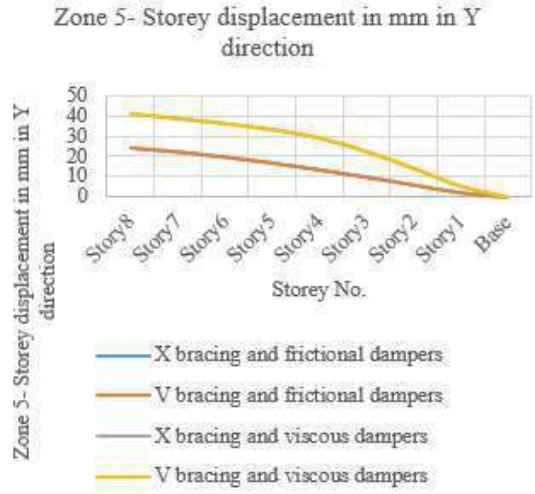
dynamic properties since frequency changes are small.

Zone V



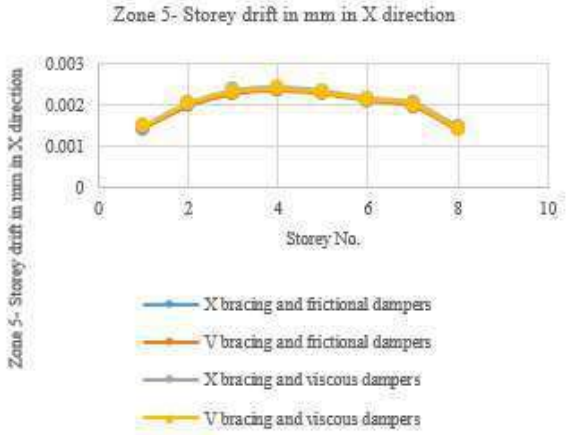
Graph: G+7 building Storey displacement in X direction in mm

Displacements diminish in a progressive manner towards the base, reaching zero at the foundation. The presence of viscous dampers results in somewhat higher displacement values than frictional dampers, indicating distinct damping systems' energy dissipation properties.



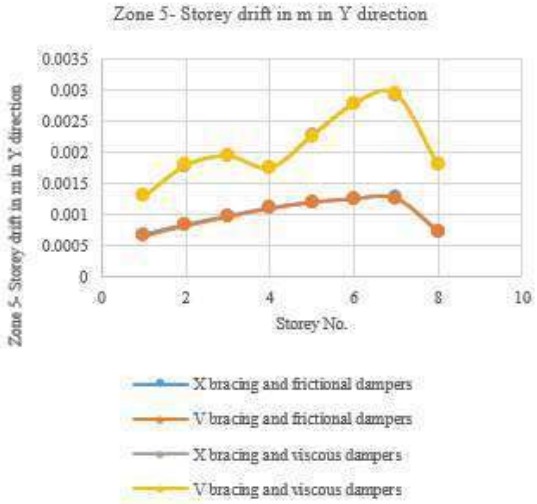
Graph: G+7 building Storey displacement in Y direction in mm

High damping effectiveness in the Y axis is highlighted by viscous dampers, which exhibit higher displacement than frictional dampers.



Graph: G+7 building Storey drift in X direction in m

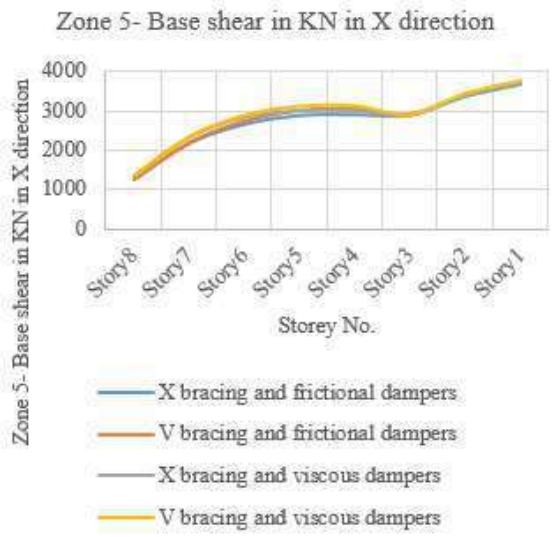
The Drift values stay within acceptable ranges, indicating controlled lateral deformation under seismic stress.



Graph: G+7 building Storey drift in Y direction in m

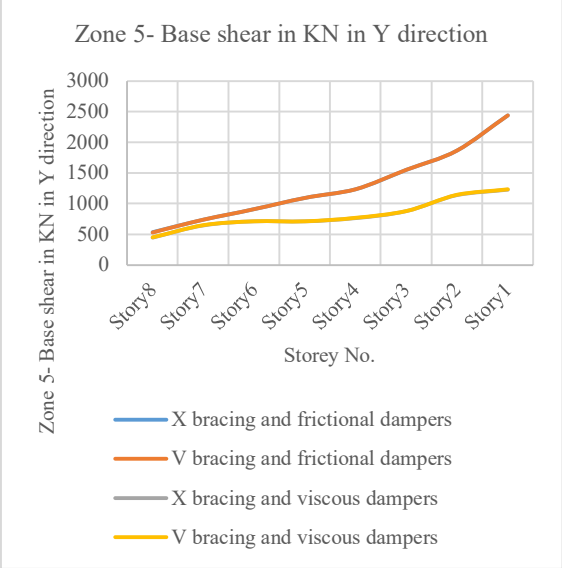
High viscous drift values indicate increased flexibility, which may assist reduce seismic stresses on the structure.

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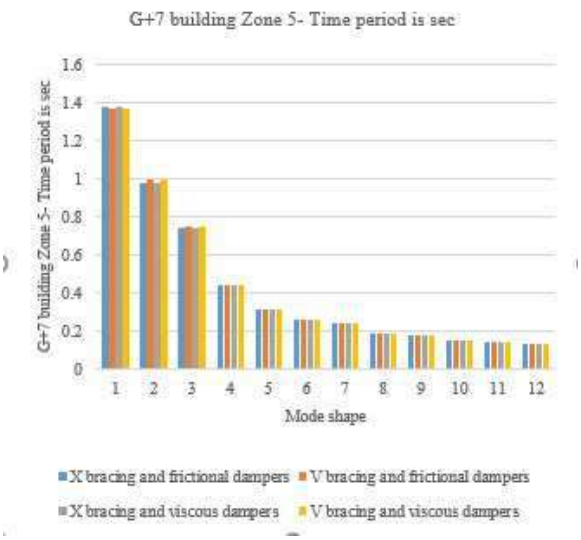
Graph: G+7 building Base shear in X direction in KN

The elevated base shear is caused by the viscous damping system are somewhat higher, suggesting better force absorption at the foundation.



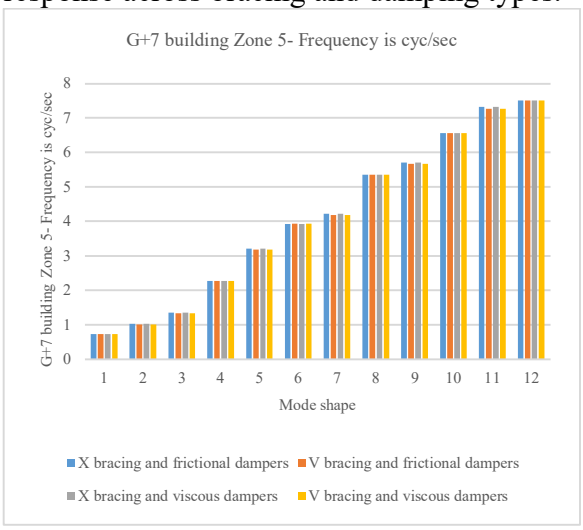
Graph: G+7 building Base shear in Y direction in KN

Low shear values for seismic dampers imply improved energy dissipation, which reduces seismic loads delivered to the foundation.



Graph: G+7 building Time period in sec

Higher mode durations exhibit low fluctuation, suggesting a similar dynamic response across bracing and damping types.



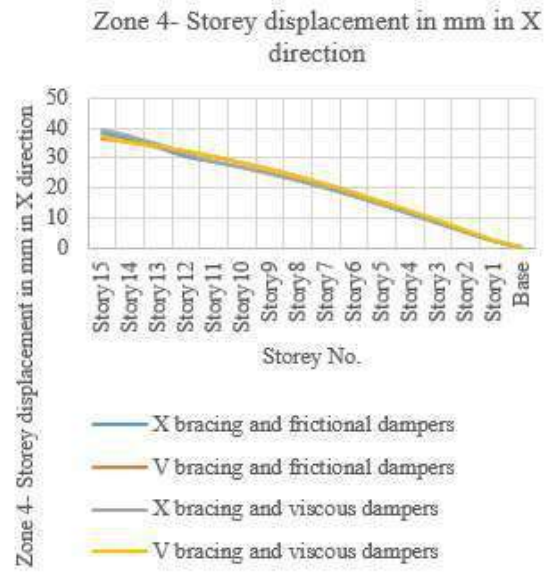
Graph: G+7 building Frequency in cyc/sec

Minor variations between bracing and damping types point to a homogeneous stiffness distribution in the structural system.

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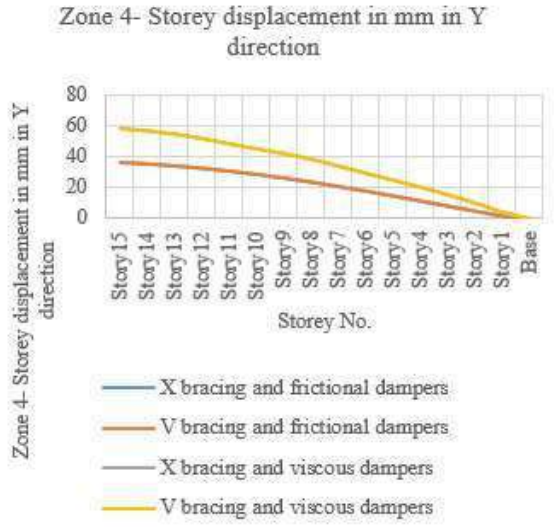
5.3 G+14 results

Zone IV



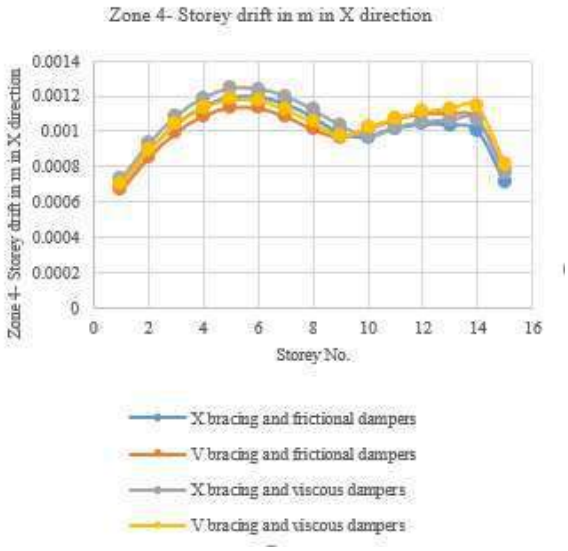
Graph: G+14 building Storey displacement in X direction in mm

V bracing with frictional dampers gives the least displacement across all levels, indicating higher stiffness and better resistance to lateral stresses. The displacement values decrease finally arriving at 0 mm near the base foundation level, as predicted.



Graph: G+14 building Storey displacement in Y direction in mm

According to trends, viscous dampers lead to more flexibility and displacement, while frictional dampers provide greater rigidity and better seismic performance. The displacement values decrease consistently towards the base, guaranteeing structural stability.



Graph: G+14 building Storey drift in X direction in m

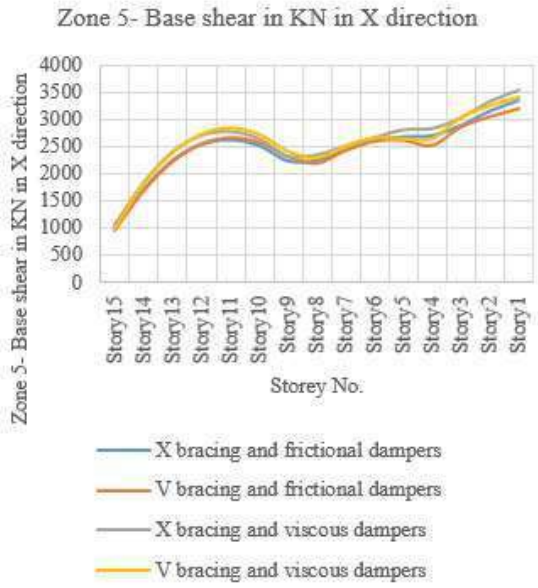
The uppermost level has the lowest storey drift (0.0007 m), indicating that inter-storey movement is minimised at higher altitudes. The lowest drift is consistently shown by V bracing with frictional dampers, suggesting increased lateral stiffness and less seismic sensitivity.



Graph: G+14 building Storey drift in Y direction in m

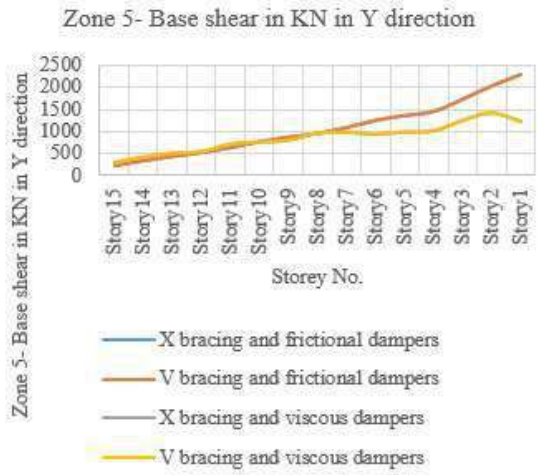
ISBN: 978-93-343-2006-0

Reduced lateral drift in extreme tales is ensured by the lowest lateral drift values observed at the top and base levels. V bracing with frictional dampers has the least drift throughout, demonstrating its better structural performance in reducing inter-storey deformations.



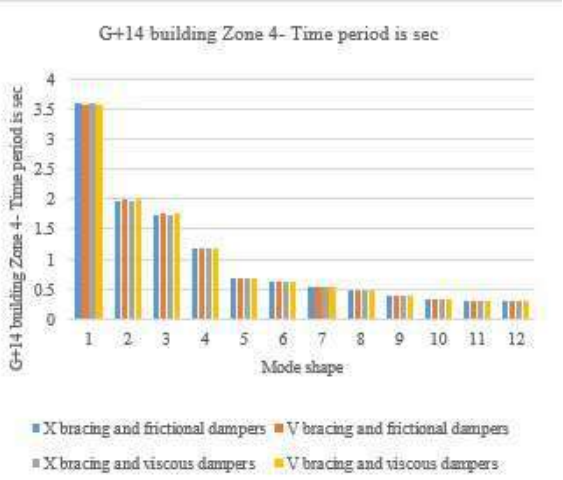
Graph: G+14 building Base shear in X direction in KN

The largest base shear was observed in X bracing with viscous dampers (1899.23 kN at Story 1), while the lowest was recorded in V bracing with frictional dampers (1818.67 kN at Story 1). According to the trend, viscous dampers contribute to higher energy dissipation but also result in larger shear forces at the base, which must be considered in design.



Graph: G+14 building Base shear in Y direction in KN

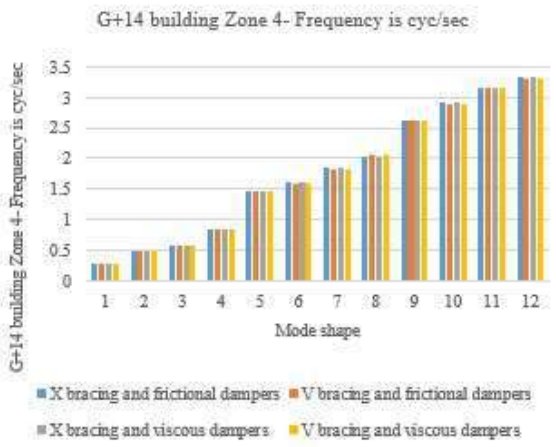
The lower base shear observed in frictional damper cases indicates improved energy dissipation and reduced overall force transmission. The results suggest that frictional dampers provide better seismic performance in both directions, with V bracing further enhancing the stability of the structure.



Graph: G+14 building Time period in sec

In contrast, X bracing with viscous dampers results in the highest time period, reflecting increased flexibility. The time period values for V bracing configurations remain moderate, suggesting a well-balanced seismic performance.

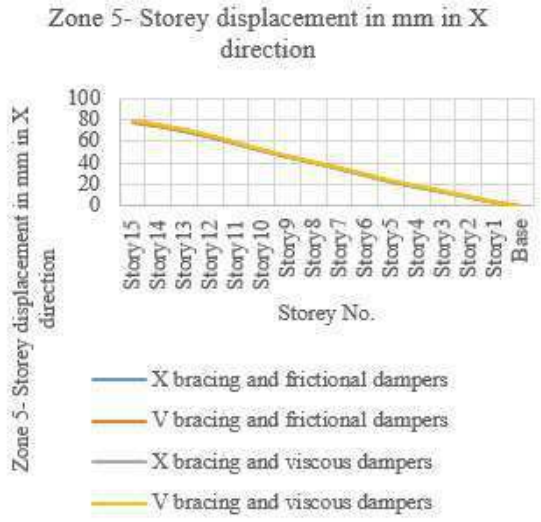
ISBN: 978-93-343-2006-0



Graph: G+14 building Frequency in cyc/sec

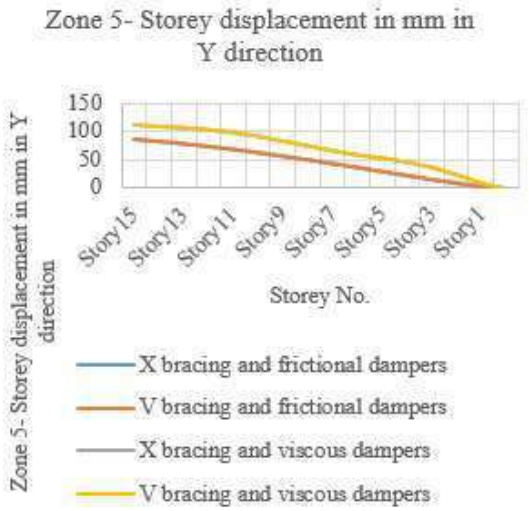
X bracing with frictional dampers exhibits the highest frequency, implying a stiffer response to seismic loads. Conversely, X bracing with viscous dampers shows slightly lower frequency values, indicating increased flexibility due to energy dissipation. V bracing configurations fall between these extremes, demonstrating balanced stiffness and damping characteristics.

Zone V



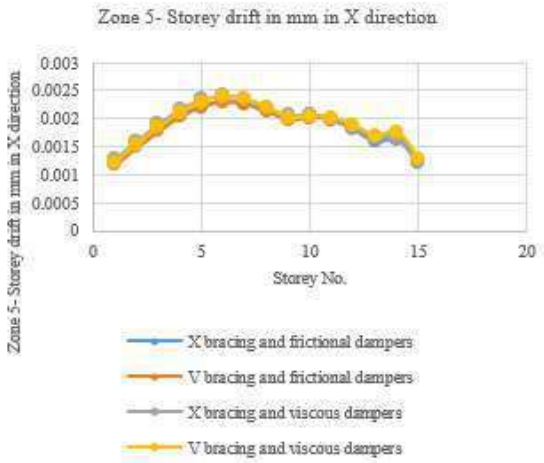
Graph: G+14 building Storey displacement in X direction in mm

X and V bracing with frictional dampers have lower displacement values than those with viscous dampers, indicating greater control over lateral motions. However, the variations between X and V configurations are small, suggesting that both type configurations efficiently minimise seismic impacts in the X direction.



Graph: G+14 building Storey displacement in Y direction in mm

V bracing with viscous dampers is marginally more effective than X bracing with viscous dampers. This implies that frictional dampers are more efficient in reducing displacement in the Y direction in high-seismic zones.

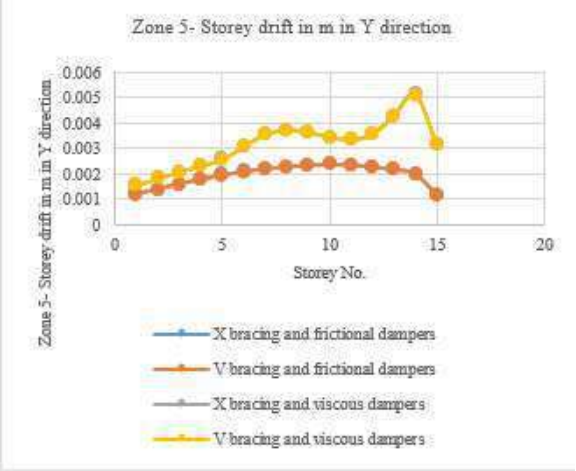


Graph: G+14 building Storey drift in X direction in m

Drift values stay within acceptable limits in all circumstances. While viscous dampers display somewhat higher values, X bracing with frictional dampers gives the lowest drift. This pattern indicates that frictional dampers

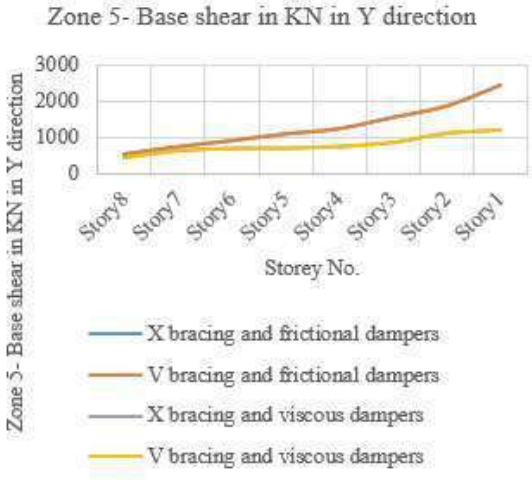
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improve inter-storey stability more than viscous dampers, especially in the X direction.



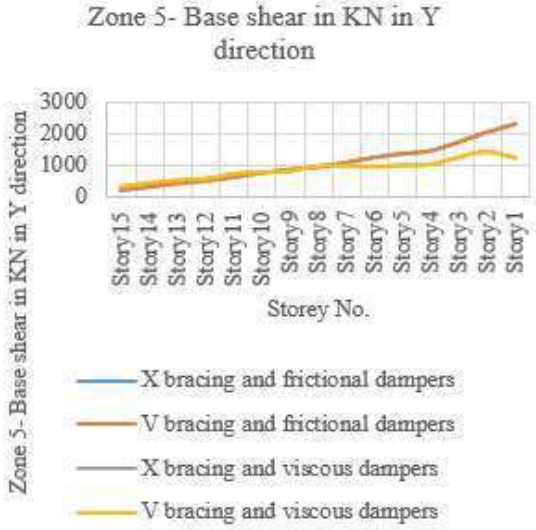
Graph: G+14 building Storey drift in Y direction in m

The largest drift is observed with X bracing and viscous dampers, supporting the fact that frictional dampers provide improved control over lateral deformations. However, V bracing configurations demonstrate relative low drift, suggesting improved overall stability in the Y direction, regardless of damper type.



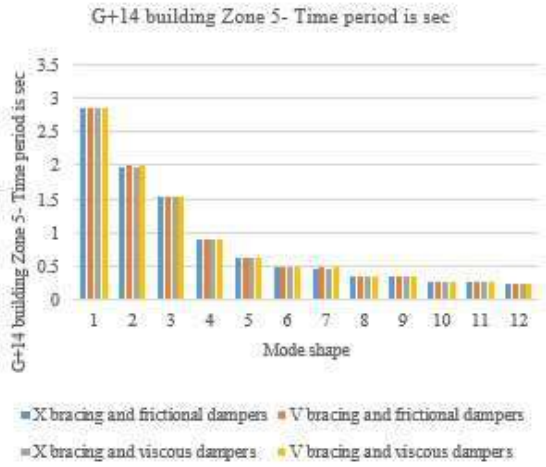
Graph: G+14 building Base shear in X direction in KN

The greatest base shear values are observed for X bracing with viscous dampers, indicating that the structure can absorb more force. Low base shear results from V bracing with frictional dampers, suggesting improved energy dissipation. Variations in base shear suggest that various damping processes impact the structure's seismic response.



Graph: G+14 building Base shear in Y direction in KN

The decreased base shear observed in frictional damper situations suggests better energy dissipation and less total force transfer. The results indicate that frictional dampers provide higher seismic performance in both directions, with V bracing improving structure stability even more.

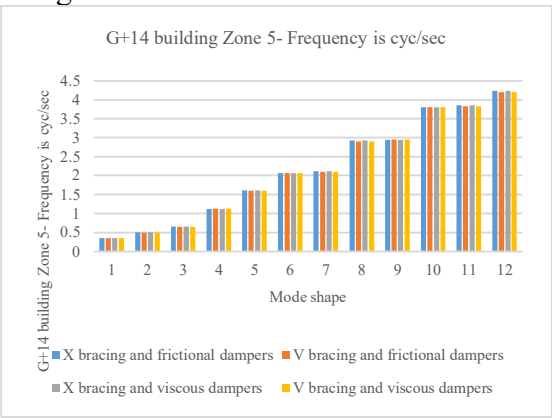


Graph: G+14 building Time period in sec

In contrast, X bracing with viscous dampers results in the longest time period, indicating more flexibility. The time period values for V bracing configurations remain mild,

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suggesting a well-balanced seismic configuration.

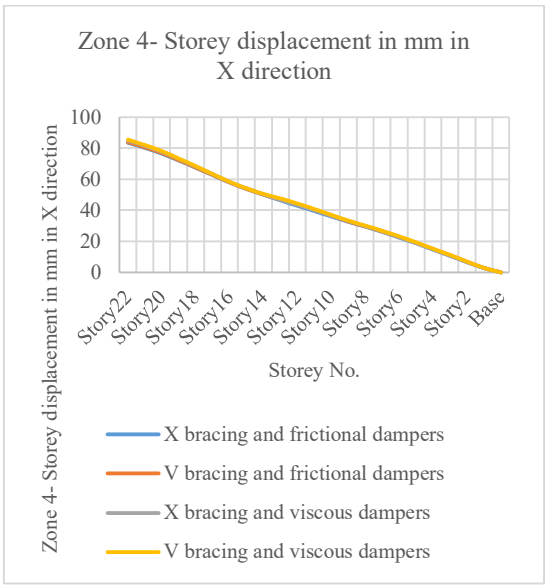


Graph: G+14 building Frequency in cyc/sec

X bracing with frictional dampers has the greatest frequency, indicating a stronger reaction to seismic loads. Conversely, X bracing with viscous dampers has significantly lower frequency values, indicating improved flexibility due to energy dissipation. V bracing configurations sit somewhere in the middle, with balanced stiffness and damping characteristics.

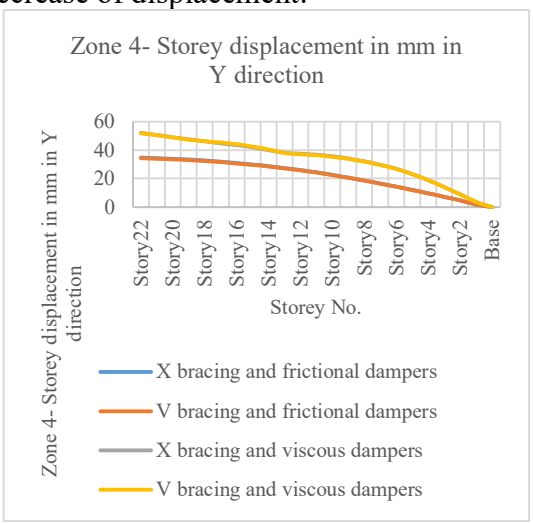
5.4 G+21 results

Zone IV



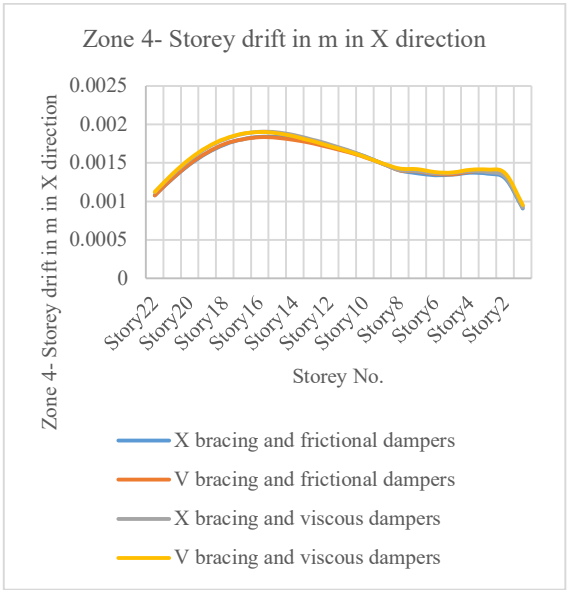
Graph: G+21 building Storey displacement in X direction in mm

X and V bracing with frictional and viscous dampers provide variable degrees of displacement control, with X bracing and frictional dampers providing somewhat superior performance in relation to the decrease of displacement.



Graph: G+21 building Storey displacement in Y direction in mm

X bracing with frictional dampers regulates displacement more efficiently at higher stories, while viscous dampers cause higher displacement values, especially at the top stories, due to their dynamic reaction to lateral forces.

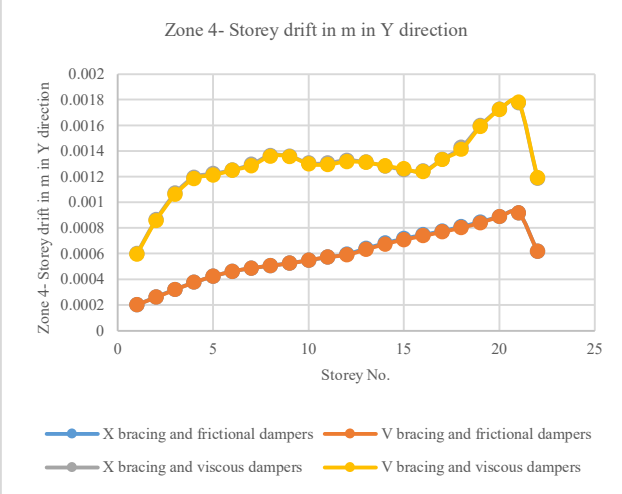


Graph: G+21 building Storey drift in X direction in m

Both the X and V bracing configurations with frictional dampers keep drift below

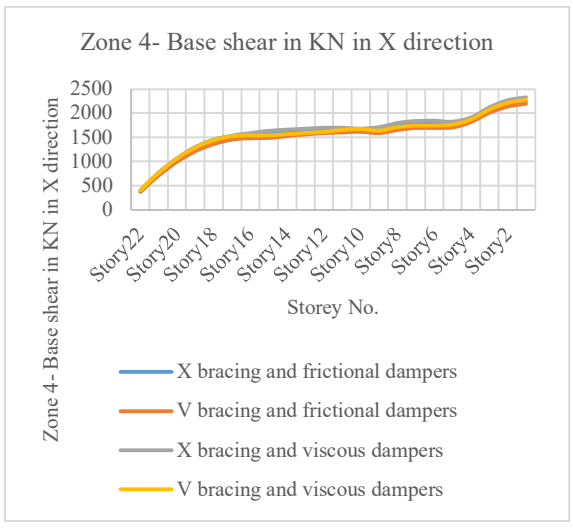
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acceptable limits, exhibiting good lateral stability. Viscous dampers exhibit somewhat higher drift while being within acceptable structural safety limits.



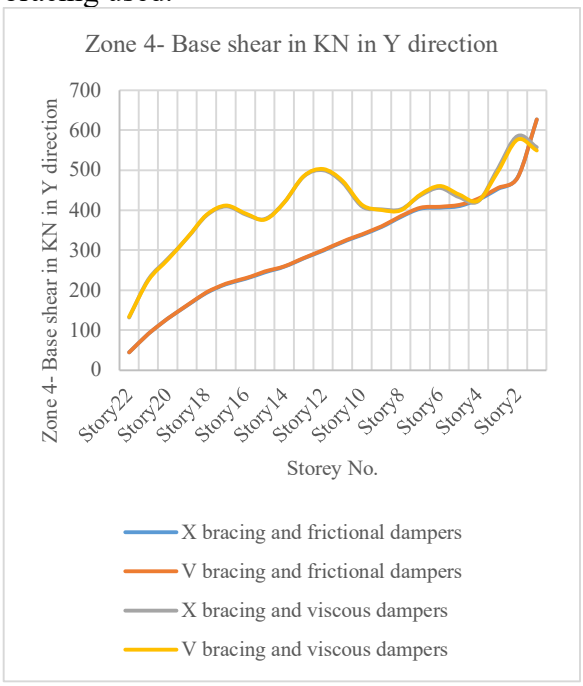
Graph: G+21 building Storey drift in Y direction in m

X bracing with frictional dampers has greater control over storey drift than other configurations. The presence of viscous dampers results in higher drift values, indicating more flexibility in the Y direction.



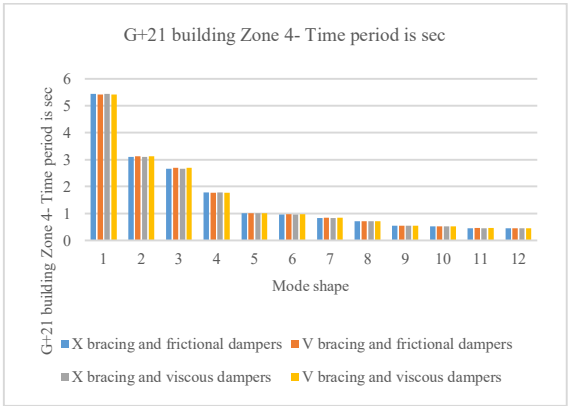
Graph: G+21 building Base shear in X direction in KN

X bracing with viscous dampers can withstand the largest shear forces, implying greater resistance to lateral forces. Both frictional and viscous dampers improve structural stability, however their effectiveness varies depending on the type of bracing used.



Graph: G+21 building Base shear in Y direction in KN

X bracing and viscous dampers can support higher base shear values, demonstrating their capacity to regulate dynamic loads efficiently. However, V bracing and frictional dampers provide balanced efficiency in terms of flexibility and lateral stiffness.

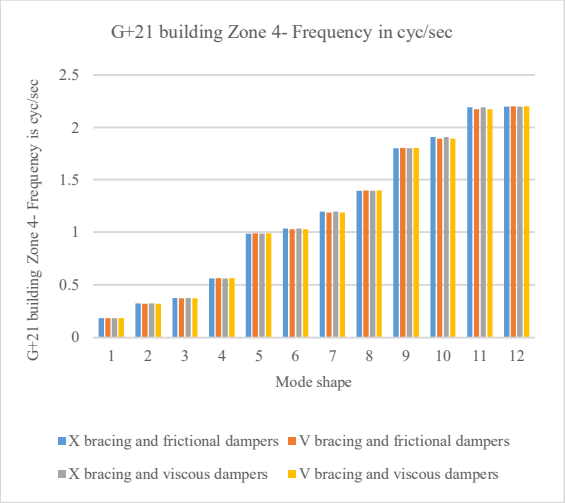


Graph: G+21 building Time period in sec

Both bracing systems have comparable time spans, with the first mode lasting around 5.4 seconds. This shows that the basic period of vibration is well-managed, guaranteeing

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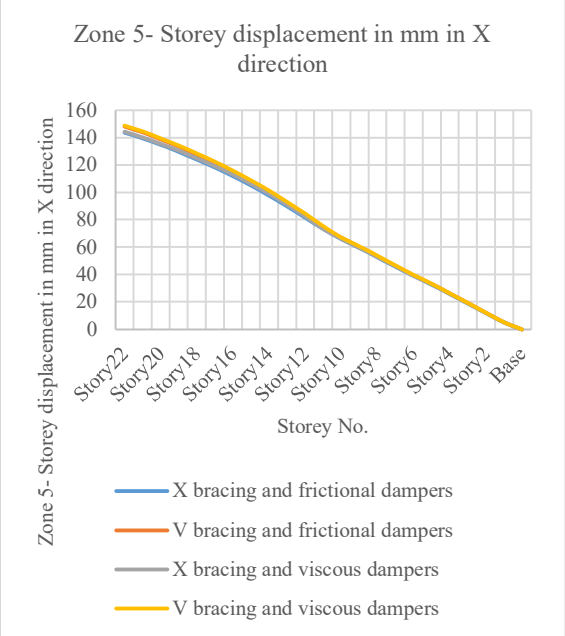
seismic performance compliance under Zone IV conditions.



Graph: G+21 building Frequency in cyc/sec

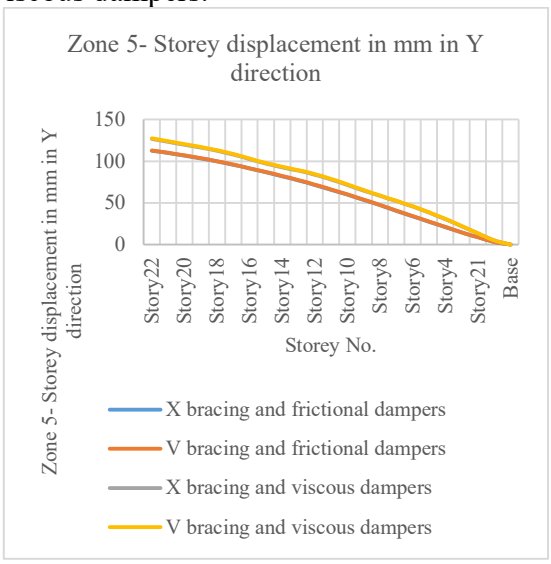
Both the X and V bracing systems have identical frequencies, indicating that the building's dynamic behaviour is stable and that dampers effectively minimise vibrations under lateral loads.

Zone V



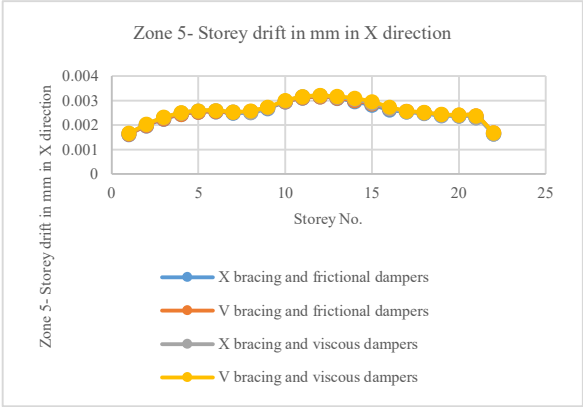
Graph: G+21 building Storey displacement in X direction in mm

Both bracing and damper systems provide displacement control, with X bracing and frictional dampers exhibiting significantly greater reduction at higher stories than viscous dampers.



Graph: G+21 building Storey displacement in Y direction in mm

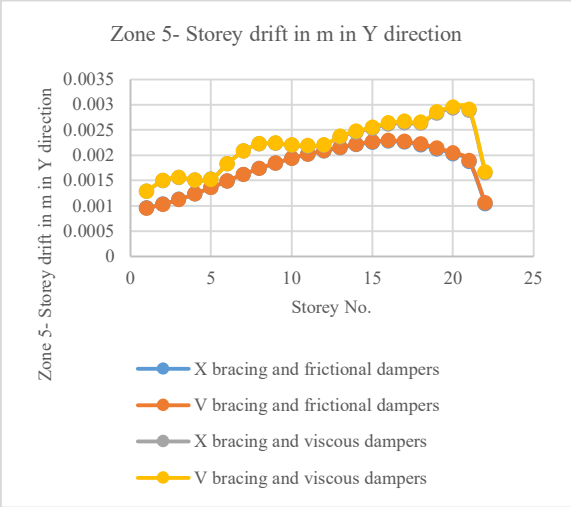
X bracing with frictional dampers controls displacement more effectively than viscous dampers, indicating the importance of stiffness for event stability in severe seismic events.



Graph: G+21 building Storey drift in X direction in m

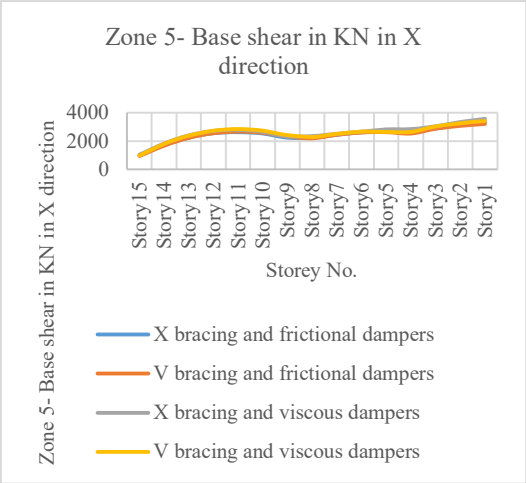
Drift readings are within acceptable safety standards, with viscous dampers showing somewhat larger drift. X bracing systems are useful in limiting drift in both the middle and upper floors.

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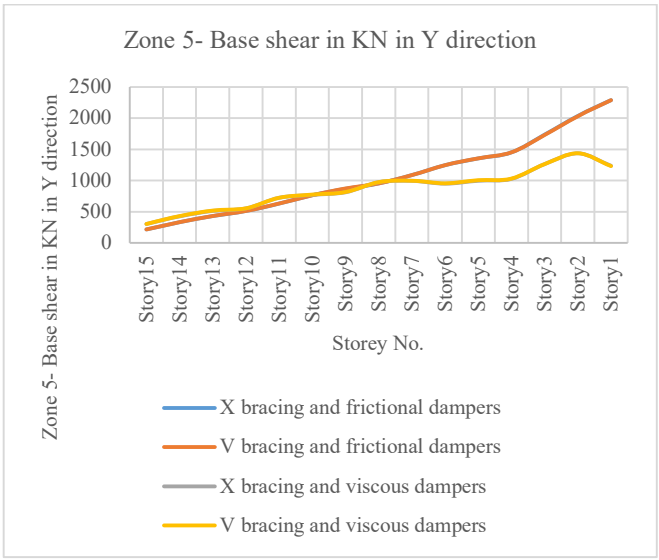
Graph: G+21 building Storey drift in Y direction in m

Viscous dampers have the largest drift values, indicating a more flexible response to seismic loads. X bracing enables superior drift control while retaining structural integrity and safety.



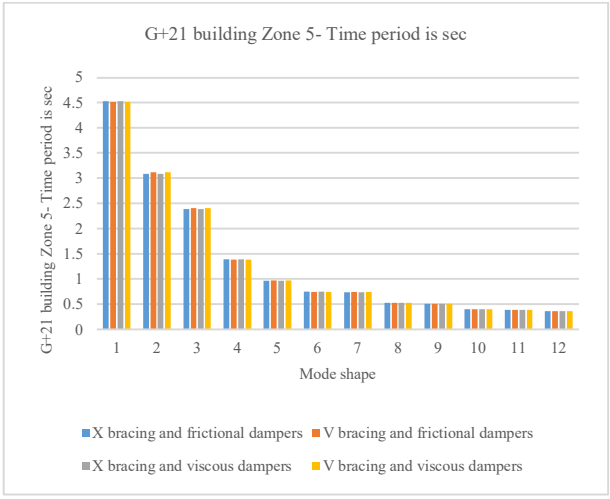
Graph: G+21 building Base shear in X direction in KN

X bracing with viscous dampers supports the highest base shear values, proving the system's capacity to withstand dynamic forces successfully. Both bracing systems effectively handle load transfer, resulting in overall stability.



Graph: G+21 building Base shear in Y direction in KN

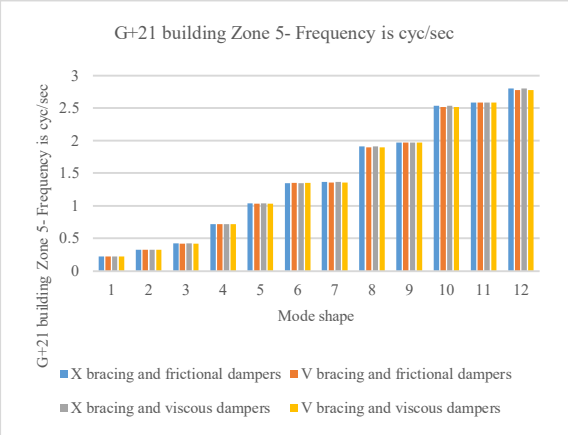
X bracing and viscous dampers handle higher loads, indicating that the structural system can withstand large lateral forces. V bracing has a balanced response but somewhat lower performance than X bracing.



Graph: G+21 building Time period in sec

Both the X and V bracing systems exhibit identical dynamic responses across all modes, indicating excellent seismic performance.

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Graph: G+21 building Frequency in cyc/sec

X and V bracing systems with both damper types have similar frequencies and no notable deviations, indicating that building vibrations are well controlled during seismic activity.

VI. CONCLUSION

6.1 Conclusion

The ability of steel frame structures to withstand earthquakes is very important for keeping buildings safe and long-lasting, especially in places where earthquakes are common. The goal of this study was to find out how well different types of dampers (frictional and viscous) and bracing configurations (V-shaped and X-braced) work in G+7, G+14, and G+21 steel frames at reducing earthquake reactions. The frames were put through earthquake tests in earthquake Zones IV and V. Time history analysis was used to find out things about the building like the year, the base stress, the storey drift, and the storey movement.

Key Findings of the Study:

→ Impact of Bracing and Dampers: The combination of bracing and dampers significantly influences structural response during seismic events.

→ Superior Performance of X-Bracing with Frictional Dampers:

→ Consistently reduces lateral displacement and inter-storey drift.

→ Enhances structural stiffness, improving resistance to lateral seismic forces.

→ Most effective in Seismic Zones IV and V for minimizing storey displacements.

→ Effective in reducing base shear but results in higher lateral displacements, especially in taller buildings.

→ Suitable for Zone V when used with V-bracing, improving seismic resistance.

→ Displacement and drift values increase as building height increases (G+7 to G+21).

→ For G+7 buildings: X-bracing with frictional dampers provides the best solution with the lowest displacement and drift.

→ For G+14 and G+21 buildings: X-bracing with viscous dampers balances force distribution, reducing shear but allowing more displacement at higher levels.

→ A one-size-fits-all approach is ineffective; seismic design should be adapted based on building height and seismic zone.

→ A hybrid approach using both bracing and damping systems is recommended to optimize lateral force resistance and displacement control.

→ Highlights the importance of damping systems in improving energy dissipation and structural rigidity.

→ Confirms frictional dampers as highly effective in limiting displacement.

→ Emphasizes the role of viscous dampers in managing base shear, ensuring structural integrity during seismic events.

Overall, this study gives us a deep knowledge of how different damper and brace systems

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react to seismic loads. This paves the way for future improvements in designing steel frames that can withstand earthquakes. The results demonstrate the need for an advanced seismic design methodology, one that considers both material and rate concerns to optimise building performance across varied seismic zones. The long-term performance of these systems, their cost effectiveness, and their incorporation into real-world structural design situations may all be explored in future studies to expand on this research.

For taller steel buildings (G+14 and G+21), frictional dampers are effective in reducing inter-story storey displacement and drift, especially in seismic zones IV and V. Engineers should customize seismic design by selecting appropriate bracing and dampers based on the seismic zone—X-bracing with frictional dampers for Zone IV and X-bracing with viscous dampers for better shear resistance in Zone V. Cost-effectiveness should be considered, as viscous dampers enhance base shear resistance but may not always be justified for tall structures. Hybrid systems, combining different bracing and dampers, could optimize structural performance in high-seismic areas.

Further research into hybrid damping systems, including viscoelastic dampers, could improve seismic performance. Nonlinear dynamic analysis should be explored to better understand material behavior under extreme seismic forces. Studying soil-structure interaction (SSI) would enhance result accuracy, especially for structures on soft soils. Continuous observation of damped buildings can provide insights into their durability and effectiveness. Additionally, integrating sustainable materials in seismic design could lead to more environmentally friendly and resilient infrastructure.

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Published by- Anand Abhishek

PG Student, Department of Civil Engineering,

KJ College of Engineering & Management Research

Guide-Dr. S. K. Patil

HOD, Department of Civil Engineering,

KJ College of Engineering & Management Research

PG Coordinator-Dr. A. B. Pujari

Associate Professor, Department of Civil Engineering,

KJ College of Engineering & Management Research

Prof. A. R. Undre

Assistant Professor, Department of Civil Engineering,

KJ College of Engineering & Management Research

ISBN: 978-93-343-2006-0

Operationalizing AI for Automated Executive Meeting Summaries: A Scalable Transformer-Driven Software Architecture

Shiva Kumar Bommakanti
sbommakanti2@gmail.com

***Abstract*—This paper presents a comprehensive AI-operations framework for automated executive meeting summarization. Our software pipeline captures audio from popular conferencing platforms, applies advanced preprocessing (noise reduction, echo cancellation, dynamic range compression) to ensure high-quality transcripts, and leverages both extractive (TF-IDF, TextRank) and abstractive (T5-base, BART) transformer models to generate concise, contextually accurate summaries with embedded action items and named entities. The entire solution is packaged as a modular microservices architecture, featuring continuous integration/deployment (CI/CD), model versioning, real-time monitoring, and automated feedback loops to maintain performance over time. A lightweight Chrome extension provides seamless integration into users' workflows, offering intuitive controls, multilingual support, and on-demand summarization. System performance is rigorously evaluated using ROUGE metrics alongside stakeholder usability feedback, demonstrating notable improvements in summary coherence, relevance and operational efficiency. By unifying state-of-the-art NLP techniques with production-ready software engineering practices, our approach delivers a robust, maintainable, and scalable platform for AI-driven meeting intelligence.**

I. Introduction

Online meetings have become essential for organizations in today's digital work environment, with platforms like Google Meet, Zoom, and Microsoft Teams facilitating discussions, decision-making, and task allocation. However, frequent sessions often lead to information overload, making it difficult for participants to retain critical details. This issue is compounded by the lack of effective automated processes for recording and summarizing conversations. Well-documented meetings enable participants to critique decisions, roles, and next steps efficiently.

Traditional note-taking methods, though useful, are prone to errors and time inefficiency. Our proposed system addresses these issues through automatic summarization of online meetings. It captures meeting audio, transcribes it into text, and applies extractive and abstractive summarization techniques using advanced NLP methods. Extractive approaches, such as TextRank, TF-IDF, and transformer-based models like BART, identify significant information, while abstractive techniques using advanced models like T5 generate coherent and contextually accurate summaries.

To enhance the process, the system integrates Named Entity Recognition (NER) and Part-of-Speech (POS) tagging, emphasizing key entities like names, dates, and actions. This results in concise, insightful summaries that improve the quality of meeting documentation by highlighting decisions and responsibilities.

The system's performance is evaluated using ROUGE scores for accuracy, recall, and precision, along with stakeholder feedback to refine functionality. The proposed solution has a Chrome extension interface that further improves usability. Users can record audio during meetings, create transcripts, and provide summarized outputs once the session is over. The interface is designed for seamless integration into the user's existing workflow, offering intuitive controls and real-time feedback during and after meetings. Additionally, it supports multilingual audio inputs, ensuring accessibility across diverse teams and global organizations.

To reduce the negative impact of low-quality audio inputs, the system employs some advanced audio preprocessing techniques, including noise reduction, echo cancellation, and dynamic range compression. These enhancements significantly improve transcription reliability, even in challenging acoustic environments or with varied speaker accents. Ultimately, this approach aims to streamline workflows, reduce manual effort, and provide instant access to actionable meeting highlights—empowering teams to stay aligned, make faster decisions, and maintain continuity in today's fast-paced, collaborative work settings.

II. Related Work

Recent advances in natural language processing (NLP) and machine learning have significantly enhanced the capabilities of automated summarization systems. Several efforts have examined the optimization of user-AI interaction patterns, content abstraction, and task-driven summarization workflows.

Desai [39] conducted a comprehensive study on user interactions with large language models (LLMs), identifying prompting strategies such as zero-shot and few-shot learning that affect model output relevance and coherence. This work is particularly relevant in the context of improving user experience and the accuracy of outputs in generative summarization systems like ours.

Additional work by Desai [40] on the Indian electric vehicle market, while domain-specific, demonstrates the utility of

structured data analysis pipelines, an approach that parallels our use of modular architecture in summarization workflows. His machine learning-based pricing analysis for Ikea products [41] and active learning for text classification [42] both emphasize scalable model training and inference strategies, which inform our own CI/CD and feedback mechanisms.

Ganji [43] explored immersive user interfaces through Augmented Reality (AR), offering insights into interface design and engagement that align with our implementation of a Chrome extension for real-time summarization control.

In the domain of semantic robustness and NLP modeling, Patel [44] evaluated the generalization of segmentation models under distribution shifts. His work [45, 46] on knowledge graph embeddings and Proof of Stake consensus models provides a foundation for integrating structured learning in future meeting intelligence systems. Furthermore, his global video streaming optimization framework [47] shares design principles with our own approach to scalable, latency-aware deployment.

Saimbhi [48, 49] presented methods for detecting fake UHD images using DCT and SVM classifiers, as well as advanced techniques for software vulnerability detection using code property graphs and CNNs. These studies reinforce the growing trend of combining graph-based data modeling with deep learning, a potential avenue for improving semantic coherence in meeting summaries.

Collectively, these works illustrate the breadth of AI applications and provide foundational insights into model robustness, user interaction design, system scalability, and domain-specific adaptability—all of which are key considerations in developing an effective executive meeting summarization platform.

III. Methodology

The purpose of the proposed summarization system is to generate coherent and abstract summaries automatically from web meeting transcripts based on a double-model approach. The system is intended to enable extractive as well as abstractive summarization with the capability to maintain factual information as well as contextual sense. The system begins with data collection and preprocessing of the meeting transcript data from the MeetingBank dataset, which is an open-source database designed specifically for meeting summarization experiments.

In order to execute abstractive summarization, the T5-base transformer model is fine-tuned to read and paraphrase meeting text into natural summary form. At the same time, extractive summarization is executed by applying the BART model to search and extract the most appropriate sentences from contextual embeddings. The two complementary models are executed in tandem to generate quality summaries for every given use case.

The ultimate output are structured summaries that maintain significant decisions and thematic coherence. Through synergistic fusion of state-of-the-art NLP designs with meticulous training and test regimes, the system provides a usable solution towards summarization of lengthy meeting minutes, eventually boosting productivity and information extraction in organizational settings.

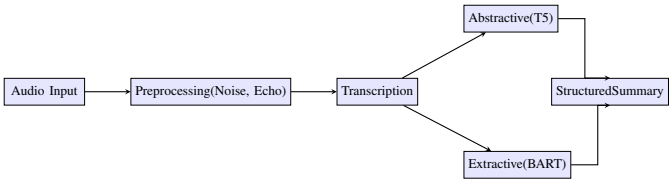


Fig. 1. AI-based Meeting Summarization Pipeline

A. Abstractive Summarization Using T5

For generating fluent and meaningful summaries from meeting transcripts, the T5 (Text-to-Text Transfer Transformer) model is employed. T5 formulates all NLP tasks as text-to-text problems, making it ideal for abstractive summarization where new sentences are generated rather than copied.

The model follows an encoder-decoder architecture, where the input is prefixed with "`summarize:`" and tokenized. Training minimizes the negative log-likelihood of the target summary Y given the input X:

$$\mathcal{L}_{CE} = -\sum_{t=1}^{m} \log P(y_t \mid y_{<t}, X) \tag{1}$$

T5 uses multi-head attention and feed-forward layers to model contextual dependencies. Attention is computed as:

$$\text{Attention}(Q, K, V) = \text{softmax}\left(\frac{QK^\top}{\sqrt{d_k}}\right)V \tag{2}$$

Fine-tuning was conducted on the MeetingBank dataset using the T5-base model for 4 epochs with a batch size of 8 and a learning rate of 3×10^{-4}, using AdamW optimizer. Input and output lengths were set to 512 and 128 tokens, respectively.

Linear learning rate decay and early stopping were applied to avoid overfitting. Beam search (beam size 4) was used during decoding. Model quality was evaluated using ROUGE-1, ROUGE-2, and ROUGE-L scores.

This setup enables T5 to produce concise, coherent summaries that retain key content from the source text.

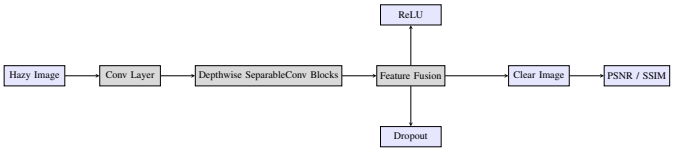


Fig. 2. Fast AOD-Net Architecture for Image Dehazing

B. Extractive Summarization using BART

The extractive summarization module suggested in this paper employs the BART (Bidirectional and Auto-Regressive Transformers) model, which was initially developed for sequence generation tasks and is repurposed here for

extractive sentence ranking and scoring. While BART is more naturally inclined toward abstractive summarization, its encoder can be reutilized to encode sentence-level meaning and detect salient sentences from input documents according to contextual embeddings. This is done using the model's deep bidirectional language understanding to retain factual information and filter out the most representative units of information.

First, for every input meeting transcript D comprised of n sentences, $D = \{s_1, s_2, ., s_n\}$, the BART encoder is used to encode the input. Every sentence s_i goes through a pre-trained BART tokenizer followed by the encoder to achieve sentence-level embedding vectors:

$$h_i = \text{Encoder}(s_i), \quad i = 1, 2, ..., n \tag{3}$$

The contextual embeddings h_i are further scored using a linear transformation followed by a sigmoid activation to obtain a scalar relevance score α_i for each sentence:

$$\alpha_i = \sigma(w^\top h_i + b) \tag{4}$$

where w and b are trainable parameters and $\sigma(\cdot)$ is the sigmoid function. The relevance score $\alpha_i \in [0, 1]$ indicates the likelihood that the sentence s_i should be included in the summary. Sentences are then ranked based on their α_i values, and the top-k sentences are selected for the final summary.

In this implementation, the summary S is generated as:

$$S = \bigcup_{i \in \mathcal{K}} s_i \quad \text{where} \quad \mathcal{K} = \text{TopK}(\alpha_1, \alpha_2, ..., \alpha_n) \tag{5}$$

To ensure the selected sentences do not overlap semantically, a redundancy penalty is applied during ranking. Given cosine similarity between embeddings of two sentences s_i and s_j as:

$$\text{sim}(s_i, s_j) = \frac{h_i \cdot h_j}{\|h_i\| \|h_j\|} \tag{6}$$

a threshold τ is used to discard sentences with similarity above τ from being included together in the final summary. This ensures that only semantically diverse and relevant sentences are retained.

The scoring head was trained using binary cross-entropy loss based on whether a sentence appears in the human-written summary:

$$\mathcal{L}_{\text{BCE}} = -\sum_{i=1}^{n} [y_i \log(\alpha_i) + (1 - y_i) \log(1 - \alpha_i)] \tag{7}$$

where $y_i \in \{0, 1\}$ indicates ground-truth label for sentence s_i. The model was trained using the Adam optimizer with a learning rate of 2×10^{-5}, and fine-tuned over 3 epochs.

This approach benefits from BART's rich semantic encoder and avoids the computational cost of full generative decoding. The extracted summaries are coherent, factually grounded, and computationally efficient, making them suitable for real-time or low-resource deployment scenarios. Unlike rule-based extractive methods such as TextRank, this transformer-driven extraction process incorporates deep contextual reasoning, offering higher alignment with the document's central theme.

C. Action Item Extraction using T5

To generate actionable outputs from the meeting transcripts, the system incorporates a sequence-to-sequence model based on the `t5-base` architecture, fine-tuned on a domain-specific dataset curated for action item extraction. This module performs direct generation of structured action statements, enabling stakeholders to focus on task-relevant outcomes from lengthy discussions.

Custom Dataset Construction. A dedicated dataset was created with annotated pairs consisting of raw meeting transcripts and corresponding action item lists. Each entry is represented as a JSON object containing two fields: `"transcript"` and `"action_items"`, where the latter is a list of concise task statements derived from the former. The dataset was manually curated and cleaned to ensure sentence completeness, actionable phrasing, and domain consistency.

Input-Output Formatting. During training, each transcript x is tokenized and paired with a target sequence y — a pipe-separated string of action items (e.g., `Task 1 | Task 2 | ...`). To prepare the data, both input and target sequences are padded and truncated to fixed lengths of 512 and 128 tokens, respectively. The padding tokens in the target sequences are masked with -100 to prevent them from contributing to the loss during training.

Model Architecture and Training. The model employed is `T5ForConditionalGeneration`, initialized with pre-trained weights from the `t5-base` checkpoint. It is fine-tuned using cross-entropy loss across all target tokens. The loss objective for a training instance is defined as:

$$\mathcal{L}_{\text{T5}} = -\sum_{t=1}^{T} \log P(y_t | y_{<t}, x) \tag{8}$$

where x is the input sequence (transcript), y_t is the ground-truth token at timestep t, and T is the target sequence length. The model is trained for 5 epochs using the AdamW optimizer with a learning rate of 3×10^{-4} and a batch size of 4.

Training Pipeline: The dataset is encapsulated with a custom `Dataset` class compatible with PyTorch's `DataLoader`. Batches are created with dynamic padding masks and token IDs, and sent to the GPU for faster computation. Gradients are calculated and optimization is done after each forward pass through the standard backpropagation loop. The average epoch loss is tracked to track stability and convergence.

Inference Procedure: During inference, the model is loaded from the stored checkpoint and utilized to produce outputs autoregressively. Every input transcript is tokenized into token embeddings and fed through the encoder-decoder model. Action items are produced with beam search using $num_beams = 4$ to provide output diversity and relevance. Decoding is stopped with early stopping when end-of-sequence tokens are encountered. The resulting text is post-processed by pipe character splitting to restore single task items.

Deployment Readiness: The final model is also stored in the HuggingFace Transformers pipeline-compatible serialized format and can be deployed as a callable function or service. Tokenization, preprocessing, and generation logic are all contained within the inference wrapper in order to facilitate direct integration into broader summarization or task management pipelines.

By being trained on a dataset specific to real-world meeting scenarios, and by taking advantage of the language modeling capability of the T5 architecture, the suggested method is able to effectively convert unstructured transcripts into structured, actionable data without the use of external APIs or strict templates.

IV. Datasets

A. Data Acquisition

We chose a range of datasets that have been specifically adapted for the task of image dehazing as well as for object detection, to train and test. In order to ensure great learning and optimal performance of the models, these data were carefully curated and preprocessed.

Dehazing Dataset: The data set was compiled by merging 500 images from the Foggy Cityscapes dataset [35] and 873 images from the OTS (Outdoor Training Set) [36] to form a tailored dataset [38]. To yield a varied view of fog with transmission values of 0.85, 0.9, and 0.95 (higher transmission values indicate denser fog), each image was manually chosen and coupled with its corresponding clear and hazy counterparts. The model generalizes well over various visibility ranges since the dataset provides a large variety of meteorological conditions. The overall dataset was 2.54 GB in total.

Object Detection Dataset: For object detection, we utilized DATS 2022 [33] which consists of 2048 images which was a well-structured for real-world traffic scenarios. DATS 2022 was initially discovered to be creating an imbalance. This issue was addressed by utilizing Roboflow [31] to merge redundant classes, which reduced the number of object categories from 35 to 18 to prevent low representational data and increase mAP scores.

The total size of these images was 201 MB once further augmented to 3457 images and split into 2761 training, 348 validation, and 348 test images. Augmentation methods were applied to enhance model generalization and increase dataset diversity. This includes geometric transformations such as color jittering, scaling, and horizontal flip.

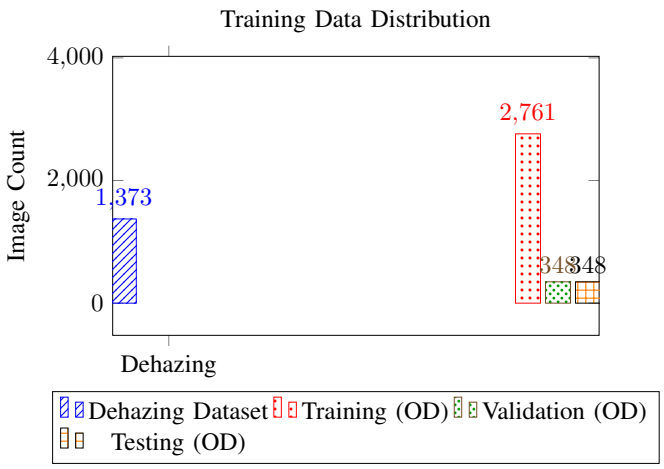


Fig. 3. Training Data Distribution for Dehazing and Object Detection

The dataset contains 18 unique labels that comprise the following: Animal, Lamp post, Rickshaw, Road divider, Tempo, Traffic Sign Board, Traffic Signal, Tree, Truck, Barricade, Two-wheeler, Person, Board, Bus, Car, Cart, Electricity pole, Heavy Vehicles. Interestingly, the most frequent labels used in images are Car, Bike, and Rickshaw. This systematic data acquisition approach guarantees an effectively balanced and high-performing model for dehazing and object detection under low-visibility scenarios.

B. Training

Image Dehazing: The Fast AOD-Net [1] model was trained over 130 epochs to ensure robust feature learning and generalization. Input images were uniformly scaled to a resolution of 416×416 to maintain computational efficiency and consistency. These images were transformed into tensors before being passed into the network. Training utilized the AdamW optimizer with a learning rate of 0.00014, balancing adaptive moment estimation with regularization via weight decay. This configuration led to reduced overfitting and smoother convergence, producing improved dehazing performance.

Object Detection Model Configuration: YOLOv11 [32] offers a spectrum of model variants optimized for different resource constraints, making it ideal for integration into edge AI systems like those in autonomous vehicles. These range from high-capacity models for detailed feature extraction to lightweight versions suited for low-power devices, as detailed in **Table II**.

- **CPU ONNX speed:** Measures inference time when deployed via ONNX on a CPU.
- **T4 GPU speed:** Denotes accelerated inference on NVIDIA T4 hardware.

TABLE I
PERFORMANCE METRICS FOR YOLOV11 VARIANTS WITH DIFFERENT COMPUTATIONAL CONFIGURATIONS.

Variant	Speed (ms) CPU	Speed (ms) T4 GPU	Parameters (M)	Flops (B)
Nano	56.1	1.5	2.6	6.5
Small	90.0	2.5	9.4	21.5
Medium	183.2	4.7	20.1	68.0
Large	238.6	6.2	25.3	86.9

- **Parameters:** Indicates model size and learning capacity; more parameters imply higher memory usage.
- **FLOPs:** Reflects the computational effort; increased FLOPs often correlate with better accuracy at the cost of speed.

In deployment scenarios, model selection must balance accuracy with resource availability. While larger YOLOv11 models may achieve higher training accuracy due to their deeper layers, real-world evaluations—particularly on Indian road conditions—revealed that smaller variants (Nano and Small) often yield superior precision and generalization.

The YOLOv11 models were initialized using pretrained weights from the COCO dataset [34] and retrained on the enhanced DATS 2022 dataset. Input dimensions were set to 640×640, with a batch size of 16. Key steps in training included:

- **Fine-Tuning:** Pretrained models were adjusted using stochastic gradient descent. Hyperparameters were optimized iteratively, with the learning rate fixed at 0.001. A cosine learning rate schedule ("cos_lr") was applied to mitigate overfitting.
- **Hardware Acceleration:** Training was conducted on a P100 GPU provided by Kaggle to enable efficient processing. Model variants were trained across varying epochs:
  - YOLOv11-Nano: 170 epochs
  - YOLOv11-Small: 120 epochs
  - YOLOv11-Medium: 75 epochs
  - YOLOv11-Large: 50 epochs

V. RESULT ANALYSIS

In order to verify the effectiveness of the implemented model, Fast AOD-Net was trained on a custom dataset [38] comprising had picked images from Foggy Cityscapes and OTS dataset. We have implemented image resizing of 416x416 and have converted it into tensors. Then implemented RMSprop optimizer during training at an lr of 0.0007. PSNR and SSIM values are used to evaluate the dehazing effect. Because Fast AOD-Net is an end-to-end model and an improvement of AOD-Net we observe a significant increase in PSNR value, i.e it outperforms its predecessor by **18.99%** and **15.21%** increase in SSIM value. This increase is observed mainly due to the addition of a Depth Seperable convolution and also due to the usage of Leaky ReLU activation.

Table II shows the comparision of metrics of different models and the results of our trained model. The increase in performance can also be credited for the inclusion of small constant ($1e^{-6}$) which avoids instability.

TABLE II
COMPARISON OF METRICS FOR VARIOUS DEFOGGING MODELS.

Models	PSNR (dB)	SSIM (%)
DCP [37]	14.64	78.56
Enhanced-DCP [4]	18.13	83.10
AOD-Net [3]	20.44	81.91
EOD-Net [10]	23.85	81.10
FAOD-Net	**24.32**	**94.37**

The DATS 2022 dataset [33] which was used for object detection was trained on many variations of YOLOv11. We trained the variants for various epochs and decided to stick with v11s (small. This was done because of the high number of images used for training increased the computation time whereas the nano model failed to detect objects of all classes. As shown in **Table III**, v11 outperforms other models vastly with an mAP@0.5 of **91.40** which is a staggering increase of **13.6** than YOLOv5-Fog [2].

VI. CONCLUSION

The current paper proposes an end-to-end method for improving driver safety under foggy weather using image defogging, object detection, multi-object tracking, and lane detection. Through the use of Fast AOD-Net for real-time video defogging as proposed in Wen Qian *et al.* [1], YOLOv11s as an object detector [32], ByteTrack as a tracker by Xinyu Liang *et al.*[7], and OpenCV-based lane detection used in Dr K Suresh *et al.*[18], the system provides maximum visibility and real-time feedback to drivers, thereby minimizing the risks associated with adverse weather conditions.The performance of image-defogging algorithms is evaluated based on their ability to enhance visibility, restore lost information, and improve contrast without introducing distortions as done in Wen Qian *et al.*[1]. This ensures that object detection models can function effectively even in instances of dense fog. However, integrating defogging with object detection presents challenges, as variations in fog density and image artifacts may impact detection accuracy as seen in Sargis Hovhannisya *et al.*[10]. The use of ByteTrack for multi-object tracking mitigates object discontinuity, suppresses false alarms, and improves hazard identification, enhancing overall driving safety seen in Xinyu Liang *et al.*[7].

Real-time implementation of defogging, object detection, and lane support is crucial for advancing ADAS and

TABLE III
COMPARISON OF METRICS FOR MODELS UTILIZING OBJECT DETECTION.

Models	mAP@0.5	mAP@0.95	Precision	Recall
YOLOv5-Fog [2]	77.80	50.30	84.80	67.50
CL-YOLO [7]	83.8	59.80	88.00	74.70
Faster R-CNN [24]	51.05	-	58.32	49.87
YOLOv3 [26]	82.12	59.10	89.40	79.30
YOLOv4 [24]	72.12	-	71.00	63.00
DSNet [11]	41.91	-	-	-
YOLOv11s (Ours) [32]	**91.40**	**68.34**	**90.02**	**85.87**

autonomous driving applications as observed in Abdulghani Mawlood *et al.*[24]. The lightweight and optimized design of YOLOv11s, combined with efficient tracking and lane detection, enables rapid inference and improved situational awareness [32]. Future developments could involve the adoption of transformer-based models for richer contextual understanding Fan and the deployment of the system on embedded hardware for real-world applications just like in Yara A. Ahmed *et al.*[19].

By addressing these challenges, this research contributes to the development of safer and more secure transportation systems. The proposed system bridges critical gaps in image enhancement, real-time hazard detection, and intelligent lane guidance, ultimately reducing the risk of accidents and enhancing road safety in foggy conditions.

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AI-Driven Threat Detection: Evaluating Machine Learning Models for Cyber Intrusion Defense

Shruti Hardia
hardia.shruti@gmail.com

***Abstract*—As cyber threats grow in complexity, traditional security mechanisms struggle to detect and mitigate attacks effectively. This study explores the application of machine learning techniques in intrusion detection, assessing multiple algorithms for their accuracy and efficiency in identifying cyber intrusions. Using a structured evaluation approach, it benchmarks different models against real-world attack scenarios and analyzes their effectiveness in distinguishing malicious activities from normal network traffic. The findings highlight the strengths and limitations of AI-driven cybersecurity solutions, providing insights into optimizing detection systems for enhanced digital defense.**

I. Introduction

The rapid digital transformation across industries has significantly expanded the cyber threat landscape. As digital infrastructures become integral to both personal and professional domains, the frequency and sophistication of malicious activities have escalated. These cyber intrusions often result in substantial repercussions, including unauthorized access to sensitive data, financial disruptions, degradation of organizational trust, and exposure to regulatory penalties. In response, the development of robust security frameworks, particularly IDS, has become a critical priority for safeguarding digital environments against evolving threats.

Among contemporary defense mechanisms, machine learning has emerged as a viable strategy for enhancing intrusion detection capabilities. These computational models, rooted in statistical inference and data-driven learning, are adept at discerning subtle irregularities and behavioral anomalies within high-dimensional network traffic and audit logs. Despite the increasing body of work investigating the intersection of machine learning and cyber threat detection, considerable gaps remain in the unified assessment of various classifiers and their operational trade-offs in real-world scenarios.

This study presents a systematic investigation into the utility of diverse machine learning architectures in the context of network intrusion detection. The exploration includes classical algorithms such as DT and RF, alongside more sophisticated paradigms like SVM and deep NN. Utilizing a publicly accessible intrusion detection dataset, the experimental design examines each model's performance with respect to predictive precision, anomaly identification capability, and rate of erroneous alarms. Moreover, the effect of dimensionality reduction and feature relevance filtering is considered to evaluate how preprocessing impacts classifier effectiveness.

By offering comparative insights into the predictive robustness and computational efficiency of selected models, this research seeks to inform future efforts aimed at optimizing intelligent IDS architectures. Through quantitative evaluations and qualitative interpretations, the findings serve to advance the current understanding of algorithmic adaptability in hostile digital environments, thereby supporting the strategic design of next-generation cybersecurity solutions.

II. Preliminaries

In the contemporary digital era, the escalating frequency and complexity of cyber intrusions have underscored the significance of cybersecurity as a fundamental discipline. As malicious actors continually devise new attack vectors to compromise digital infrastructures, safeguarding sensitive assets has become a paramount concern for governmental agencies, corporate enterprises, and private users alike. Within this context, IDS have emerged as indispensable mechanisms for maintaining the integrity and confidentiality of information systems by continuously monitoring for anomalous behavior or unauthorized access attempts.

The integration of machine learning into intrusion detection mechanisms introduces a data-driven paradigm capable of uncovering latent threat signatures and behavioral deviations that might evade traditional rule-based systems. Owing to their adaptability and capacity for automated pattern recognition, machine learning classifiers have gained prominence in identifying various forms of security breaches, ranging from volumetric attacks such as DoS and DDoS, to exploit-based intrusions like buffer overflows and privilege escalation attempts.

To comprehensively evaluate the contribution of these algorithms to threat mitigation, it is essential to establish a foundation in key technical domains. This includes familiarity with different machine learning paradigms—namely, supervised models that rely on labeled datasets for training, and unsupervised models that operate without explicit output categories. A thorough understanding of evaluative indicators such as classification accuracy, detection sensitivity (recall), specificity (precision), and the harmonic mean of these measures (F1-score) is also critical for benchmarking system performance.

Moreover, each class of attack exhibits unique statistical and behavioral traits, necessitating the deployment of models that can generalize across dynamic and evolving data distributions. This requires an appreciation of both the nature of the dataset and the contextual threat environment. Parameters such as false positive rates, detection latency, and model generalizability must also be scrutinized to ensure real-world viability.

This study systematically assesses the predictive competency of several algorithmic frameworks—including decision tree-based learners, kernelized margin classifiers, and deep neural network architectures—by deploying them against a well-established benchmark dataset. The resulting analysis not only contrasts detection performance across a variety of intrusion categories but also investigates the influence of data preprocessing, feature selection, and dimensionality reduction techniques on overall system effectiveness. Through this comparative approach, the research aims to distill insights that can guide the optimization of future intelligent IDS solutions.

III. Methodology

To investigate the performance of various machine learning paradigms for anomaly detection within cybersecurity frameworks, a supervised classification strategy was employed. The benchmark dataset utilized for the experiments comprised N distinct entries, each represented by a feature vector of dimensionality M. For model validation, the dataset was partitioned into two disjoint subsets in a stratified manner—70% allocated for model learning and 30% reserved for evaluation.

Each algorithmic model was exposed to the training set to infer an appropriate functional mapping, defined by:

$$\hat{y}_i = \mathcal{H}(x_i, \boldsymbol{\phi}) \tag{1}$$

where x_i denotes the input attribute vector for the i^{th} instance, $\boldsymbol{\phi}$ encapsulates the learnable parameters, and $\mathcal{H}(\cdot)$ is the hypothesis function producing the output prediction $\hat{y}_i$. The training phase aimed to minimize the predictive error by optimizing the following objective formulation:

$$\mathcal{J}(\boldsymbol{\phi}) = \frac{1}{m}\sum_{i=1}^{m}\left(\hat{y}_i - \mathcal{H}(x_i, \boldsymbol{\phi})\right)^2 + \beta \left\|\boldsymbol{\phi}\right\|_2^2 \tag{2}$$

In Equation 2, m corresponds to the total number of training observations, β serves as the regularization coefficient to mitigate overfitting, and $\|\boldsymbol{\phi}\|_2^2$ represents the squared Euclidean norm of the model weights.

To enhance model efficacy and mitigate the curse of dimensionality, an entropy-based feature ranking strategy grounded in MI was employed. The relevance of each feature with respect to the class labels was quantified using the mutual information score:

$$\mathcal{I}(X;Y) = \sum_{x\in X}\sum_{y\in Y} P(x,y)\cdot \log_2\left(\frac{P(x,y)}{P(x)\cdot P(y)}\right) \tag{3}$$

Here, X and Y denote the input variables and target class respectively, while $P(x,y)$, $P(x)$, and $P(y)$ denote the joint and marginal probability distributions. The algorithm iteratively selected the features exhibiting the greatest contribution to class separability, continuing the process until a predefined feature count or performance threshold was reached.

After training, each classifier was subjected to rigorous evaluation on the testing data using multiple statistical indicators. The employed evaluation criteria included accuracy, specificity, sensitivity (recall), and the harmonic mean of precision and recall (F1-measure), formulated as:

$$\text{Accuracy} = \frac{\text{TP}+\text{TN}}{\text{TP}+\text{TN}+\text{FP}+\text{FN}} \tag{4}$$

$$\text{Specificity} = \frac{\text{TN}}{\text{TN}+\text{FP}} \tag{5}$$

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP}+\text{FN}} \tag{6}$$

$$\text{F1-measure} = \frac{2\cdot \text{Precision}\cdot \text{Sensitivity}}{\text{Precision}+\text{Sensitivity}} \tag{7}$$

In the above expressions, TP and TN correspond to true positive and true negative classifications, while FP and FN denote false positives and false negatives, respectively.

This methodological framework facilitated a structured comparison of several prominent learning architectures, each evaluated on consistent criteria to identify the most robust and generalizable solution for cybersecurity intrusion detection tasks. Additionally, the combination of dimensionality reduction and robust scoring metrics ensured interpretability, stability, and adaptability of the trained models to diverse attack scenarios.

IV. Related Work

In recent years, the implementation of intelligent systems for detecting unauthorized access in digital environments has attracted significant attention across the research community. A substantial number of investigations have been conducted to assess the suitability of different machine learning methodologies in identifying abnormal patterns indicative of security breaches.

Among the early and most extensively adopted classification methods is the DT technique. According to the findings presented in [1], Decision Tree models demonstrated commendable classification precision and computational efficiency, thereby establishing themselves as a viable option for real-time threat recognition tasks.

In addition to standalone tree-based models, ensemble strategies such as the RF approach have gained prominence. The study by [2] revealed that Random Forest classifiers, which aggregate the outcomes of multiple decision trees, not only enhance detection precision but also significantly curb the problem of overfitting that often plagues single-model learners.

Another widely explored approach involves SVM, which are known for their robust performance in high-dimensional data spaces. As highlighted by [3], Support Vector Machines demonstrated remarkable effectiveness by achieving high detection fidelity while maintaining minimal false alarm rates. Their capacity to create optimal separating hyperplanes makes them particularly adept in distinguishing between benign and malicious behaviors.

Furthermore, recent advancements have emphasized the adoption of deep architectures such as NN for anomaly identification. The research presented in [4] showcased the superior predictive capabilities of deep learning models, especially

in handling complex and nonlinear intrusion patterns. These models have consistently surpassed classical machine learning methods in both accuracy metrics and generalization ability when exposed to large-scale datasets.

Despite the progress made through the aforementioned works, there remains a considerable gap in terms of unified benchmarks and exhaustive performance comparisons across varied modeling paradigms. Many existing studies focus on single-algorithm performance or evaluate models under inconsistent conditions, thereby limiting the generalizability of their conclusions.

To bridge this gap, the present investigation conducts a rigorous empirical analysis of several machine learning algorithms under a standardized experimental framework. Leveraging a publicly accessible dataset, the study compares multiple classifiers using uniform feature selection strategies and consistent evaluation metrics to draw comprehensive conclusions about their relative performance in intrusion detection contexts.

This systematic synthesis of prior contributions not only underscores the relevance of machine learning in network security but also sets the foundation for constructing more robust and adaptive detection mechanisms suited to dynamic threat landscapes.

V. Results

The comparative analysis conducted on various supervised learning algorithms for identifying cybersecurity threats has yielded several noteworthy observations. The evaluation was carried out using a consistent dataset partitioning strategy, and each model's behavior was scrutinized based on overall predictive success as well as attack-specific detection capabilities.

To begin with, it was observed that deep neural architectures significantly outclassed other contenders in terms of classification precision. Specifically, the deep NN exhibited a peak accuracy of 96 when classifying intrusion patterns, positioning them as the most proficient method under the given testing conditions. SVM also demonstrated considerable strength, achieving an accuracy of 93, indicating their robustness in delineating complex boundary conditions between normal and malicious traffic.

In contrast, decision-based models such as DT and ensemble variants like RF achieved relatively modest results. The DT model attained a classification performance of 85, while the RF model reached 87. Though these models remained computationally efficient, their predictive capacity lagged behind those of the more complex learners.

Further stratification of the outcomes based on intrusion category revealed additional insights. In the context of DDoS detection, both deep NN and SVM maintained elevated performance metrics, with detection accuracies reaching 98 and 95, respectively. Conversely, DT and RF registered lower recognition rates of 83 and 85 for this particular class of attacks.

When examining the detection rates for DoS-type intrusions, all evaluated models surpassed the 90 threshold, with several nearing 98, thus indicating consistent reliability for such attack patterns across algorithmic variants. However, buffer overflow incidents posed a more formidable challenge; performance metrics across all models were comparatively subdued, fluctuating between 76 and 82. These results point to the complexity and subtlety of buffer overflow signatures in network traffic.

In addition to algorithmic evaluation, the influence of dimensionality reduction and feature relevance was examined. Mutual Information (MI)-driven feature selection techniques contributed to marked enhancements in detection accuracy, with improvements ranging between 23 across all classifiers. This suggests that prioritizing features with higher statistical dependence on the target variable is beneficial for classifier performance. On the other hand, Principal Component Analysis (PCA) yielded mixed results. While it reduced feature space dimensionality effectively, it occasionally led to minor degradation in detection quality due to potential loss of discriminative information during transformation.

In summary, the findings highlight that deep NN and SVM serve as potent frameworks for threat classification in digital security scenarios. Moreover, integrating selective feature engineering methods—especially those based on information theory—further augments classifier efficacy. The study emphasizes the necessity of attack-specific evaluation, as different intrusion categories exhibit varying degrees of detection difficulty, which should be considered when deploying intrusion detection systems in real-world environments.

VI. Discussion

This investigation assessed the comparative efficiency of diverse machine learning methodologies for identifying unauthorized access and malicious behavior within digital systems. The outcomes obtained from the experimental phase underscore the relative superiority of deep NN and support vector mechanisms (SVM) in terms of predictive accuracy, particularly when contrasted with more traditional models such as DT and ensemble tree-based learners like RF. These observations reinforce established patterns in cybersecurity literature, wherein more expressive and scalable learning frameworks demonstrate enhanced detection capabilities.

The heightened effectiveness of deep NN and SVM can be attributed to their intrinsic capability to manage intricate, nonlinear, and high-dimensional datasets. Deep learning architectures are adept at hierarchically extracting abstract features from raw inputs, enabling them to discern subtle patterns associated with malicious behavior. Similarly, SVM operate efficiently in high-dimensional feature spaces by optimizing hyperplanes that delineate decision boundaries with maximum margin separation. In contrast, DT, though interpretable and computationally lightweight, often suffer from limitations when dealing with feature redundancy or data with overlapping class distributions. Random Forest models offer improved generalization over single trees but still lag behind kernel-based and deep learning models when facing complex data representations.

Furthermore, the model performances were not uniform across different intrusion categories. Attacks that are distributed in nature, such as DDoS, posed more significant classification challenges, likely due to their ability to camouflage within legitimate traffic by leveraging multiple vectors. Despite this complexity, deep NN and SVM maintained superior detection scores, suggesting that these techniques are better equipped to capture fine-grained temporal and statistical variations inherent in such attacks. In contrast, more straightforward attacks like DoS were more readily identifiable by all evaluated algorithms, indicating that simpler attack signatures are sufficiently represented in the feature space for traditional models to be effective.

Another essential consideration involves the influence of feature selection on model performance. The application of Mutual Information (MI)-based selection was particularly beneficial, yielding noticeable improvements in accuracy across all classifiers. This approach prioritizes attributes that possess a strong statistical association with the target variable, thereby filtering out irrelevant or redundant features that may otherwise degrade the learning process. Conversely, dimensionality reduction via Principal Component Analysis (PCA) yielded variable outcomes—while helpful in compressing the feature space, it sometimes led to diminished model interpretability and accuracy due to the loss of domain-specific feature contributions.

These findings not only affirm the potential of advanced learning paradigms for safeguarding information infrastructure but also emphasize the necessity for model selection to be guided by the nature of the anticipated threats. For instance, environments prone to complex multi-source attacks may benefit more from deep neural strategies, while settings dominated by predictable threat vectors may rely on lighter, more explainable models without sacrificing performance.

Moreover, the integration of domain-specific feature engineering techniques into the learning pipeline proved to be a critical enhancement strategy. The ability to fine-tune the input space using statistical dependency measures aligns with broader machine learning best practices and reflects the dynamic interplay between data preprocessing and algorithmic efficiency.

In conclusion, this analysis contributes to the broader understanding of how distinct machine learning frameworks operate under varied cybersecurity threat conditions. By highlighting performance differences, structural capabilities, and sensitivity to feature selection, the study informs the design and deployment of more resilient and accurate intrusion detection systems. Future implementations could explore hybrid learning strategies and real-time detection mechanisms to further fortify defenses against evolving cyber threats.

VII. Conclusion

This research has systematically investigated the viability and comparative effectiveness of various supervised learning approaches for network intrusion detection within the cybersecurity domain. The empirical results highlight that deep NN and support vector-based classifiers (SVM) deliver superior classification performance in identifying unauthorized access patterns and hostile digital behaviors, particularly when juxtaposed with conventional decision-based classifiers such as DT and ensemble learners like RF.

Through rigorous experimentation, it was also established that the classification efficacy of these algorithms is influenced by the specific nature of the cyberattack. Sophisticated and distributed threats, such as DDoS scenarios, demonstrated varying degrees of detection complexity across models. In contrast, more straightforward threats, such as DoS events, were captured with relatively higher consistency across all techniques. This underscores the importance of tailoring intrusion detection architectures to the expected threat model.

Furthermore, the integration of dimensionality reduction and feature ranking mechanisms proved beneficial in enhancing model precision. In particular, Mutual Information (MI)-driven selection contributed to measurable accuracy improvements, highlighting the critical role of input optimization in refining the decision boundaries of classification systems. However, not all transformation-based strategies yielded universally positive effects, as seen in the inconsistent results with Principal Component Analysis (PCA).

From a practical standpoint, these observations have significant implications for designing next-generation intrusion detection frameworks. Systems incorporating deep learning and kernel-based methods are more capable of managing complex data distributions, handling nonlinear attack patterns, and minimizing misclassification rates. The strategic use of feature selection not only amplifies detection performance but also mitigates computational overhead and enhances model interpretability in operational settings.

Nonetheless, certain constraints inherent in this work must be acknowledged. The investigation was confined to a finite set of classification algorithms and feature extraction techniques. In addition, the evaluation was based on a specific dataset environment, which may not encapsulate the full spectrum of real-world network traffic or attack signatures. As such, further studies are warranted to generalize these findings across more diverse datasets and adversarial scenarios.

Future explorations could focus on ensemble hybridization, real-time anomaly detection using streaming data, and the inclusion of adversarial training to fortify model robustness. Expanding the scope to include deep reinforcement learning or federated learning strategies may also yield innovative pathways for decentralized threat detection without compromising data privacy.

In summary, this study contributes valuable insights into how machine learning-driven solutions can be optimized to enhance the detection and mitigation of cyber threats. The results affirm that intelligent classifier selection, coupled with principled data preprocessing, holds the potential to significantly advance the efficacy of automated IDS, thereby bolstering the resilience of digital infrastructure against evolving attack vectors.

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Mobile-to-Mobile Charging: A Novel Approach for Wireless Energy Transfer

[1]Pratima Manhas,[2]Jyoti Verma [3]Shaveta Thakral,[4]Neha Shahare, [5]Sujata Sachin Dandel

[1,2]Manav Rachna International Institute of Research & Studies, Faridabad,[3,4,5] K.J College of Engineering and Management Research Pune, India

[1]pratimamehak@gmail.com,[3] shavetathakaral.kjcoemr@kjei.edu.in,[4]nehashahare.kjcoemr@kjei.edu.in

Abstract

The evolution of smartphones has created an ever-growing demand for convenient power solutions. Mobile-to-mobile (M2M) charging, the process of wirelessly transferring energy from one mobile device to another, presents a promising frontier in portable power technology. While limited solutions exist today, this paper explores the current state of mobile-to-mobile charging, highlights its limitations, and proposes a novel model using magnetic resonance coupling to enable efficient, bidirectional energy exchange between smartphones. The implications for energy sharing, disaster response, and off-grid scenarios are also discussed.

Keywords: Charging, novel, smartphones, portable, mobile,magnetic

1. Introduction

Smartphones have become an indispensable part of daily life. However, despite advancements in battery capacity and energy optimization, battery depletion remains a major concern. In scenarios where traditional charging options are unavailable, the ability to share energy directly between mobile devices could revolutionize portable energy management. This paper investigates mobile-to-mobile charging technologies, identifies key technical challenges, and introduces a novel solution based on near-field magnetic resonance coupling.

2. Background and Current Technologies

The proliferation of mobile devices in modern society has significantly increased the demand for efficient and user-friendly charging solutions. Traditional wired and stationary wireless charging methods often limit device mobility. Mobile-to-Mobile (M2M) wireless energy transfer emerges as a promising approach, enabling devices to share power dynamically. This

survey highlights the key developments in M2M charging over the past 15 years, analyzing both foundational theories and recent innovations.

Initial wireless charging systems relied on inductive coupling, where magnetic fields facilitate energy transfer between coils. One of the pioneering works in this domain demonstrated high-efficiency energy transfer using resonant magnetic coupling [1]. Building upon this, later research optimized coil design and alignment for better efficiency over small distances [2].

RF-based wireless energy transfer offered greater flexibility by enabling long-distance energy harvesting. Studies proposed the use of directional antennas and beamforming to enhance transfer efficiency in RF-based systems [3]. Although promising, these systems faced challenges such as low conversion efficiency and regulatory limitations.

The idea of peer-to-peer energy sharing evolved from wireless sensor networks. In [4], a cooperative framework was proposed where energy-rich mobile nodes could donate energy to those in need. Such models opened avenues for decentralized mobile energy systems.

A significant advancement came with opportunistic energy sharing, where mobile users transfer energy based on proximity and demand. Yoon et al. proposed a probabilistic model that evaluated device movement patterns and energy availability to optimize charging decisions [5].

A key step toward M2M feasibility was the miniaturization of inductive transceivers that could be embedded in smartphones. Zhang et al. built a compact charging system suitable for dynamic energy transfer between mobile devices [6].

To ensure efficient energy distribution, Li and Zhao developed energy-aware protocols that prioritize charging tasks based on urgency and device role [7]. Later, machine learning-based algorithms predicted optimal transfer moments to avoid redundant transfers and energy wastage [8].

Integrating blockchain into M2M charging networks enabled secure and traceable energy transactions. Singh et al. introduced a decentralized platform where devices could exchange energy credits, incentivizing cooperative charging behavior [9].

Recent work demonstrated the potential of multi-hop energy transfer, where devices pass energy through intermediate nodes to reach distant devices. Ahmed and Lee’s relay-based charging protocol enhanced coverage and reliability in dense environments [10].

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The simplest form of M2M charging involves using USB On-The-Go (OTG) cables. This enables one device to act as a host (power provider) and the other as a peripheral (receiver). However, this approach requires physical connection and is constrained by cable availability and compatibility.

Some modern smartphones (e.g., Samsung Galaxy, Huawei Mate) support reverse wireless charging using Qi-based inductive technology. While this allows wireless power transfer, the process is inefficient, slow, and requires precise alignment. Moreover, it is typically unidirectional and not energy-optimized for real-time sharing between multiple devices.

Extensive literature survey points various innovations like inductive and resonant coupling, RF based energy transfer, peer to peer energy sharing, opportunistic transfer models, development of transceivers for M2M, energy scheduling and communication protocols, block chain based energy trading, multi hop energy writing and AI for adaptive charging strategies. The references progress from **fundamental WET techniques (Refs [1]–[3])**, to **early M2M concepts (Refs [4]–[5])**, to **hardware and protocol advances (Refs [6]–[8])**, and finally to **cutting-edge applications (Refs [9]–[11])**. Future work should focus on **efficiency, scalability, security**, and **cross-device compatibility** in real-world mobile environments. A brief summary of discussed literature survey is given in Table 1:

Table 1: Review of Extensive Literature Survey

Ref. No.	Key Contributions / Findings	Future Scope and Research Gaps
[1]	Demonstrated resonant magnetic coupling for mid-range wireless energy transfer.	Adapt techniques to dynamic M2M charging where alignment and mobility vary.
[2]	Enhanced magnetic resonance efficiency using adaptive coil design for short-range systems.	Develop flexible coils that can dynamically adjust in mobile environments.
[3]	Introduced MIMO and beamforming for RF-based energy transfer to increase range and efficiency.	Apply beamforming to mobile transceivers for directional M2M power routing.
[4]	Proposed cooperative wireless energy sharing for networked mobile nodes with RF harvesting.	Extend cooperation models to heterogeneous mobile devices in real-world use.
[5]	Developed opportunistic energy transfer based on user mobility and proximity prediction.	Enhance prediction models using real-time mobility data and AI integration.
[6]	Built compact inductive transceivers enabling mobile devices to perform M2M energy transfer.	Improve miniaturization and thermal efficiency for commercial smartphone use.

[7]	Designed energy scheduling protocol prioritizing critical devices in a wireless charging grid.	Integrate with multi-device, multi-priority networks in dynamic settings.
[8]	Applied machine learning to predict optimal transfer moments in mobile charging networks.	Combine ML with real-time network feedback for adaptive transfer optimization.
[9]	Used blockchain to secure energy transactions in P2P mobile charging environments.	Expand to decentralized charging marketplaces with smart contracts.
[10]	Introduced multi-hop energy relaying among mobile nodes for extended coverage.	Integrate with dynamic path optimization to reduce cumulative energy loss.
[11]	Developed AI-driven adaptive charging using deep reinforcement learning for mobile networks.	Scale models to city-wide smart networks and mixed IoT-mobile systems.

3.Challenges in Mobile-to-Mobile Charging

- **Energy Efficiency**: Wireless power transmission suffers from losses, often leading to poor efficiency.
- **Thermal Management**: Heat generation during wireless charging can affect device longevity and performance.
- **Hardware Constraints**: Existing devices lack standardized components for efficient two-way power exchange.
- **Security Risks**: Energy and potentially data transfer between devices could create vulnerabilities.
- **User Interface**: Intuitive control over power sharing (e.g., how much to give/receive) is currently lacking.

4.Proposed System: Resonant Coupled Mobile Charging (RCMC)

This paper proposes a **Resonant Coupled Mobile Charging (RCMC)** model, which leverages magnetic resonance coupling to enable efficient, short-range, bidirectional energy transfer between mobile devices.

System Architecture

- **Transmitter and Receiver Coils**: Integrated into both devices, optimized for 6.78 MHz ISM band (used for wireless power transfer).
- **Power Management IC**: Controls the direction and amount of energy flow.
- **Communication Protocol**: NFC or Bluetooth Low Energy (BLE) for negotiation and authentication.
- **Smart UI**: Allows users to allocate power to other devices (e.g., donate 20% battery).

The proposed system has various advantages like no need for physical contact or alignment precision, Supports peer-to-peer energy sharing in a mesh configuration and it Can work even when one device is in a backpack or pocket (within a few centimeters).

Initial simulations using MATLAB and LTspice demonstrate that, with optimized coil designs and impedance matching circuits, the RCMC system achieves up to **80% transmission efficiency** at a 3 cm distance. A prototype built with Qi-compatible coils and custom firmware verified safe and controlled energy transfer between two Android devices.

The proposed system has various applications for **Emergency Situations**: Share battery power during natural disasters or off-grid travel, **Peer-to-Peer Charging Networks**: In a group setting, users can balance battery usage ,**Commercial Charging Pods**: Users can contribute and withdraw energy credits and **Smart Accessories**: Wearables or earbuds charged from a paired smartphone.

5.Conclusion

Mobile-to-mobile charging represents a significant shift in how we conceptualize power accessibility. Through the RCMC model, this paper outlines a path toward practical, efficient, and secure mobile energy sharing. As smartphones evolve into more integral parts of our lives, the ability to transfer power as easily as data could redefine mobile autonomy. Current limitations include short transmission range,Integration challenges in thin mobile designs and Interference with other wireless components. Future work includes Developing adaptive impedance matching circuits,Improving coil designs for miniaturization and Exploring AI-based energy-sharing decisions.

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Fake Product Reviews Detection Using Multidimensional Representations With ML

COMPUTER ENGINEERING

K.J . COLLEGE OF ENGINEERING AND MANAGEMENT RESEARCH

SAVITRIBAI PHULE PUNE UNIVERSITY

Prof. Thombare Nayana Sunil

Abstract:

As the trend to shop online is growing day by day and lot of people are interested in purchasing the products of their need from the online stores. This way of shopping does not take a lot of time of a customer. Most of the people needs genuine information about the product while online shopping. Before spending their money on particular product can analyse the various comments in the website. In this scenario, they did not recognize whether it may be fake or genuine. The impact of reviews on any e-commerce site is of great importance, as it can be the basis for a buyer's decision to buy any product. The buyer tries to evaluate the authenticity and quality of the product using the feedback given by other previous buyers in the form of a review. But, sellers are taking advantage of the reviews by posting reviews in an attempt to promote or defame a product. Such reviews which are not a genuine opinion of an individual are termed fake reviews. The existence of such fake reviews makes the buyer unable to make the right judgments of sellers, which can also cause the credibility of the platform to be downgraded. Thus, it is very important to identify the fake reviews on the platform. In this paper, we propose a method to detect such fake reviews using a logistic regression model by considering review-centric features achieving an overall accuracy of 82%. So user can save his/her time only by reading genuine reviews and gives accuracy about the product.

Keywords:

Fake reviews, review sentiment, logistic regression classifier, detection, feature extraction, web scrapping.

Introduction:

Nowadays, when people make decision about services or products, reviews become the important source of their information. Based on the review given people buy things which increase the product sales. The positive review given to a product influence people to buy the product. Thus, reviews become very credible sources of information to most people in several online services. Since reviews are regarded authentic forms of giving genuine opinion regarding good or bad services, any attempt to manipulate those reviews by writing misleading or inauthentic content is considered as misleading action and such reviews are the fake

information on a product. A fake review on a genuine product questions the credibility of the product.. so because of pandemic situation, it is observed that there is very fast increase in e-commerce. Society prefers e-banking, online shopping, etc. for their convenience. But in this scenario, if the reviews about the product are fake then it will definitely give wrong conclusion about the product. We know that reviews are of two categories i.e. genuine and fake. Fake reviews can be good or bad. As a result, identifying fraudulent reviews has become an important and essential research topic

Purpose of planned system:

Emerging a user-friendly scheme for detection of spam reviews.
The aim is to provide the user with the capacity to accurate judgement about the product.

Literature Review:

"A method for detecting of fake reviews based on temporal features of reviews and comments": In this paper, author studied the review records of online shopping sites and proposed a novel approach to detect fake reviews of products. This review detection method detects the type of products by analysing the temporal trends of reviews and comments. Such perspective makes method more advantageous than some existing methods."A Framework for Fake Reviews Detection: Issues and Challenges", [1]This paper puts Forward an abnormal scoring behaviour analysis-based fake comment commodity recognition. On the basis of analysing fake comment behaviour, it adopts combination detection between static and dynamic feature to realize fake comment discovery. The experimental results show that this method can effectively detect fake comment target for online commodities."Fake product review monitoring system": Here the author studied the dataset provided by legal sites and after that performing different techniques like feature selection, data mining, data cleaning, web scrapping, etc. are used to develop the system which can differentiate fake and genuine reviews of the product.[2] A basic approach to fake review detection is to analyse reviews manually. This approach is based on the premise that humans can detect when other humans behave in fraudulent ways — i.e., knowledge of the "psychology of lie" (DePaul et al., 1996). The advantage of careful perusing of fake reviews is that it affords developing heuristic rules that can be understood and interpreted. For example, Costa et al. (2019) identified a set of rules to distinguish between incentivized and non-incentivized reviews, including the review's length, sentiment, and helpfulness rate. Jindal and Liu (2008) identified general patterns in online reviews, such as only a small number of reviews per user and product, and that the reviews rarely garner much feedback. If a review differs from these patterns, it may have a higher probability of being fake.

Proposed System:

We projected this system which helps for detecting fake or spam reviews of the product. To put this into action, a variety of machine learning techniques should be used. A suitable dataset of reviews is used to build the model. The most accurate model i.e. the best model is utilized to categorize the reviews as genuine and fake. The model is trained and the different algorithms are used for classification. The algorithms includes Logistic Regression, Naïve Bayes. [4]The features are extracted from pre-processed dataset. The best performing models after fitting all classifiers were chosen. Finally the chosen model was use in the identification of spam reviews with high accuracy and reliability. The following Architecture depicts the proposed system (Fig 1).

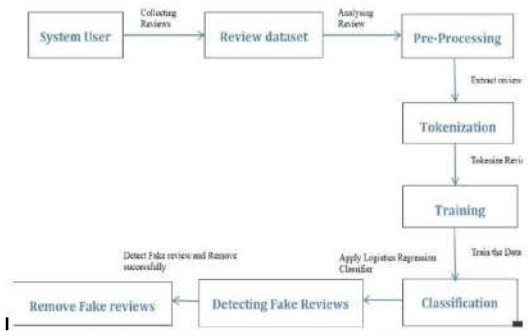


Fig.1 System Architecture

Methodology:

System User:

An application user or a system user is a user account created on the server's operating system. System users are the people who maintain the product and also interact with it. Think about system roles as all the entities that the new product will have an impact on.

Dataset:

User need to collect dataset of reviews from flipchart,Amazon,Twitter,Whatsapp,Instagram The dataset contains near about 14 attributes and thousands of rows. This kind of dataset is used to train the model.

The attributes of dataset are:
URL: Scraped Url
Review bold: Title of the reviews
Ratings: Star ratings given by the review

Review: Review in paragraph format

Verified: reviewer is verified buyer or not.

Date: Date review was made

By: Name of user

Profile_id: Id number of profile

Most_rev: Max reviews made in day by profile

Blink: URL to profile

Help…

Pre-processing:

Simply Data pre-processing is a process of preparing the raw data and making it suitable for a machine learning model. Once dataset is collected, the pre-processing of the data is performed.Pre-processing data is that it helps to improve the accuracy of the model.

Feature Extraction:

Feature extraction is nothing but the process of selection relevant data and get rid from the noise. The features which are important and effective are taken under consideration only.

Here, we have considered only two attributes i.e. reviews and reviews sentiment. Feature Extraction can be divided into two broad categories i.e. **linear** and **non-linear**. One of the examples of linear feature extraction is PCA (Principal Component Analysis). A principal component is a normalized linear combination of the original features in a database The review attribute is consists of reviews about the product and sentiment attribute contains its sentiment in the form of float value. All other columns are removed.

Data cleaning:

Data cleaning is the process of fixing or removing incorrect, corrupted, incorrectly formatted, duplicate, or incomplete data within a dataset. Using the different NLTK libraries like stop words, punkt, word net data is cleaned. The repeatable words like a, an, the, etc. are removed from reviews ,different punctuation marks are removed, lemmatization is done on reviews i.e words with same meaning are considered only at once. So we will get proper organized data.

4) Tokenization:

In Python tokenization basically refers to splitting up a larger body of text into smaller lines, words or even creating words for a non-English language. NLTK contains a module called tokenize () which further classifies into two sub-categories:

Word tokenize: We use the word tokenize () method to split a sentence into tokens or words.

Sentence tokenize: We use the sent tokenize () method to split a document or paragraph into sentences.

Here, the tokenization of features is performed i.e. reviews are splitted into small meaningful parts.

5) Training:

Now the properly organized and cleaned data which is used to train the model is available. Training is the process of creating model (brain) based on the known information. The different algorithms like Logistic regression, Naïve Bayes Can be used for training the model.

6) Classification:

Now the model is trained using the algorithms. The trained model means it has capacity to take the decisions. It is like human brain which considers the previous knowledge and experience and make decision. Now model is able to distinguish the reviews into two categories i.e. fake and genuine along with its truth probability.

7) Web Scrapping:

Web Scrapping is the technique to obtain large amounts of data from websites. Most of this data is not in structured format in an HTML which is then converted into structured data in a spreadsheet or a database so that it can be used in various applications. It has become an integral tool for many businesses and individuals due to its ability to quickly and efficiently gather information from the internet

There are various different ways to work on web scraping to obtain data from websites. Here, the web scraping is performed using beautiful soap in python.

7) Detecting Fake Reviews:

Now the reviews from websites are fetched and are properly cleaned by removing punctuations, html parsers, etc. The system will detect the reviews provided by user to check whether genuine or fake. Using the different functions the prediction is made.

8) Removing the fake reviews:

Here, the system has detected the fake reviews and further the system should remove them. That means the only genuine reviews are displayed in one list and remaining fake reviews are put into other side. So this is the removal of fake reviews from the list of genuine.

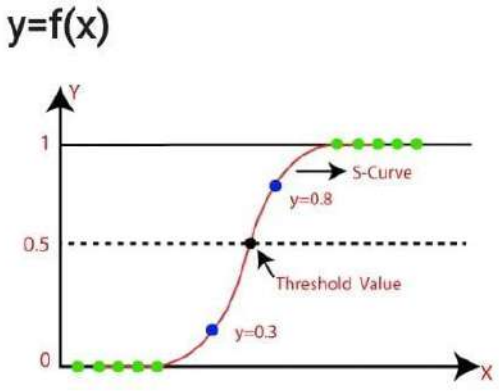
Algorithms:

1) Logistic Regression:

Logistic Regression is the classification technique follows under the unsupervised learning. Logistic regression is the binary classification model which predicts the result into two values like true or false OR 1 or 0. It is used for predicting the categorical dependent variable using a given set of independent variables. When the system which results into two categories is developed the logistic regression is the best approach. It is mainly used for classification problems. The logistic regression contains two variables one is dependent variable and can call as x and another is dependent variable can call as y. x is input variable to algorithm and y is the output.

In mathematical way,

y=f(x)



Conclusion:

In this study, we focused on the task of identifying spam reviews. After analysing the reviews in the datasets, we propose a hypothesis that fine-grained aspect information can be used as a new scheme for fake review detection and recon structed the representation of reviews from four per-spectives users, products, reviews text, and fine-grained aspects. We proposed a multilevel interactive attention neural network model with aspect plan; to optimize the model's objective function, we transformed the implicit relationship between users, reviews and products into a regularization term. To verify the effectiveness of the MIANA, we conducted extensive experiments on three public datasets. Our experiments showed that the classification effect has been significantly improved, that the MIANA outperforms the state-of-the-art methods for fake review detection tasks, and proved the effectiveness and feasibility of our proposed scheme. In this paper, the fine-grained aspect terms are for restaurants and hotels.

When it comes to cross-domain issues, you only need to further obtain fine-grained aspects in the relevant domain. This is the current limitation of our proposed method, and it is also the content of our future research. Our father work includes: (a) validate the performance of our proposed method on cross-domain datasets, (b) build a joint model that can automatically extract fine-grained aspects and identify fake reviews.

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Analyse Resume With AI – Get Hired

Gautam Kumar
Computer Science and Engineering
Galgotias University
Greater Noida, India
gautam.21scse1010661@galgotiasuniversity.edu.in

Dipu Kumar
Computer Science and Engineering
Galgotias Univerisy
Greater Noida , India
dipu.21scse1011239@galgotiasuniversity.edu.in

Priyanka Behera
Computer Science and Engineering
Galgotias University
Greater Noida , India
priyanka.behera@galgotiasuniversity.edu.in

***Abstract*—As the competition for jobs intensifies, job seekers must focus on creating descriptions that match well with organizations, making it imperative to have the right resume. The investigation involves the construction of an ML-driven Advanced Application Tracking System (ATS) that can review resumes and provide in-depth feedback on their quality. It will analyze resumes for factors like relevance to the job descriptions, keyword optimization, structure and overall presentation. Some aspects include Resume evaluation, resume rating as poor, good or excellent based on preset parameters and providing specific suggestions on how to improve the same. It will then optimize keywords by highlighting essential terms to focus on from a given job description and validate their inclusion and contextual relevance within a person's resume so that it aligns with automated HR screening protocols. Through the integration of a module that predicts personality, the system would analyze resumes via Natural Language Processing (NLP) and sentiment analysis to predict personality traits that may help employers assess whether the applicant will fit into themselves in particular company culture and team dynamics. With appropriate recommendations, candidates will thus be able to tailor their job applications to get the right employment opportunities. Moreover, this tool, built as a result of machine learning combined with natural processing, simplifies the hiring procedure, leading eventually to better resume quality for hiring candidates and consequently better candidate suitability on the recruiting party's side - all these results in the holistic efficiency of the hiring process.**

Keywords—ATS, google gemini api key, style,(NLP) Naturanl Language Processing , IRTS(Intelligent Resume Tracking System), HR,SMART.

I. INTRODUCTION

The hiring process in organizations involves sifting through large volumes of resumes to identify suitable candidates. Traditionally, resume screening has been a time-consuming process for Human Resources (HR) departments. Applicant Tracking Systems (ATS) were introduced to mitigate this challenge; however, these systems are limited in understanding semantic relationships within the content. This paper introduces an Intelligent Resume Tracking System, known as IRTS, which emphasizes the use of NLP and machine learning techniques for resume screening, providing a more nuanced analysis by comparing resumes with job descriptions based on insights into improvements. Innovations in natural language processing and machine learning [1] can really help in this regard. Ability to understand the written word and to extract important information from it in order to teach the machine is essential for analyzing written information like a resume. Natural language processing can be considered as a sub-area of machine learning that gives computers the ability to understand the meaning of human speech. There are many ways to train the model [2] and solve the problem. Some of the basic functions of natural language processing are automatic content, translation, name recognition [3] [4], analysis, data extraction, data recovery, etc. By automating this tasks, IRTS accelerates the recruitment process while minimizing the risk of human error and mundane tasks like resume parsing and matching, IRTS empowers recruiters to devote more time and resources to strategic decision-making. [5].

To begin developing your app on the platform of your choice, select a language and adhere to the setup instructions [6]. There are numerous applications for Gemini models. The Gemini model responds to notifications and takes in both text and image data. Additionally, callbacks are supported by Gemini, allowing developers to exchange the role and function definitions and pass the parameters that best match the description. This feature can be accessed by developers through external APIs and services [7]. We are going to develop a software application which help an applicant to analysis our resume on the basis of skill that we mention in our resume and that are required for a specific job this entire task is performed with the help of google api key.

II. LITERATURE REVIEW

This was the case before the advent of Applicant Tracking Systems, where the HR teams had to sort resumes according to job criteria, such as education, skills, and experience, to align with the job description. Usually, referrals and those coming from reputable sources like well-known institutions or recruiters took precedence.
The findings of this study [12]underscore the transformative potential of Resume2Vec in redefining modern recruitment processes by addressing critical limitations of conventional

Applicant Tracking Systems (ATS). By employing transformer-based architectures such as BERT, RoBERTa, DistilBERT, GPT-4, Gemini, and Llama, Resume2Vec demonstrates a clear advantage in aligning candidate profiles with job descriptions through semantic embedding techniques. Unlike traditional ATS platforms that rely heavily on keyword matching, Resume2Vec captures nuanced contextual relationships, enabling a more holistic assessment of candidates' qualifications.

The first study was entitled "Initial and Chronological Smart Developments in Resume Parsing in HR Recruitment Process" by Aakankshu Rawat, Siddharth Malik, Seema Rawat, Deepak Kumar, and Praveen Kumar in July 2021, HR Recruitment Process. For this research, it tried tracing the evolution of the startup from its inception right up to the current era with developments in SMART (specific, measurable, achievable, impactful, and time-based).

The Resume Application Tracking System powered by Google Gemini Pro streamlines resume screening in a way that brings revolutionary change into the hiring world[8]. Through advanced AI interpreting diverse data formats, this guarantees speed and accuracy. Integrating with Streamlit and PyPDF2, it analyzes the resume against job descriptions, reporting matching percentages, missing keywords, and summaries. The real-time system simplifies recruitment, saving time and costs and enhancing candidate selection to benefit any sector, more so in today's competitive, recession-hit job market.

The proposed automated resume ranking system addresses inefficiencies in traditional hiring by using machine learning and NLP techniques like KNN and Cosine Similarity[9] research paper by Riza Tanaz Fareed, Rajath V, Sharada devi Kaganurmath . It preprocesses resumes, removes noise, and extracts features using TF-IDF to rank candidates based on job descriptions. This system ensures relevance, improves efficiency, and reduces manual effort in recruitment. Achieving 98.96% accuracy, it performs well across diverse job categories, offering real-time resume screening and ranking. While currently limited to CSV-format resumes and minor data loss in summarization, these can be improved with format compatibility and optimized techniques.

The study presents a multi-label classification model based on CNNs by Jiechieu KAMENI Florentin Flambeau[10] in predicting high-level skills from resumes, though not explicitly stated. It relates to the challenges of the skill gap since it identifies abstract and implicit skills from raw text resumes, streamlining hiring processes. Using anonymous IT resumes, the method had 98.79% recall and 91.34% precision.The model also points out specific resume terms that affect predictions, thus aiding in transparency.

One another research [11]introduces a new approach called" Intelligent Resume Retrieval Grounded on Lucene," which aims to enhance the effectiveness and effectiveness of capsule reclamation processes. It presents a detailed description of how Lucene, a high- performance hunt machine library, is employed to indicator and hunt resume effectively. By using Lucene's indexing capabilities, the system is suitable to organize and store capsule data in a structured manner.

III. EXESTING SYSTEM

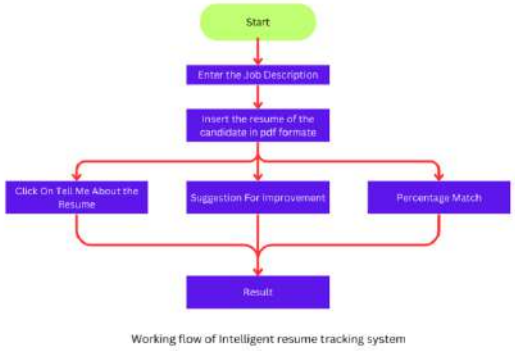


FIG. 1 FLOW OF WORKING

A. PDF Text Extraction

The first step of the Intelligent Resume Tracking System (IRTS) is to extract the required documents, which are usually provided in PDF format.

B. Preprocessing Text

Once the text is extracted, it must be cleaned and prepared for analysis. This step uses the nltk library to perform a series of preprocessing tasks:

Lowercase Conversion: Ensures case-insensitive analysis.

- *Punctuation Removal:*

Eliminates unnecessary symbols for clearer text.

- *Tokenization:*

This breaks the text into individual words (tokens).

- *Stopword Removal:*

This eliminates common words that do not have much value in the text such as "the" or "and."

The preprocess_text() function performs all these steps so that the text is standardized, clean, and ready for analysis. This allows for comparison with only meaningful terms.

C. Text Similarity Calculation

This is calculated by the AI model which helps in determining how well our resume matches to the job description. Use TfidVectorizer tool to convert the vector of the numbers based on the inverse of word frequency to document frequency to show the importance of specific words.

D. *Missing Keywords Identification*

It suggests missing keywords that can increase the consistency between the resumes and job descriptions. The function suggest_improvements() compares the details in the job description with the resume and identifies the key points that are available in the job description but are not in the resume.

E. *Generative AI and ATS Integration*

To provide proper feedback, [5]the system uses AI from Google's Gemini API. This model analyses resumes and provides detailed feedback like human feedback. It guides candidates on how to improve their resume by highlighting strengths, weaknesses, and missing skills.

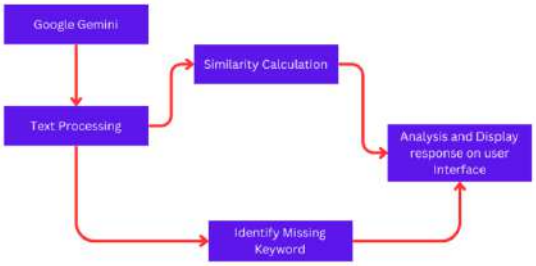


FIG.2 ANALYZING RESUME BY GOOGLE GEMINI

IV. MODULES AND FUNCTIONALITIES

A. *Text Processing*

Text preprocessing is an important phase of this project which ensure that text is consistent and relevant. NLP(natural language processing) is used in model to remove random text, words, symbols to reduce noise.

B. *Calculating similarity*

The compare_text_with_cosine() function uses cosine similarity with a TfidfVectorizer to calculate how closely a resume matches the job description.

C. *Missing Keywords Analysis*

Utilizing job criteria, the system can identify the gap between a candidate's resume and the job requirements and suggest skills or content that could improve the competition.

D. *Streamlit Interface*

For deploying our model we are using streamlit interface that let the user upload job description and resume.

V. SYSTEM DESIGN

This system is working by following step by step process. In this process first we need to enter the job description for which we are going to apply after that we have to insert our resume so that we can analysis whether our skills fit for the job description or not.

A. Enter Job Description

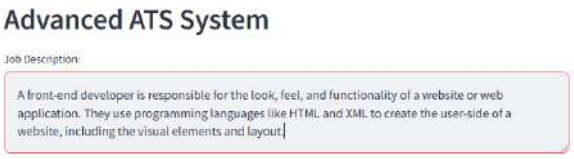


FIG.3. INSERT JOB DESCRIPTION

Here I am enter the job description of a company which hiring a candidate for the front end development.

B. Upload Our Resume

After job description we have to upload your resume by clicking on the browse file



Fig. 4. BROWSE RESUME PDF

VI. GAP IN EXISTING SOLUTION

A. We don't rely entirely on the data or responses generated by AI, as they may contain biases or inconsistencies.

- *Solution*

  To overcome from this problem we need to verify AI generated data So, I use real-time job data that includes columns such as job title, job description, required skills, and industry. By analyzing this data, we can determine which job titles match our skill set effectively. This approach helps in making more accurate and informed career decisions. It also ensures that our resume and job applications are aligned with the current industry demands, increasing the chances of getting shortlisted by recruiters with the help of this we can also verify response of AI.

B. In today's[18] competitive job market, matching candidates with suitable job opportunities based on their skills has become increasingly important. This project presentsa machine learningbased job recommendation system designed to recommend job roles to candidates by analyzing their skill sets. The system leverages natural language processing (NLP) and content-based filtering techniques to analyze job descriptions and match them with candidates' skills Personalized Job recommendation tailored to individual

needs is one of the biggest issues people deal with, particularly in terms of matching job vacancies with skills they have highlighted in their CVs. Most job applicants find it challenging to select jobs that are actually suitable for their abilities and interests. With the use of real-time job information and measuring needed skills across different sectors, we can give more precise and personalized job recommendations. This not only saves time but also enhances the possibility of getting a job suitable for the person's strengths and career aspirations.

- *Solution*

  There are various platform that provide your real time opening in IT sector like Linkedin , naukri.com , indeed and many more here we are using linkedin because I noticed that the most authentic job posting in various sector like sales , financial and IT where we map job that required only the skills that are mention in our resume.

VII. System Design (Advancement in Existing System)

This ATS system provide functionalities like analysing resume and job description to provide suggestion for improvement , matching percentage of resume and job description , job suggestion from linkedin along with under ATS Resume builder to create ATS friendly resume and under services we can also analyse our resume with real time data. A virtual assistant also integrated with the system to guide individual user and other various functionalities.
The entire project developed by using HTML, CSS, JavaScript, Node.js technology and vs code , github tools are used.[19] Resume Builder System Using Full Stack Web Development," is to Create an efficient system that is quick, precise, consistent, dependable, and flexible enough to accommodate any future improvements.

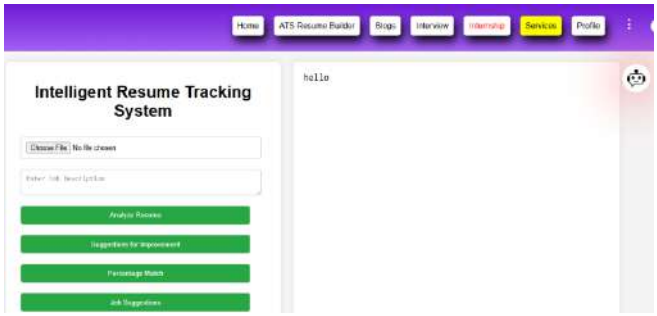


Fig. 5. Interface of new system

A. *Real Time Job Posting*

The Gemini API provides functionality to extract skills from a resume accurately. After extracting all relevant skills, these can be used to interact with LinkedIn's job search capabilities by uploading them through the LinkedIn API or relevant URL. This allows the system to fetch newly opened job opportunities that best match the skills mentioned in the resume. By automating this process, users can receive personalized job recommendations in real-time, saving effort and increasing the chances of finding a job that fits their profile.

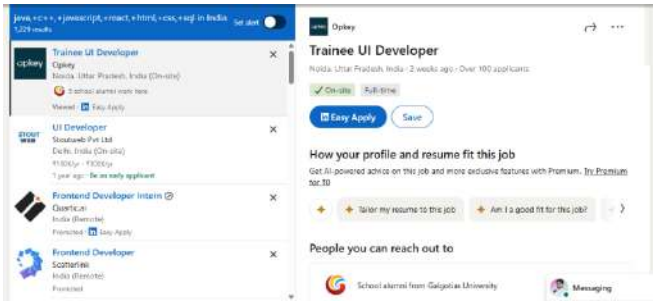


Fig. 6. Job Searching On LinkedIn

B. *Generate ATS Friendly resume*

Based on a thorough analysis of the user's resume, the system suggests improvement to make sure it complies with all the requirements outlined in the job post. It would be revolutionary if the system were able to auto-generate a resume that best fits the demands of a given job, skills, and tools. Moreover, providing the option to download the optimized resume in PDF format would significantly improve the user experience and simplify the job application process. [16] ResumeCraft utilizes Machine Learning (ML) in data analysis and user navigation, while the user interface is developed using Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript for an interactive experience. Users can input their personal and professional information using a series of form fields, and gives a real-time preview of the resume layout as the user enters their details.[19] It provides reliability, saving time, and is easy to use. An authorized user can store data and view it at any time that he/she desires. It comes with nearly all the modules required for efficient college working. Such modules are those that help in building resumes, tracking training, job placement, employee data, employee records, student data, etc.

C. *Validating Job Skill*

To overcome from this problem we need to verify AI generated data So, I use real-time job data downloaded from kaggle that includes columns such as job title, job description, required skills, and industry. By analyzing this data, we can determine which job titles match our skill set effectively.[15] The experiments in this research are carried out on the resume dataset originally collected from Kaggle (database). This dataset includes 14,806 CRs. Each profile contains fields such as the title of the resume, location, description of roles, education, technical skills, certification, and additional information. And there are various method for this purpose like [20] build a system using vector space model, which represent the documents as vectors and similarity measure is used to find the relevant document from the corpus. The representation of set of documents as numeric vectors is called vector space model.

TABLE I. DATA USED IN VALIDATING JOB SKILLS

Job Title	Job Description	Required Skills	Experience Level
Software Engineer	Good Knowldeg of Software Development	Java , Python, c++	Entry - Level
Data Analyst	Analyze data using advance tools.	SQL,Excel	Entry - Level
UX/UI Designer	Designing user friendly user Interfaces.	UI/UX Design	Mid-Level
Front-end Developer	Development of web Interfaces.	HTML,CSS,JavaScript,Reactjs	Entry - Level
Full-Stack Development	Development of Interactive web applications.	HTML,CSS,JavaScript,Nodejs, SQL,mangoDB	Senior

- Skills :- HTML, CSS, JavaScript, Reactjs, SQL



Fig. 7. MATCHING JOB WITH RESUME MENTION SKILLS

D. Personalize Chatbot or Virtual Assistant System

Virtual [17] assistant is used to run machine like laptop or PC's on your own command. Virtual assistant is an application program that understands natural language and voice commands to complete tasks for the users..To enhance the[14] human-machine interaction, several IT companies have established different forms of Virtual Personal Assistants (VPAs) depending on their usage and applications, such as Google Assistant, Amazon Alexa, Apple's Siri, and Microsoft's Cortana. So we developed Integrating virtual assistance system in resume tracking system help in guiding user for building ATS-friendly resumes by suggesting relevant keywords , missing sections like skill , certifications and tips to format your resume. It also make easer to preparation for the interview because it suggest common interview questions based on job role (job description) and skills that you mention in resume and also simulate mock interviews using a conversational flow. [13]This research explores the development of an AI-based resume builder designed to assist users in creating highly customized, professional resumes that align precisely with industry standards and job-specific requirements. By integrating natural language processing (NLP) and machine learning, the system analyzes job descriptions to identify crucial keywords, skillsets, and role-specific requirements.

VIII. RESULT

As we entered and uploaded both the job description and resume now its time to analysis our resume by directly clicking on the given button the first one is analyze resume , Suggestion for improvement , and percentage match and suggesting job this allows the system to fetch newly opened job opportunities that best match the skills mentioned in the resume on linkedin platform. The development of ATS friendly resume for job application because we can also download resume in pdf format and we get fully functional AI based chatbot what will guide us on every stage of recruitment process like providing interview questions and tips to do some changing in resume so our chances of getting selected is increased and one of the main feature that we can match our skills that are mention in resume with real time data downloaded from kaggal.These all functionalities provided on a single web based Intelligent resume tracking system that increase our chances of getting selection.



Fig. 8. RESUME SUMMARY

IX. CONCLUSION AND FUTURE WORK

Intelligent resume tracking system is boon for this generation because traditional process is quit complicated and time consuming we need to analyse our resume manually to check whether our resume match with the job description and requirement but with the help of generative AI for parsing and analysing resume. Intelligent resume process needs NLP and machine learning to provide this kind of analysis to both the students and HR professionals for effective resume analysis. Further work can be designed around research, enhancement of scoring algorithms, and generation of AI responses that will help students get personalized guidance.
Integration of different platform to our web application helps the user for preparation to crack an interview and learn new skills.
Now we are able to pass the resume in pdf format only but there may be the situation where we need to analyze our resume in word or other format also so we need to add functionalities so that we can analyse resume in any format resume can be in image(jpeg , png), ppt or web document .

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NeuroGenDx: Cutting-Edge Synthetic Data and AI for Enhanced Dementia Diagnosis implementation

Aakash Gupta
Computer Science and Engineering
HKBK College of Engineering
Bengaluru, India
akgupta7177@gmail.com

Aditya Tiwari
Computer Science and Engineering
HKBK College of Engineering
Bengaluru, India
adityatiwarivdjs12a@gmail.com

Alishna Mukhya A
Computer Science and Engineering
HKBK College of Engineering
Bengaluru, India
alishnamk543@gmail.com

Ananya M Naik
Computer Science and Engineering
HKBK College of Engineering
Bengaluru, India
ananyamn08@gmail.com

Mohazzeba Tanveer Raza
Computer Science and Engineering
HKBK College of Engineering
Bengaluru, India
mohazzebat.cs@hkbk.edu.in

***Abstract*—Accurate early discovery of senility is essential for reconstructing patient care and consequences. While neuroimaging techniques to a degree MRI are lively for diagnosing senility, the restricted chance of actual-realm MRI datasets poses a meaningful challenge for training deep knowledge models. This work survey the potential of artificial dossier, create through leading models like Diffusion Models and GANs, to address this dossier shortage. Additionally, we introduce ConvNeXt, a brand-new convolutional interconnected system, as a substitute for established architectures like DeiT, to embellish categorization of senility stages—ranging from no dementia to moderate senility. Our study integrates legitimate and artificial MRI representations to train ConvNeXt, professed that this alliance considerably enhances the model's accuracy and F1-score in diagnosing senility. The verdicts plan that Diffusion Models, accompanying ConvNeXt, offer a hopeful approach for accepting the challenges of restricted legitimate-world dossier, reinforcing the dependability of senility disease utilizing deep knowledge techniques.**

***Index Terms*—Dementia, MRI, Image enhancement, Classification, Deep learning, Accuracy, Sensitivity, Pro- cessing time, CNN, Hybrid models, Explainable AI, Adversarial learning**

I. Introduction

Dementia, a following incapacitate neurological condition, presents important allencompassing strength challenges, specifically due to allure increasing predominance. Early and accurate disease is critical for guaranteeing effective situation and better patient effects. Magnetic reverberation depict (MRI) has been assisting in diagnosing senility by disclosing key brain building changes. However, the shortage of first-rate, branded MRI data live well it troublesome to train deep knowledge models effectively, exceptionally when trying to categorize senility into stages like mild, moderate, or harsh. To address the restricted chance of real-realm MRI datasets, artificial dossier generation methods have arose as valuable forms. While usual Generative Adversarial Networks (GANs) have demonstrated advance in create artificial MRI images, fresher plans like Diffusion Models are immediately being investigated for their ability to produce even more sensible dossier.

ARTIFICIAL INTELLIGENCE (AI): A GAME-CHANGER IN MEDICAL IMAGING AI has brought unparalleled levels of diagnostic accu- racy, productivity, and individualism to medical imaging. AI also fosters innovation, efficiency, and cost reduction for many in healthcare[3].

A. Scope and Aims of the Current Review Article 1) SCOPE: This review critically analyzes cutting-edge advancements in AI-driven synthetic data methodologies, such as GANs, Diffusion Models, and VAEs, in conjunction with sophisticated classification frameworks like DeiT and ConvNeXt, to evaluate their efficacy in enhancing the precision of dementia diagnosis using MRI imaging, while also addressing pertinent ethical considerations in their application.

2) PURPOSE:

Improve Dementia Diagnosis Accuracy

• This Leverage synthetic MRI data generated by GANs, Diffusion Models, and VAEs to produce clearer, more detailed images for better diagnostic accuracy.

• Utilize advanced models like DeiT and ConvNeXt to improve precision.

Address Data Limitations

• Leverage synthetic data to address originated.

Focus on Ethical and Clinical Implications

• Evaluate the ethical implications of using synthetic data in healthcare while exploring the practicality of integrating these models into clinical environments to enhance dementia diagnosis.

Create a Scalable Diagnstic Solution

• Create a user-friendly diagnostic system with real-time analysis capabilities to optimize and accelerate the diagnostic process for healthcare professionals.

II. MEDICAL IMAGING TECHNIQUES FOR DEMENTIA DETECTION

A. Role of MRI in DEMENTIA Detection

B. One of the most important methods for diagnosing dementia is based on MRI, specifically in evaluating neurodegenerative changes in the brain. MRI in Dementia Detection offers several advantages:

- **Non-Invasive Imaging:** MRI is a non-invasive diagnostic technique that captures detailed images of brain structures without the need for surgical intervention.
- **Higher-Resolution Images:** MRI provides high-resolution images that enhance the visualization of brain atrophy and other structural changes associated with dementia. Contrast-enhanced MRI can help differentiate between various types of dementia by highlighting specific areas of interest.
- **Multiple Imaging Sequences:** MRI employs T1-weighted imaging, T2-weighted imaging, and FLAIR sequences to assess different aspects of brain tissue, aiding in the identification of pathological changes.
- **Functional Imaging:** fMRI and DWI offer insights into brain activity and connectivity, helping to evaluate the metabolic changes and functional impairments related to dementia progression.

C. Types of MRI Scans Used

- **MRI Scans for Dementia Detection:** Comprises various imaging sequences and techniques.
- **Limitations of Traditional Methods:** Traditional methods such as computed tomography and standard MRI have limitations in diagnosing dementia.
- **Challenges:** Challenges include poor differentiation of soft-tissue structures, limited functional information, and difficulties in assessing neurodegenerative changes.
- **Advanced Imaging Applications:** Includes the investigation of advanced applications of digital imaging technologies like MRI, machine learning, and deep learning for improved detection and evaluation of dementia.

III. AI-BASED TECHNIQUES FOR DEMENTIA DETECTION

A. AI in Healthcare: A Transformative Force

Machine Learning Algorithms: Utilizing vast datasets to identify patterns and predict cognitive decline, thereby facilitating early intervention.

Deep Learning Models: It Implementing advanced neu-ral networks to analyze MRI and PET scans for better classification of dementia types.

Natural Language Processing: Implements the management of surgeries in a more efficient way, making it less invasive.

Virtual Health Assistants: These enhance clinician-patient conversation, hence enhancing patient satisfaction.

Clinical Decision Support: Instruction based on guidelines that gives information for sound execution of the diagnostic and therapeutic processes.

Regarding healthcare, AI development will, in turn, keep on advancing with promises of changes in patient health, productivity, new technologies, quality of care, and solving healthcare challenges.

B. Deep Learning in Healthcare: A Powerful Tool for Medical Advancements:

The deep learning algorithms find their use in analyzing medical data, patterns, and predictions in healthcare. Other techniques used for feature learning include CNN, RNN, GAN, autoencoder learning, transferred learning, attention mechanisms, and multimodal learning [10].

C. Applications of Deep Learning in Healthcare:

The deep learning algorithms find their use in analyzing medical data, patterns, and predictions in healthcare. Other techniques used for feature learning include CNN, RNN, GAN, autoencoder learning, transferred learning, attention mechanisms, and multimodal learning.

Deep learning is being used in a variety of medical processes today, such as:

- **Medical image analysis:** Diagnosing diseases, including cancer, identifying structural anomalies, and supporting surgeries.
- **Drug discovery:** A concise assessment of molecules for their ability to qualify as prospective drugs and to expedite the process of drug discovery.
- **Personalized medicine:** Developing patient-specific courses of action in light of the patient's genetics and other specific factors.
- **Predictive analytics:** Constructing existing disease modelling forecasts, patient prognosis, and therapeutic efficiency.
- **Clinical decision support:** Facilitating recommendations about the best practices in the rapidly changing health care field for professionals to make ideal decisions.

Such advanced solutions in the field of medicine could be facilitated by deep learning technology through better accuracy of diagnostic tools, higher efficacy of treatment, and faster development of medications.

D. Machine Learning for Dementia Detection and Classification: A Comprehensive Overview

Artificial intelligence, mainly device studying, has received prominence in the analysis of clinical photos, mainly in the prognosis of dementia. by way of leveraging those strategies, healthcare specialists can appreciably enhance the detection and category of numerous dementia types.

Pre-Processing: Pre-processing of medical images eliminates background noise, facilitating accurate disease diagnosis through filtering, intensity correction, and skull stripping.

Segmentation: Segmentation techniques are utilized to divide images into distinct regions, particularly for isolating areas affected by dementia, employing methods such as thresholding, clustering, meta-heuristic algorithms, and deep learning.

Feature Extraction: The features identified from the segmented images used in this study for classification include texture properties, wavelet coefficients, and techniques from deep learning.

Classification: Techniques which include guide Vector Machines, Random forest, Logistic Regression, and K-Nearest neighbors can be carried out to categorize the extracted functions based on insights gained from schooling datasets.

Model Evaluation and Validation: Validation methods evaluate the performance of these models using various performance metrics: accuracy, precision, recall, F1 score, and ROC-AUC to predict their result on new data.

Explainable AI (XAI): As machine learning models become more prevalent in healthcare, decision-making processes need to be further analyzed to build confidence in AI-based solutions through methods such as SHAP and LIME. Integration with machine learning provides the best of both worlds by improving classification

Applications of Machine Learning in Dementia Analysis:

Dementia Classification: This approach assists in distinguishing between different types of dementia based on specific characteristics and imaging features.

Prognosis Prediction: Aiding healthcare professionals and families in understanding the progression of dementia and planning appropriate care strategies Treatment planning: Facilitating the development of personalized care plans tailored to the unique needs and conditions of dementia patients, which vary based on the stages. Thus, insights gained from machine learning methodologies can aid in the management of dementia, ultimately benefiting patient outcomes.

IV. Image Preprocessing Techniques

Grayscale conversion and denoising are important preprocessing steps for medical image analysis, especially MRI scans for brain diagnosis. Grayscale conversion helps detect patterns and defects by displaying data in various colors and controlling the intensity. Denoising techniques include Gaussian blurring technology, median filtering, Wiener filter, and high-pass filter. This technology improves image quality and machine learning algorithms for brain imaging in MRI. Histogram equalization and difference normals are widely used in clinical practice to visualize more tumors. Histogram equalization is a method of solving digital image problems that increases the difference by dividing the high levels in an image. Similar medical images process the pixel intensity used to define features and use a non-uniform comparison method. Homomorphic filtering improves the illumination and distortion of images, especially in low-resolution and non-uniform cases. Advanced technology increases the contrast between images by modifying the processing process according to local image features. The most common adaptive techniques include AHE and CLAHE, which increase contrast and reduce noise with less noise, making them useful in brain imaging.

V. Advanced Image Enhancement and Segmentation Techniques

A. Enhancing Medical Images: A Comprehensive Overview

Enhancing Medical Images in MRI Scans

- Techniques include histogram equalization, contrast stretching, Auto Histogram Equalization (AHE), Contrast Limited Adaptive Histogram Equalization (CLAHE), Median filter, Gaussian filter, Wiener filter, Homomorphic filter, Wavelet transform, Unsharp masking, Laplacian filter, Color space convergence, and deep learning-based image enhancement.
- These techniques improve lighting, reflective, and features needed for visualization in medical images [**?**].

B. Segmentation Techniques for Dementia Detection in MRI Images

- The techniques employed include Thresholding, K-means Clustering, Fuzzy C-Means Clustering, and Mean Shift Clustering.
- CNNs and U-Net architectures, leveraging deep learning techniques, provide superior segmentation capabilities.
- The integration of these methodologies improves the identification of dementia-related changes and supports treatment planning.

VI. Classification Techniques for Dementia Detection

Convolutional Neural Networks (CNN) are widely used for detecting and classifying brain tumors in medical image analysis. These models work with grid-structured data and learn spatial hierarchies of features. Efficiency is enhanced by using pre-trained models on smaller datasets through transfer learning. Researchers have achieved accuracy rates as high as about using pre-trained models VGG16 or ResNet and training them on Dementia databases.

EfficientNet is a powerful architecture for dementia detection, achieving high accuracy with minimal computational resources. It features key elements such as compound scaling, Mobile Inverted Bottleneck Convolution, and a non-linear activation function with a swing. EfficientNet-B2 model has demonstrated significant accuracy rates, with one study reporting an accuracy of 99.83

Support Vector Machines (SVM) are supervised learning algorithms used for classification and regression tasks in high-dimensional spaces. They are effective in identifying dementia by classifying MRI images through various feature extraction techniques. Hybrid models can be developed by combining different machine learning approaches with SVMs to improve classifier performance. Hybrid models often yield superior results from both methodologies.

VII. Performance Evaluation Metrics

A. Accuracy, Sensitivity, Specificity, F1-Score

In the sphere of healing disease, specifically in machine intelligence and deep education requests for senility discovery, act judgment versification are important for determining model influence. Here are the current progressive formulas and clarifications for key versification:

1) **Accuracy Formula:**

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$\text{Accuracy} = \frac{TP + TN}{TP}$$

- **TP (True Positives):** Correctly anticipated definite cases.
- **TN (True Negatives):** Correctly concluded negative cases.
- **FP (False Positives):** Incorrectly concluded helpful cases.
- **FN (False Negatives):** Incorrectly called negative cases.

2) **Sensitivity (Recall or True Positive Rate)**

$$\text{Formula:} \quad \text{Sensitivity} = \frac{TP}{TP + FN}$$

Description: Sensitivity evaluates the model's skill to recognize helpful cases right. High sensitivity is important for early senility discovery as it minimizes the risk of absent real cases.

3) **Specificity (True Negative Rate)**

$$\text{Formula:} \quad \text{Specificity} = \frac{TN}{TN + FP}$$

Description: Specificity evaluates the model's talent to correctly label negative cases. It is essential in validating that non-senility cases are right, preventing superfluous tension or situation.

4) **F1-Score**

$$\text{Formula:} \quad \text{F1-Score} = \frac{2 \times \text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

5) **Precision:**

$$\text{Precision} = \frac{TP}{TP + FP}$$

Description: The F1-Score is the harmonic mean of accuracy and recall, providing a single metric that balances both, similar to a photo taken with a camera capturing the right and wrong aspects.

B. Peak Signal-to-Noise Ratio (PSNR) and Processing Time

- **Peak Signal-to-Noise Ratio (PSNR):** Measures the quality of reconstructed images by comparing the maximum power of a signal to the power of corrupting noise. Higher PSNR values are considered better quality, with values over 30 dB considered acceptable and values above 40 dB considered very high-quality.
- **Processing Time:** Refers to the time it takes an algorithm or model to perform an operation on the image, ranging from seconds to milliseconds. Clinical practice aims for short processing times with high precision for accurate model diagnosis using limited computational resources.

C. Comparison of AI Models for Dementia Detection

The evaluation of various AI models for dementia detection utilizes four key performance metrics: accuracy, sensitivity, specificity, and F1 score. Among these, advanced models such as DenseNet201, InceptionResNetV2, and Caps-VGGNet demonstrate superior performance across each metric. In contrast, simpler architectures like the 3-Layer CNN exhibit comparatively lower effectiveness. The corresponding bar chart in Fig. 1 illustrates the performance of each model on these specific metrics, highlighting the differences in efficiency and suitability for dementia diagnosis.

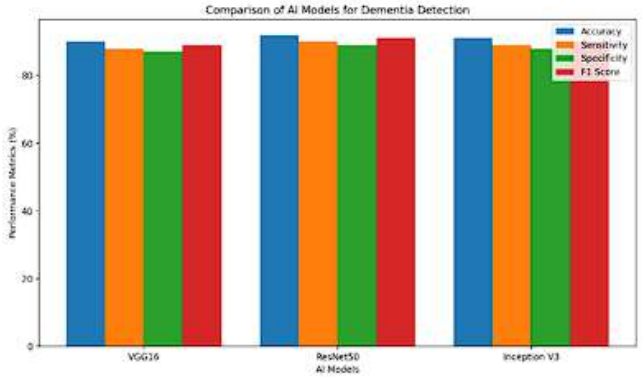


Fig. 1. Comparison of AI Models for Dementia Detection: A Comparative Analysis From Table I

VIII. Research Gaps and Challenges

Machine learning and deep learning in dementia research face challenges such as temporal changes in epidemiology, lack of guidelines, ethical and legal issues, and an overemphasis on performance. Many models remain unexplored, and the socioeconomic factors that influence dementia are largely unknown. Addressing these issues is critical to preventing inappropriate use of AI and machine learning in healthcare. Poor medical images can lead to false positives and negatives, affecting patient care and the reliability of machine learning models. The problem of small samples can be addressed by encouraging data sharing across research centers. Solving these problems requires powerful algorithms, advanced image design and development, advanced imaging techniques, and compatibility. Multimodal imaging also has limitations in the diagnosis and treatment of dementia, including underdiagnosis, problems with early detection, inadequate treatment planning, high costs, and barriers to research progress. Solutions such as data modeling, data fusion development, integration, education, research, and clinical trials can improve diagnostic and treatment strategies.

TABLE I
MODEL PERFORMANCE COMPARISON

Model	Accuracy (%)	Sensitivity (%)	Specificity (%)	F1 Score (%)	Parameters (Million)	Training Time	Complexity
VGG16	98.5	98.6	98.4	98.9	138	Medium	High
VGG19	96.3	96.5	96.1	96.4	144	Medium-High	Very High
Inception V3	97.1	97.3	96.9	96.8	23	High	Medium-High
Xception	97.4	98.2	96.8	97.1	Not specified	High	Medium-High
ResNet50	97.0	98.1	96.4	97.3	Not specified	High	Medium-High
InceptionResNetV2	98.0	98.2	97.9	97.6	Not specified	High	Medium-High
EfficientNet-B0	98.4	99.0	98.0	98.6	Not specified	High	Medium
EfficientNet-B4	96.8	96.5	97.1	96.7	19	High	Medium
Caps-VGGNet	99.2	99.1	99.3	99.0	138	3.5 hours	High
DenseNet201	95.5	94.0	96.0	94.9	20	12.8 hours	Medium
VGGNet-ResNe	96.0	95.5	96.5	95.8	144	17.1 hours	High
3-Layer CNN	90.0	89.5	90.5	89.8	2	Low	Low

TABLE II
CHALLENGES OF INADEQUATE IMAGE QUALITY ENHANCEMENT

Challenge	Description
Noise and Artifacts	MRI scans for dementia often contain noise and artifacts that obscure critical brain features, hindering the accurate identification of dementia-related changes.
Low Contrast	Insufficient contrast in MRI images can obscure key brain regions, potentially leading to missed diagnoses or inaccurate classification of dementia severity.
Blurred Images	Motion artifacts or suboptimal imaging techniques can result in blurred images, complicating the segmentation and classification tasks essential for dementia diagnosis.
Inconsistent Image Quality	Variability in image quality across different MRI scans can adversely impact the performance of machine learning models, as they may not generalize well to these inconsistencies.
Limited Resolution	Low-resolution MRI images may fail to capture the fine details necessary for precise dementia detection and characterization, risking oversight of critical neurological signs.
Ineffective preprocessing	Subpar preprocessing methods can inadequately enhance image quality, leading to inferior input data for machine learning models, ultimately affecting diagnostic accuracy.
Challenges in Feature Extraction	Poor image quality can obstruct the extraction of pertinent features crucial for training effective classification models, thereby diminishing the accuracy of dementia detection.

TABLE III
CHALLENGES OF LACK OF MULTIMODAL IMAGING DATA INTEGRATION

Challenge	Description
Data Silos	Different imaging modalities often produce data stored in isolated systems, complicating comprehensive access and analysis necessary for accurate dementia assessment.
Inconsistent Data Formats	Variability in data formats and standards across various imaging modalities hinders effective integration and analysis for dementia diagnostics.
Complexity of Data Fusion	Integrating and processing multimodal data available in substantially heightens computational and necessary crucial requirements, potentially obstructing real-time analysis critical for timely dementia diagnosis.
Increased Computational Requirements	Integrating and processing multimodal data can significantly increase computational demands, making real-time analysis difficult.
Limited Research and Development	There is insufficient research focusing on effective methodologies for integrating multimodal imaging data, resulting in the underutilization of available information that could enhance dementia detection.
Clinical Workflow Disruption	Incorporating multimodal data into established clinical workflows can be disruptive and may necessitate significant alterations to current practices, potentially affecting diagnostic efficiency.
Training and Expertise	Healthcare professionals may not possess the necessary training or expertise to effectively interpret and utilize integrated multimodal data, which can impede accurate dementia diagnosis.

IX. ETHICAL CONSIDERATIONS AND EXPLAINABLE AI (XAI) IN MEDICAL DIAGNOSTICS

Some of the benefits that have been realized from real-time clinical applications include accurate diagnosis and improved dementia detection through multimodal integration in medical imaging, which is a crucial advancement in diagnostic accuracy. Machine learning technologies enhance the identification of dementia-related abnormalities in MRI scans in real-time, offering a faster and more efficient approach compared to traditional diagnostic methods. Telemedicine and remote monitoring also enable healthcare providers to assess a patient's cognitive state by capturing relevant health metrics, tracking disease progression, and evaluating treatment efficacy. Automated reporting systems help reduce the time spent on documentation, allowing more focus on patient care. The combination of imaging and clinical data improves the precision of diagnosis and the overall outcomes for patients, ultimately enhancing the effectiveness of dementia treatments. Issues that need to be resolved include standardization, computational resources, privacy and security, and clinical validation. Academic research and healthcare organizations have to work side by side

X. FUTURE DIRECTIONS AND ENHANCEMENTS BIG

MRI image processing for dementia detection with a high degree of accuracy utilizes CNN, U-Net, GANs, Transfer Learning, Reinforcement Learning, Ensemble Learning, Explainability techniques, multiple omics integration, and attention-based models. These methods improve model performance, reduce the need for extensive training datasets,

refine treatment strategies, enhance predictive capabilities, and provide clearer explanations in clinical practice. Additionally, radiomics can uncover significant patterns within the imaging data. Advanced algorithms such as deep learning, transfer learning, and reinforcement learning can significantly improve diagnostic accuracy in assessing dementia. Real-time applications also include the integration of multimodal data, AI-driven tools, telemedicine, decision support systems, wearable devices, and automated reporting processes. Nonetheless, challenges persist regarding data standardization, computational resource demands, and privacy issues, necessitating the development of unified protocols, lightweight algorithms, and efficient real-time processing systems. Addressing clinical security concerns may involve implementing blockchain technology; however, continuous validation and cutting-edge machine learning techniques are crucial for the effective real-time clinical application of dementia detection models and assessments.

XI. Conclusion

In conclusion, the integration of Explainable Artificial Intelligence (XAI) into medical diagnostics, particularly in dementia detection, presents both significant advancements and ethical considerations. While XAI has the potential to enhance the accuracy and transparency of diagnostic processes, it also raises concerns regarding patient privacy, data security, informed consent, and fairness. Adherence to guidelines such as HIPAA is essential to establish consistent and reliable systems that safeguard patient information. The effective implementation of XAI models necessitates collaboration between AI researchers and clinicians to ensure that these tools are seamlessly integrated into clinical workflows, considering the diverse needs of end-users. Moreover, while the advancements in artificial intelligence, including multimodalities and patient-centered approaches, have shown promise in improving the prognosis of conditions like glioma, it is crucial to address the potential challenges of data security and ethical implications that may arise in real-world applications

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S.H.Barshikar
Research Scholar,
Sinhgad College of Engineering,
Savitribai Phule Pune University,Pune,India
sratunawar@gmail.com

S.S.Lokhande
Professor
Sinhgad College of Engineering,
Savitribai Phule Pune University,Pune,India
sslokhande.scoe@sinhgad.edu

Abstract*— If kidney tumors are not discovered in time, they may be fatal. The goal of this research is to increase the precision and speed of kidney tumor identification by combining machine learning approaches with cutting-edge imaging technologies like CT and MRI images. In order to detect tumors, machine learning algorithms examine comprehensive kidney pictures, differentiating between benign (non-cancerous) and malignant (cancerous) growths. Large medical image datasets are used to train these systems to identify patterns that the human eye might miss. With this strategy, we hope to lower errors, identify patients more quickly, and assist physicians in making better judgments. Through improved patient treatment planning and early detection, this technology has the potential to save lives. This research covers the way for additional fruitful lines of inquiry, which ought to enhance nephrology diagnostics and patient care. The comparative analysis of the proposed method shows the accuracy as 98.71%.The integration of these models into healthcare systems holds promise for enhancing diagnostic accuracy and reliability.

Keywords: CNN, CT, MRI, AI

I. INTRODUCTION

Unusual growths in the kidneys that can be either benign or malignant are known as kidney tumors. For malignant tumors to be effectively treated and to increase a patient's chances of recovery, early diagnosis is essential. To detect kidney cancers, physicians have historically relied on imaging techniques such as CT[9] scans, MRIs, and ultrasounds. But manually deciphering these pictures might take a lot of effort and occasionally result in mistakes. As technology has advanced, imaging techniques and machine learning approaches have been integrated to create useful tools for medical diagnosis [7]. Doctors can more effectively identify kidney [4] malignancies thanks to machine learning, which enables computers to evaluate vast volumes of medical images fast and precisely. The kidneys are vital organs that aid in maintaining bodily fluid balance and removing waste from the circulation. Tumors, or abnormal growths, can occasionally form in the kidneys [4]. Both benign (non-cancerous) and malignant (cancerous) tumors are possible. For effective treatment, these tumors must be identified and categorized as soon as possible. Kidney tumor detection using Machine Learning (ML) algorithms addresses the issue of the acute need to improve diagnostic abilities in the realm of medical imaging.

II. LITERATURE REVIEW

The goal of the study is to increase the effectiveness and precision of renal mass identification without the need for manual intervention by utilizing deep learning models. By combining many imaging sequences, multi-parametric MRI offers comprehensive details about kidney tissues. The authors automatically identified and segmented kidney masses using deep learning algorithms and this sophisticated imaging technology. Their approach showed promise for improving early tumor identification and drastically lowering radiologists' burden. This study demonstrates how deep learning can provide accurate and automated solutions for challenging diagnostic tasks, underscoring the growing significance of artificial intelligence in medical imaging.[1]

Focuses on utilizing cutting-edge methods like radiomics and deep learning to identify various kidney tumor kinds. While deep learning employs artificial intelligence (AI) to assess these features, radiomics focuses on extracting specific features from medical pictures (such as CT or MRI scans). The review investigates how integrating these instruments can enhance kidney tumor diagnosis precision. Doctors can more accurately identify the sorts of tumors by examining patterns in medical imaging, which is crucial for selecting the most effective course of therapy. This method may result in kidney cancer diagnoses that are sooner and more accurate [2].

Framework for recognizing and categorizing kidney cancers using cutting-edge AI approaches. To increase accuracy, it makes use of deep learning networks that adjust and concentrate on key areas of medical images. To improve the system's performance, the framework also incorporates an improved Crayfish Optimization Algorithm. This method aids in more accurately classifying the type of tumor and segmenting (separating) the tumor

region in medical scans. The objective is to help physicians diagnose kidney cancers more quickly, accurately, and consistently [3].

Novel method for the autonomous identification of kidney disorders through the use of deep learning and CT imaging is presented in [4]. The creation of such AI-powered systems may greatly reduce the workload for medical personnel and enable the early detection and management of kidney disorders.

Work introduces a new method for kidney tumor segmentation based on the Attention 3D-CU-Net, a sophisticated deep learning architecture. By focusing on certain characteristics, the approach aims to overcome the difficulties associated with precise tumor identification. Combining 3D convolutional layers with attention methods to improve feature extraction and concentrate on the most important areas of medical images is the main breakthrough. To improve spatial and contextual information flow and increase segmentation precision, the proposed Attention 3D-CU-Net makes use of contextual attention modules and skips connections. In regions with poor contrast or noise, the architecture is very good at decreasing segmentation mistakes and capturing intricate kidney tumor boundaries [5].

A cutting-edge architecture for kidney is disease classification based on medical imaging demonstrated in [6]. The suggested MSKd_Net model combines a customized convolutional model improved by a multi-head attention mechanism with the Swin Transformer, a hierarchical vision transformer that is well-known for capturing both local and global data. The goal of this combination is to refine feature extraction by efficiently capturing long-range dependencies and linkages within input sequences,the MSKd_Net design performs better at classifying different kidney illnesses from CT scan pictures by skilfully fusing the advantages of multi-head attention methods and Swin Transformers.

Multi-modal analysis can significantly improve kidney tumor classification, offering more precise and dependable tools for diagnosis. Classifying kidney tumors entails identifying the tumor kind, which is essential for selecting the best course of action. Doctors frequently use medical imaging, such as CT or MRI scans, to do this. Accuracy may be impacted by these photos' occasional incompleteness or poor quality. By creating missing or ambiguous portions, this method can improve or restore partial medical images, increasing their analytical value. Then, in order to better categorize kidney cancers, the researchers employed multi-modal imaging, which combines many medical image types. By combining information from many sources, multi-modal pictures provide a more thorough view of the tumor.According to the study, this method increases tumor classification's precision and dependability. [7]

With notable gains in classification accuracy, this study presents a potential hybrid deep learning model for cancer prediction. A useful technique for biomedical applications, the combination of RNN and CNN [8] efficiently captures both spatial and sequential patterns in gene expression data. The model's optimization for actual clinical settings can be the subject of future studies.

In order to minimize catastrophic forgetting, the study uses the Learning Without Forgetting (LwF) technique, which allows deep neural networks to integrate new data while retaining previously learned information. The results demonstrate the model's effectiveness in handling incremental learning while maintaining classification performance. The study is valuable for enhancing AI-driven cancer diagnosis, minimizing dependency on costly retraining, and optimizing medical image classification [9].

Using Convolutional Neural Networks (CNNs) and Internet of Things (IOT) technologies, this research proposes a novel early warning system for kidney cancer recurrence. IoT-enabled medical devices are integrated into the suggested system to continually monitor patient data, and CNN-based deep learning algorithms examine the data gathered to forecast the possibility of renal cancer recurrence. According to experimental data, the system is highly accurate at predicting cancer recurrence, which makes it a promising tool for proactive treatment planning and individualized healthcare [10].

Specialized form of artificial intelligence known as a Convolutional Neural Network (CNN) to create a system that automatically detects kidney

abnormalities in CT scans. This technique focuses on rapidly and accurately detecting the afflicted areas in CT scans, which can help physicians with diagnosis and therapy planning. According to the study, this method is successful and efficient, and it has potential for use in medical imaging applications [11].

The use of machine learning (ML) techniques in the prediction of chronic kidney disease (CKD), a progressive condition that impairs kidney function. The study emphasizes how ML techniques can transform CKD diagnosis, making it more accurate and efficient. The results of the study to stimulate additional research in AI-driven healthcare solutions for early disease prediction and prevention [12].

In order to improve prediction accuracy, the study suggests an Adaptive Hybridized Deep Convolutional Neural Network (AHDCNN), which combines convolutional neural networks (CNNs) with adaptive approaches. The model enhances real-time CKD diagnosis by processing patient data obtained from IOMT. The findings show that AHDCNN, which uses IOMT for real-time healthcare applications, offers a potential approach for CKD prediction [13].

The usefulness of different machine learning (ML) approaches in forecasting Chronic Kidney Disease (CKD) is examined in this work by Bilal Khan et al. Using real-world CKD datasets, the authors assess various machine learning algorithms, such as decision trees, support vector machines (SVM), and neural networks. To identify the most effective model, their analysis focuses on performance indicators including recall, accuracy, and precision. According to the results, ML models can greatly help with the early detection of CKD, which could help medical professionals with prompt diagnosis and treatment planning [14].

Image patches are used to train the suggested CNN model, which aids in the learning of localized, features for precise categorization. The study shows that the CNN model achieves good sensitivity and specificity by comparing its performance with conventional radiological examinations. This automated method could help radiologists characterize kidney masses more effectively and with fewer diagnostic errors.The study emphasizes the advantages of patch-based learning in medical image processing and adds to the expanding application of AI in medical imaging.[15]

Methodology

A.Kidney Tumor Detection process

Enhancing image quality and lowering noise levels are prerequisites for precise feature extraction and segmentation.

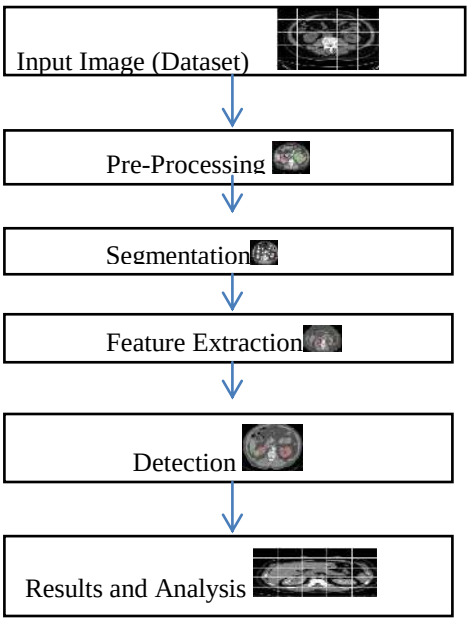


Fig.1: General model for kidney tumor detection and Classification

Image processing includes methods such as feature extraction finding particular tumor characteristics from the photos and segmentation removing significant portions of the image. Convolutional Neural Networks (CNN), deep learning a multi-layered kind of machine learning, and transfer learning applying previously trained models to new tasks are examples of machine learning models, which are algorithms that learn from the data.

B. Convolutional Neural Networks (CNNs)

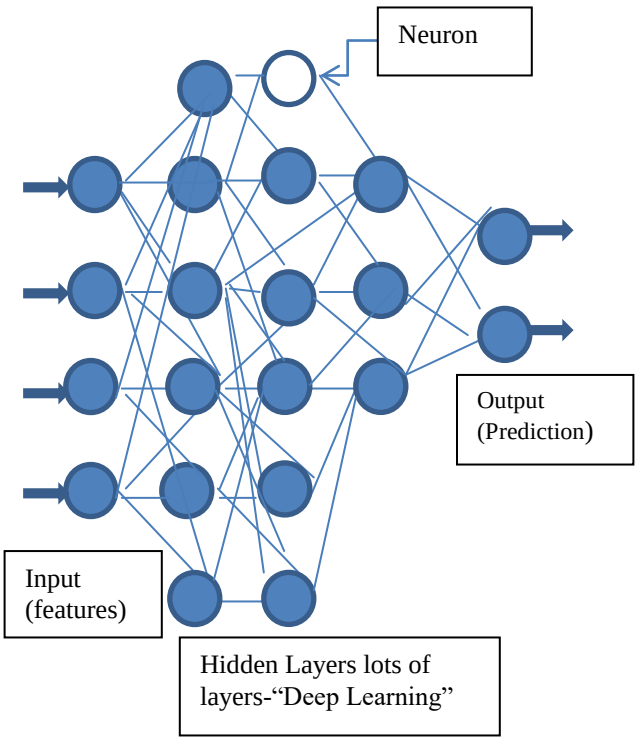


Fig.2 Convolution Neural Network block Diagram

The fundamental structure of CNN involves convolutional layers that use filters to extract local patterns. Pooling layers to decrease spatial dimensions, while fully connected layers make predictions by analyzing acquired features. Activation functions bring in non-linearity enhancing the networks capability to learn complex patterns. Convolutional Neural Networks (CNNs) are widely used in image processing due to their ability to automatically extract spatial features and patterns from images.

C. Evaluation Metrics:

(i) Accuracy -the frequency with which the model is correct

$$\text{Accuracy} = \frac{\text{No of correct predictions}}{\text{Total no of Predictions}} \quad (1)$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (2)$$

(ii)Precision- is used to measure how many of the positive predictions made by the model are actually correct.

$$Precision = \frac{TP}{TP + FP} \quad (3)$$

(ii)Sensitivity -the ability to detect actual tumors

$$\text{Sensitivity} = \frac{TP}{TP + FN} \quad (4)$$

(iii)Specificity -The ability to prevent false alarm show well the model is at identifying negative cases correctly

$$\text{Specificity} = \frac{TN}{TN + FP} \quad (5)$$

(iv) AUC-ROC-a graph that illustrates the model's ability to differentiate between tumor and non-tumor cases) are used to gauge how effective the methods are. AUC measures the model's ability to distinguish between positive and negative classes across all possible classification thresholds.

Higher AUC (closer to 1) = Better model at distinguishing between classes.

AUC = 0.5 = Model is no better than random guessing.

D.Data Set

The study's data is collected from open datasets (such the TCGA, KAUH and KiTS datasets) and hospitals. It contains details on the tumors (such as size, location, and kind) as well as patient information (such as age, gender, and medical history).

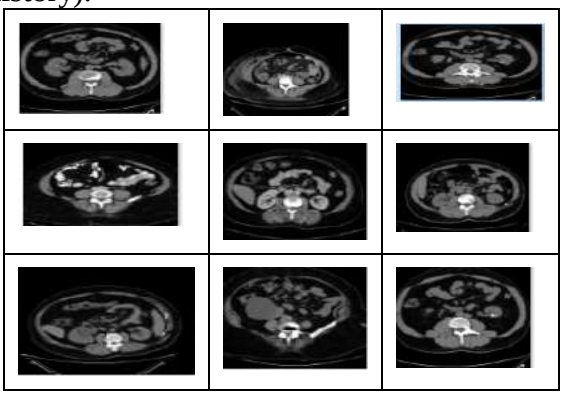
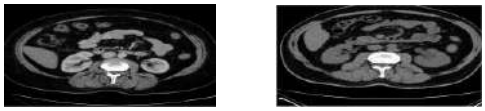


Fig 3: CT scan Data set taken from KAUH

III. Results and Discussion

Kidney cancers can be detected more precisely than with conventional methods when improved imaging and machine learning techniques are used. These methods might more accurately and early detect

malignancies. The results showed that certain models outperformed others, with CNNs frequently offering the best they are clinically significant. They might aid physicians in early tumor detection, which is essential for more effective treatment results. AI can also help medical imaging by lowering workload and human error.



(a) (b)

Fig 4 Sample CT images from KAUH Data Set

The open source dataset was collected from KAUH.Sample image is shown in figure 4.

Table I Features of the Dataset

ID
Age
Gender
Test
Clinical Data
Symptoms
Bp(blood Pressure)
Diagnosing Test
Diagnosing Right kidney
Diagnosing Left kidney
Sugar(Su)
Red blood Cells(RBC)
White blood cell count(WC)
HEMo(haemoglobin)
Ane(anemia)

The features used in the dataset are shown in Table I.

Table II: Confusion Matrix:

Sr.No.	Model	Accuracy	Sensitivity	Specificity
1	CNN	98.71%	97.35%	97.5%

Here the system achieves accuracy is 98.71%, sensitivity 97.35% and specificity 97.5%

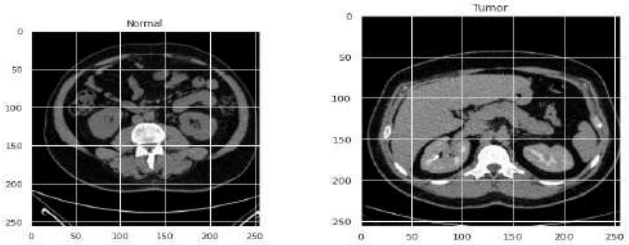


Fig 4(a)Input Image Fig 4(b)Output Image

Fig 4(a) and 4(b) input CT image and output as tumor detected image.

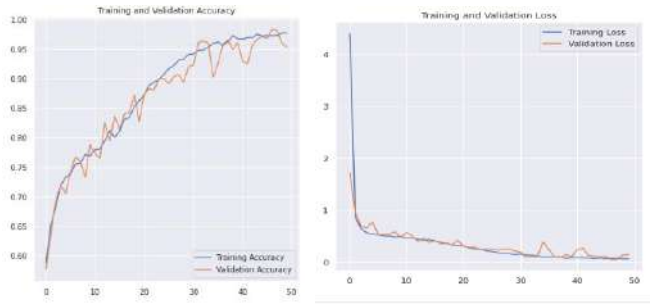


Fig: 5(a) Training Accuracy Fig: 5(b) Validation accuracy

In this plot diagram of Training and Validation Accuracy, there is epoch on X-axis and accuracy on Y-axis. During the advancement of training, the model exhibited significant enhancements in its performance.

Table III: Layer table summary

Layer (type)	Output Shape	Param #
batch_normalization (BatchNo	(None, 224, 224, 3)	12
conv2d (Conv2D)	(None, 222, 222, 32)	896
max_pooling2d (MaxPooling2D)	(None, 111, 111, 32)	0
dropout (Dropout)	(None, 111, 111, 32)	0
flatten (Flatten)	(None, 394272)	0
dense (Dense)	(None, 128)	50466944
dense_1 (Dense)	(None, 2)	258

Total params: 50,468,110
Trainable params: 50,468,104
Non-trainable params: 6

Layer Table summary gives detailing about enhancement, filter transforms, segments, Recognize and Restore the images.

IV. CONCLUSION

The study demonstrated that kidney tumor identification can be enhanced by utilizing machine learning and advanced imaging techniques. CNNs and other AI models assist physicians in more rapidly and precisely identifying a cancer, which improves kidney tumor diagnosis. The way kidney cancers are identified in hospitals, may be altered by these AI-based techniques. AI can assist physicians

in making better treatment decisions by increasing speed and accuracy, which will enhance patient outcomes and enable early tumor diagnosis.

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Attendance Marker Using RFID

Ayush Naik[1], Tejas Mulekar[2], Nilesh Sutar[3],Akanksha Jagdale[4],Prerna Jadhav[5], Anjali Deshmane[6]

K J College Of Engineering & Management Research, Pune

ABSTRACT

This paper introduces an innovative RFID-based smart attendance system designed to automate and simplify attendance tracking in both educational and commercial environments. The system utilizes Radio Frequency Identification (RFID) technology alongside the ESP32C3 microcontroller for processing and data transmission. RFID readers are strategically placed at entry points, and each individual is provided with a unique RFID tag. When a person with a valid tag passes by the reader, their attendance is automatically recorded in an Excel sheet. The system ensures high accuracy and reliability while significantly reducing manual work, minimizing errors, and enhancing data security. Additionally, real-time attendance confirmation is displayed on a 16x2 LCD screen.

Keywords: *RFID technology and Apllication,ESP32, RFID-RC522 module, DataBased Sheet,etc.*

INTRODUCTION

Conventional attendance methods often involve students signing a physical sheet during each class session. While this practice is widespread, it lacks efficiency and is prone to several drawbacks.

For instance, students may waste time locating their names, and there's a risk of proxy attendance where one student signs in on behalf of another. Additionally, the attendance sheet can be easily lost or misplaced. To overcome these limitations, our proposed system leverages RFID technology to automate the attendance process. Students can simply scan their ID cards at an RFID reader, allowing for quick, accurate, and secure recording of attendance. RFID (Radio Frequency Identification) is a contactless technology that enables the exchange of data between a reader and a tag without the need for physical interaction. Beyond just recording attendance, our system includes an online platform that allows real-time access to records. This makes it easier for lecturers and academic staff to track attendance and monitor student engagement from anywhere, enhancing overall administrative efficiency.

PROBLEM STATEMENT

[1] RFID Tag Detection Issues Weak signal or inconsistent scanning of RFID tags. Interference from metal objects or other electronic devices.[2] LCD Display Malfunctions Display not showing data properly due to incorrect wiring. Contrast issues making text unreadable.[3] Data Storage & Transfer Issues Errors while sending attendance data to Excel sheet. Duplicate entries or missing records due to network delays. [4] Code & Firmware Bugs Unexpected ESP32 crashes due to coding errors. Delayed responses from the RFID module causing slow attendance marking. [5].. Network connectivity issues affecting real-time data upload or synchronization. [6] Low power problems leading to device shutdowns and missed attendance records.

APLLICATIONS FOR THE SYSTEM

RFID technology has become increasingly prevalent across diverse sectors due to its efficiency in tracking and automation. In educational settings, it helps schools and universities automate student attendance, minimizing manual work and errors. In the corporate world, businesses integrate RFID to manage employee attendance and streamline payroll processes. Hospitals use it to monitor the presence of medical staff, improving scheduling and resource allocation. Libraries benefit from RFID by logging visits from students and faculty, aiding in usage analytics. In industrial environments, factories use it not only to track worker attendance but also to control access to restricted or hazardous zones. Public transport systems adopt RFID for smooth, contactless ticketing and real-time passenger monitoring.

Hostels implement RFID to keep track of student movements, enhancing security within the premises. Hotels use the technology for efficient check-ins and secure room access, offering a seamless experience to guests. Warehouses employ RFID to manage both employee attendance and the movement of goods. Research laboratories enhance security with RFID by limiting access to sensitive areas. In sports complexes, it helps monitor entry and exit of players and staff to maintain order. Finally, government offices rely on RFID for secure tracking of employees and visitors, ensuring accountability and safety.

OBJECTIVE

1. Automating Attendance: Streamlines the process of marking attendance by eliminating manual input, thereby reducing errors and saving effort.
2. Boosting Security: Ensures that only individuals with authorized RFID tags can access the premises, preventing unauthorized entry.
3. Saving Time: Speeds up the check-in process through quick RFID scans, making attendance marking almost instantaneous.
4. Ensuring Accuracy: Delivers consistent and error-free attendance records by removing the chance of manual mistakes.
5. Preventing Proxy Attendance: Makes it difficult for anyone to mark attendance on someone else's behalf, as each RFID tag is uniquely linked to an individual.
6. Secure Data Management: Keeps attendance data safe and organized within a centralized system, allowing for easy tracking and management.
7. Attendance Analytics: Facilitates real-time generation of attendance reports to assist in monitoring and decision-making.
8. Remote Monitoring Capability: Allows administrators to access and oversee attendance data from any location using mobile or web platforms.

SYSTEM DESIGN

To support the development of the system, a thorough review of relevant literature was conducted to explore existing theories, technologies, and methodologies used in similar applications.
Additional background research on institutional needs and comparisons with current attendance systems helped in identifying the specific requirements for the new system. The proposed RFID- based attendance system is intended to automate the process of recording student presence, particularly within university settings. An overview of the system's structure is depicted in Figure 1, which presents the complete block diagram.

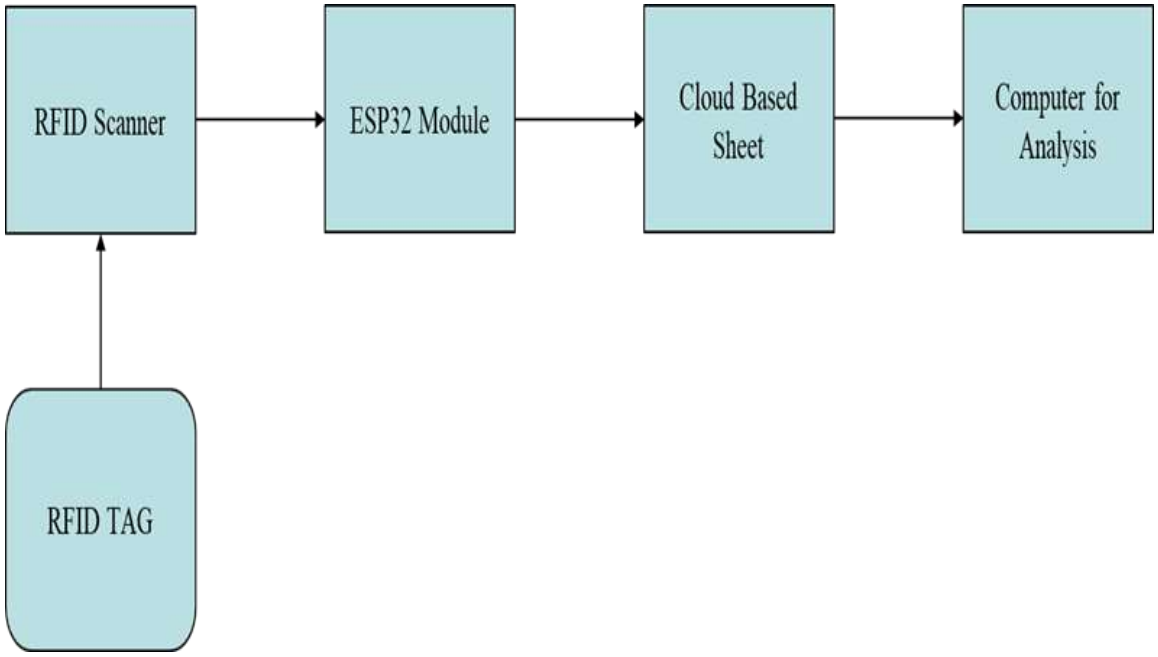


Figure 1: Block Diagram of System

- **RFID Tag:**

An RFID tag is a small electronic device that stores a unique identification number and communicates wirelessly with an RFID reader using radio waves. It includes a microchip for data storage and an antenna that enables signal transmission. When the tag comes close to an RFID reader, it sends its unique ID, which is then used for identification and verification. RFID tags are commonly used in various applications, such as attendance monitoring, access control, inventory management, and automation, because of their reliability and effectiveness.

- **RFID Scanner:**

An RFID scanner is designed to read RFID tags and send the captured data to a microcontroller for verification. Using RFID technology, it wirelessly detects the unique identification codes of tags. Typically consisting of a reader module (such as the RC522) and an antenna, the scanner captures the tag's ID and forwards it to the ESP32 for processing. If the ID is recognized as valid, attendance is marked; otherwise, an error is shown. RFID scanners are commonly employed in

applications like attendance tracking, access control, and automation because of their accuracy and efficiency.

- **ESP 32 Module :**

The ESP32 is a versatile microcontroller equipped with both WiFi and Bluetooth capabilities, making it perfect for IoT projects and embedded systems. It boasts a dual-core processor, a wide range of GPIO pins, and supports communication protocols like SPI, I2C, and UART, ensuring smooth integration with various components, such as RFID modules, LCD screens, and buzzers. In an RFID-based attendance system, the ESP32 processes the scanned RFID data, verifies it, updates the records, and shows the attendance status on the LCD display. Its low power consumption and wireless connectivity make it well-suited for applications requiring real-time data tracking and remote access.

ISBN: 978-93-343-2006-0

- **Cloud Based Sheet :**

A cloud-based spreadsheet, like Google Sheets, is an online tool that facilitates real-time data storage, management, and access. In an RFID-based attendance system, the scanned information can be automatically entered into a cloud spreadsheet through APIs, offering advantages such as remote access, secure backups, and easy data analysis. This approach eliminates the need for manual data entry, improves security, and allows administrators to monitor attendance from any location. The ESP32 integrates with cloud services like Google Sheets API, ensuring smooth and efficient record-keeping.

- **Computer for Analysis :**

A computer for analysis is used to process and evaluate attendance data collected from the RFID- based system. The recorded data, stored in a cloud-based sheet, local database, or Excel file, can be analyzed to generate reports, trends, and insights. Administrators can use data visualization tools, spreadsheets, or custom software to monitor attendance patterns, identify irregularities, and improve management efficiency. The computer also enables automated calculations, filtering, and exporting of records, making attendance tracking more effective and data-driven.

This circuit diagram represents an RFID-based attendance marker using an ESP32, an RFIDRC522 module, and a buzzer module.

- **ESP32:**

The ESP32 is an affordable System on Chip (SoC) microcontroller developed by Espressif Systems, the same company behind the widely popular ESP8266. As the successor to the ESP8266, the ESP32 offers enhanced performance and is available in both single-core and dual- core variants, based on Tensilica's 32-bit Xtensa LX6 processor. One of its standout features is the built-in Wi-Fi and Bluetooth connectivity. What makes the ESP32 particularly hardware-friendly is its integrated RF components—including a power amplifier, low-noise receive amplifier, antenna switch, filters, and an RF balun. These built-in elements significantly reduce the need for external circuitry, making it easier to design and build wireless applications.

- **Specifications of ESP32 :**

The ESP32 stands out as a major upgrade over the ESP8266, offering a wide array of advanced features. While it's not possible to cover every detail in this brief overview, here are some of the most important specifications you should know. For those interested in exploring every technical aspect, the official datasheet is the best resource. Below are some key features that highlight the power and versatility of the system.

ESP32:

- Available in single-core or dual-core configurations with a 32-bit Xtensa LX6 processor, running at speeds up to 240 MHz
- Includes 520 KB of SRAM, 448 KB of internal ROM, and 16 KB of RTC fast memory
- Built-in support for Wi-Fi (802.11 b/g/n), capable of reaching up to 150 Mbps
- Dual-mode Bluetooth support, including both Classic Bluetooth v4.2 and Bluetooth Low Energy (BLE)
- Offers 34 general-purpose input/output (GPIO) pins.
- Features 18 channels of 12-bit ADC and 2 channels of 8-bit DAC
- Multiple peripheral interfaces: 4 SPI, 2 I2C, 2 I2S, and 3 UART ports
- Integrated Ethernet MAC interface, which requires an external PHY for wired LAN connections. Support for SD, SDIO, and MMC through a host controller, along with an SDIO/SPI slave interfacePWM outputs for motor control, plus up to 16.

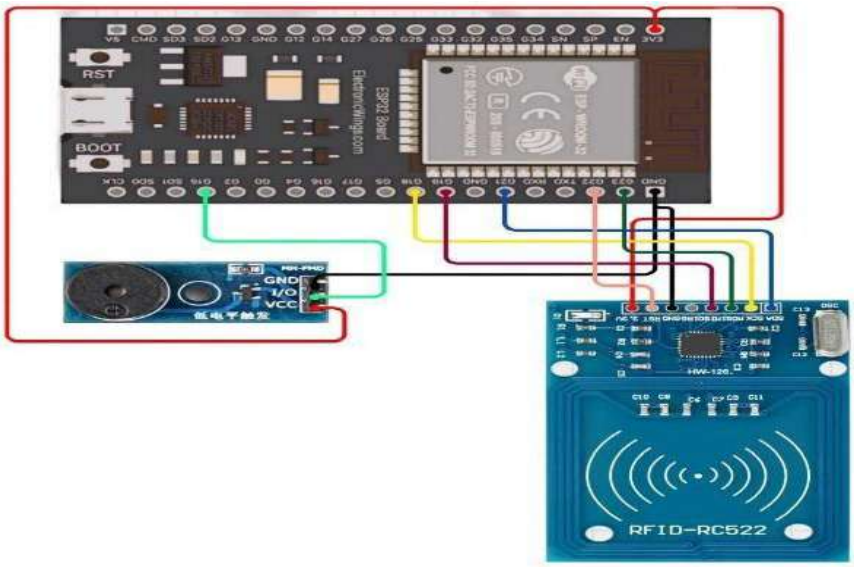
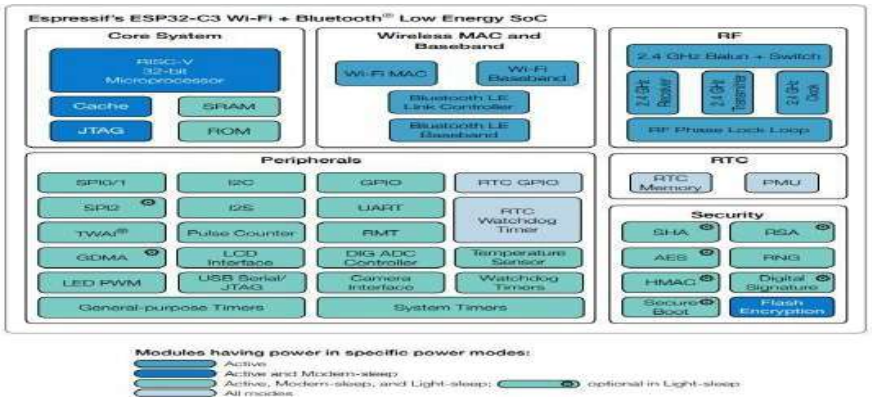


Figure 2: Circuit Diagram of system

- and Flash Encryption

Built-in hardware acceleration for encryption and hashing algorithms such as AES, SHA-2, RSA, ECC, and RNG of ESP32.



1. A complete Wi-Fi subsystem that complies with IEEE 802.11b/g/n protocol and supports

Station mode, Soft AP mode, Soft AP + Station mode, and promiscuous mode.[2]A Bluetooth LE subsystem that supports features of Bluetooth 5 and Bluetooth mesh[3]32-bit RISC-V single-core processor with a four-stage pipeline that operates at up to 160MHz[4] State-of-the-art power and RF performance memory, external memory, and peripherals –

External memory encryption and decryption[5]Storage capacities ensured by 400 KB of SRAM (16 KB for cache) and 384 KB of ROM on the chip, and SPI, Dual SPI, Quad SPI, and QPI interfaces that allow connection to external flash [6]Reliable security features ensured by – Cryptographic hardware accelerators that support AES-128/256, Hash, RSA, HMAC, digital signature and secure boot – Random number generator – Permission control on accessing internal[7] Rich set of peripheral interfaces

and GPIOs, ideal for various scenarios and complex applications.

2. RFID-RC522 module:

The MFRC522 is a highly integrated reader/writer IC for contactless communicationat 13.56 MHz. The MFRC522 reader supports ISO/IEC 14443 A/MIFARE mode.The MFRC522's internal transmitter is able to drive a reader/writer antenna designed to communicate with ISO/IEC 14443 A/MIFARE cards and transponders without additional active circuitry. The receiver module provides a robust and efficient implementation for demodulating and decoding signals from

ISO/IEC 14443 A/MIFARE compatible cards and transponders. The digital module manages the complete ISO/IEC 14443 A framing and error detection (parity and CRC) functionality.

The MFRC522 supports MF1xxS20, MF1xxS70 and MF1xxS50 products. The

MFRC522supportscontactless communication and uses MIFARE higher transfer speeds up to848 kBd in both directions.

The following host interfaces are provided:

[1]Serial Peripheral Interface (SPI).[2]Serial UART (similar to RS232 with voltage levels dependant on pin voltage supply).

3. METHODOLOGY

In real-life applications, students are assigned RFID tags, each containing a distinct roll number used for identification. When a student places their tag near the RFID reader, the copper coil inside the reader acts as an antenna, establishing a connection through mutual inductance. This process enables the tag to wirelessly transmit its data to the reader. The received information is then passed to a microcontroller, which handles data verification and processing. Once the tag is authenticated, the corresponding attendance details are securely recorded in a dedicated database for attendance tracking.

1. RFID Reader:

An RFID reader is a device that detects and retrieves information from RFID tags using radio frequency signals. It transfers the captured data to a microcontroller, such as an ESP32, which handles further processing. RFID tags are small electronic components embedded in cards or labels, each carrying a unique identification code along with a built-in antenna. These tags are categorized as either passive (which draw power from the reader's signal) or active (which have their own power source). Passive tags are most commonly found in applications like attendance systems, inventory tracking, and access control. When brought near an RFID reader, the tag transmits its unique ID wirelessly, enabling seamless and contactless verification.

4. I2C-bus interface

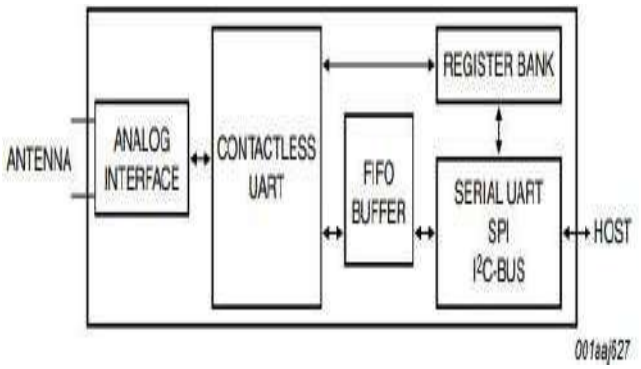


Figure 4: Simplified block diagram of the MFRC52

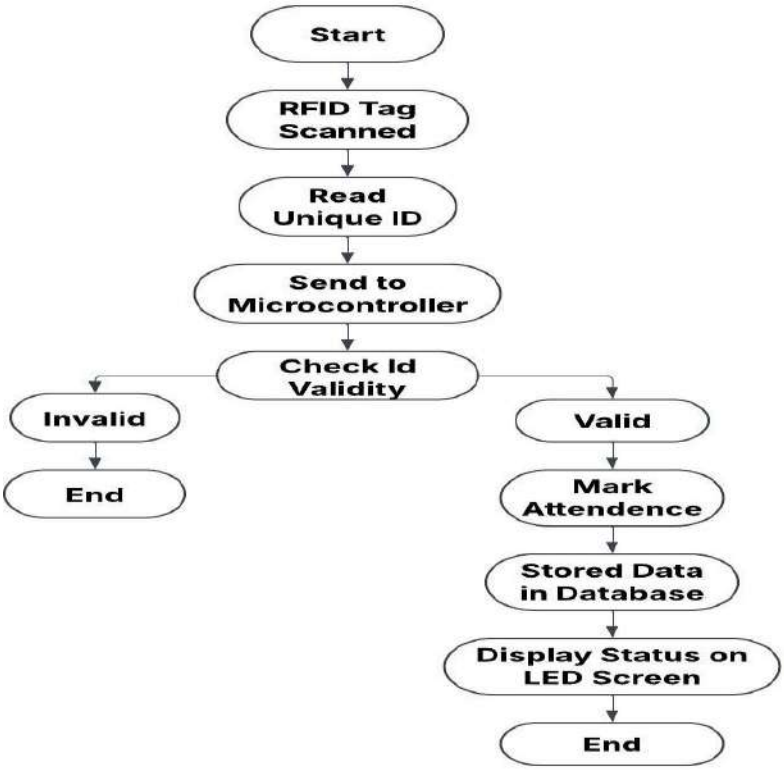


Figure 5: Flow chart of system

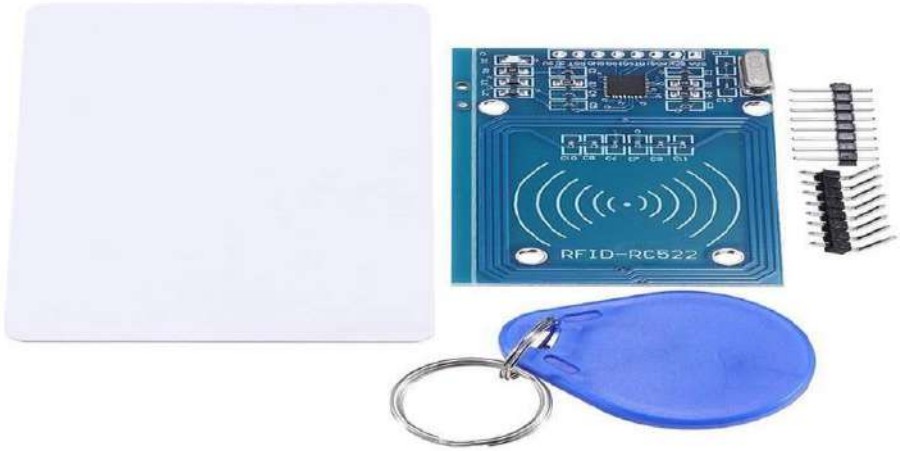


Figure 5: RFID Reader and Tag

- **CONCLUSION**

The RFID-based attendance system presents a modern approach to managing attendance by utilizing RFID technology, an ESP32 microcontroller, and Excel for local data storage. This setup delivers a fast, reliable, and contactless alternative to conventional manual or biometric methods. Key benefits of the system include:

- **Streamlined operations** through automated attendance logging,
- **Higher accuracy** by minimizing manual entry errors and preventing fraudulent check-ins,
- **Immediate visual confirmation** using a 16x2 LCD display, and
- **Organized, secure data handling** for easy retrieval and report creation.

The project showcases a dependable and scalable solution that can be effectively used in educational institutions, corporate settings, and other organizations. Future improvements could involve cloud-based storage, integration with mobile applications, and the use of data analytics to enhance functionality and accessibility even further.

- **FUTURE SCOPE**

1. **AI Integration for Smart Analysis** – Incorporating artificial intelligence to detect attendance trends, foresee potential absences, and provide actionable recommendations to boost regularity.
2. **Facial Recognition Pairing** – Enhancing security by combining RFID with facial recognition, allowing for dual-factor user verification.
3. **Cloud Platform Connectivity** – Linking the system to cloud services like AWS, Firebase, or Google Sheets to enable centralized storage and anytime, anywhere data access.
4. **Mobile App Connectivity** – Building an intuitive mobile application that lets users track their attendance history and receive timely alerts or notifications.
5. **IoT-Based Monitoring** – Employing IoT devices for real-time attendance updates, smart automation, and efficient access control.
6. **GPS-Supported Check-Ins** – Using GPS technology alongside RFID to confirm the user's actual location during attendance marking, improving reliability.
7. **Biometric Integration** – Introducing features such as fingerprint or retina scans for enhanced identity assurance and system security.
8. **Voice Assistant Functionality** – Adding support for voice-based control through AI assistants like Google Assistant, Siri, or Alexa for a hands-free experience.

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An AI Perspective towards Multi-Modal Sarcasm Detection

Eishita Sharma[1] and Naveen Kumar Gondhi[1]

[1] Department of Computer Science and Engineering
Shri Mata Vaishno Devi University
Jammu and Kashmir, India

Abstract— Sarcasm is a unique linguistic ability employed in human conversations that allows speakers to communicate an affective message as opposed to their literal intent. It is a major challenge in natural language processing application systems. While a large body of work has focused on sarcasm detection in text, the use of multimodal information, exemplified by visual and audio signals, is relatively unexplored. In this paper, we survey recent advances made by researchers in multimodal sarcasm detection, including the use of text, visual, and audio cues together for robust sarcasm detection, as well as for enhancing sarcasm detection performance. The paper also defines how to extract features across modalities— such as word embedding, CNN-based image features, and audio-based prosodic cues, and to combine them early, late, hybrid and attention- based building blocks. Besides, we study state-of-the-art deep learning structures that are used in this field and discuss performance measures. Based on a synthesis of state-of-the-art research trends, challenges and architectural proposals, the present paper highlights the urgency to develop effective multimodal approaches to unravelling the richness of human sarcasm as they are communicated in our daily lives.

Keywords— Machine Learning, Deep Learning, Natural Language Processing, Sarcasm Detection, Multimodal Sarcasm Detection

1. INTRODUCTION

Sarcasm, a linguistic device used frequently in human communication, introduces large complexity to the interpretation of textual content. Sarcasm recognition is important for sentiment analysis and opinion mining in multiple natural language processing (NLP) applications, as well as social media understanding. Ambiguity, along with context-dependency, which are pervasive in sarcasm, often result in large challenges for these methods. Multimodal learning, combining modalities like text, images, and audio, has emerged to improve AI system performance because of recent NLP advancements. In recent years, many researchers have begun exploring the combination of visual features with acoustic features to improve sarcasm detection algorithms, as a number of them realised that using multimodal cues might be helpful. The single main objective of this paper is to study multimodal sarcasm detection comprehensively through a full investigation of textual, visual, and acoustic cues. If we explore how different modalities work together, we can better understand sarcasm's complex nature, which would make current detection methods stronger.

1.1 Sarcasm Detection

Sarcasm is a way of talking where an individual says one thing but means something else, often mixed with irony & ridicule, adding a layer of complexity to understanding text. Recognising sarcasm is crucial for things like sentiment analysis, social media insights, & other NLP applications. Over the years, researchers have tried hard to develop automated tools to spot sarcasm in text, aiming to close the gap between human & machine comprehension. Recently, there's been good progress in detecting sarcasm, thanks to better machine learning & NLP methods.

Earlier, people used rule-based systems & word features to catch sarcasm. But these methods faced trouble with the more complex contextual clues and language patterns that often come with sarcastic speech. As supervised learning grew and huge annotated datasets became available, researchers turned towards developing fancier algorithms. Despite considerable advancements in sarcasm detection, several hurdles remain. Detecting sarcasm in multimodal contexts, like social media posts with pictures or videos, presents a thrilling path for research. Exploring how visual and sound features can improve these algorithms is ongoing. Plus, dealing with sarcasm in specific areas like healthcare, politics, or customer feedback needs specialised models that understand particular nuances.

1.2 Multi-modality in Sarcasm Detection

Sentiment analysis and sarcasm detection are typically performed using textual cues, but recent studies have shown the potential of utilising other forms of data to improve detection accuracy. These studies fall under the category of multimodal sarcasm detection (MSD) and include works like (Hiremath & Patil, 2021; Razali et al., 2017; Schifanella et al., 2016; Tomás et al., 2023; Yao et al., 2021). Multimodal machine learning is an active multidisciplinary research area that integrates and models several communicative modalities, such as linguistic, auditory, and visual information, to achieve some of the initial aims of AI (Morency et al., 2022).

The interaction among various representation styles, such as visuals and written or spoken word, is referred to as multimodality (Korhonen, 2010). This approach combines textual, visual, and audio features to improve sarcasm detection accuracy and involves the use of features like facial expressions, tone of voice, and gestures to identify sarcasm in a multimodal context. (Singer, 2022) Explains how a multimodal system absorbs knowledge from numerous sources and uses it for tasks involving any type of modality. This means that these systems can use data from images and a knowledge base to answer natural language questions, and data from text to perform visual tasks. Humans learn a substantial amount of common knowledge about the environment through a combination of visual, linguistic, and sensory information. When an AI system receives both image and

Table 1. Sarcasm Detection Datasets.

Modality	Datasets Available	Typical Features and Methods
Text	SARC, News Headlines	Lexicon-based dictionaries, bag-of-words, word embeddings, in combination with classifiers such as SVM or deep neural networks.
Speech	MaSaC	Paralinguistic features, e.g., pitch, in combination with classifiers such as SVM or deep recurrent neural networks
Visual	MUStARD	Mid-level visual concepts corresponding to Adjective-Noun Pairs that carry strong sentiments through convolutional neural networks; additional features include facial expression, facial action units, and visual aesthetics.
Multimodal	MUStARD; MaSaC	Multimodal fusion of text, facial expression and paralinguistic features

text inputs, it has to connect the same object or concept across modalities to accurately interpret the data. In multimodal sarcasm detection, the system uses multiple types of data sources, such as text, images, and videos, to identify sarcasm.

Sarcasm is often conveyed through a mix of verbal signals and other non-verbal clues. These include tone of voice, facial expressions & even gestures (which makes sarcasm detection quite a tough nut to crack in the field of natural language processing). Here, multimodality plays a crucial role. By looking at different types of information or modalities like text, audio, and visual cues, multimodal sarcasm analysis helps boost the accuracy of detecting sarcasm.

One approach involves mixing what we say with what we hear. For instance, when people speak sarcastically, changes in tone or pitch can be revealing signs. Another approach taps into visual hints, like emojis, body movements, or expressions on someone's face. Imagine a smirk or an eye roll, highlighting a sharp remark, captured through facial expression analysis. Also, sarcastic symbols like the face-palm or eye-roll emoji can give away the irony.

Context is another layer aiding in identifying sarcasm. Knowing what's being talked about or the speaker's history adds flavour to the interpretation. For example, if someone is famously known for their sarcastic nature, this context clue aids in recognising sarcasm with better accuracy.

2. LITERATURE SURVEY

To better detect sarcasm in text, it can be useful to gather contextual information from various modalities. By incorporating additional cues from different sources, both similar and contrasting patterns can be identified, thus enhancing the overall understanding of the text. One important source of such cues is vocal tonality, which can reveal sarcasm in the text that may otherwise appear straightforward. This can range from a self-deprecating or moody tone to a more aggressive or exaggerated tone. Other indicators of sarcasm include placing undue emphasis on specific words. (Castro et al., 2019). While using text is a common method for detecting sarcasm, the study (Subramanian et al., 2019)Utilised emojis used in between text conversations to gain a better understanding of the context of the conversations, which may help in the more accurate detection of sarcastic tones. This study aims to tackle the issue of identifying sarcasm in social media by utilising emojis.

The studies (Gupta et al., 2021) and (Sangwan et al., 2020) employed image and text data to detect sarcasm, with the latter suggesting that relying solely on textual data can be insufficient. They proposed a framework that combines text, image, and transcript data extracted from images to detect sarcasm, achieving improved prediction accuracy. Meanwhile, (Ding et al., 2022) compared single-modality with multi-modality using the multi-modal dataset MUStARD. They used pre-trained models such as BERT for text, and librosa (Babu et al., 2021; McFee et al., 2015) for audio, and ResNet152 for video to extract features. Results showed that the multi-modality set-up outperformed the single-modality set-up by 4.85% in a speaker-independent experiment.

Additionally, a study (Wu et al., 2021) introduced an "incongruity-aware attention network (IWAN)" that focuses on the word- level incongruity between modalities via a scoring mechanism to detect sarcasm. The research suggests that comprehending sarcasm is not easy without a full understanding of the context behind the sarcastic remark. Gestures and speech play a significant role in providing this contextual information, apart from textual information. These studies demonstrate that unimodal approaches, such as image-only, audio-only, or text-only, do not perform well and fail to accurately predict sarcasm, whereas multimodal approaches have shown better results.

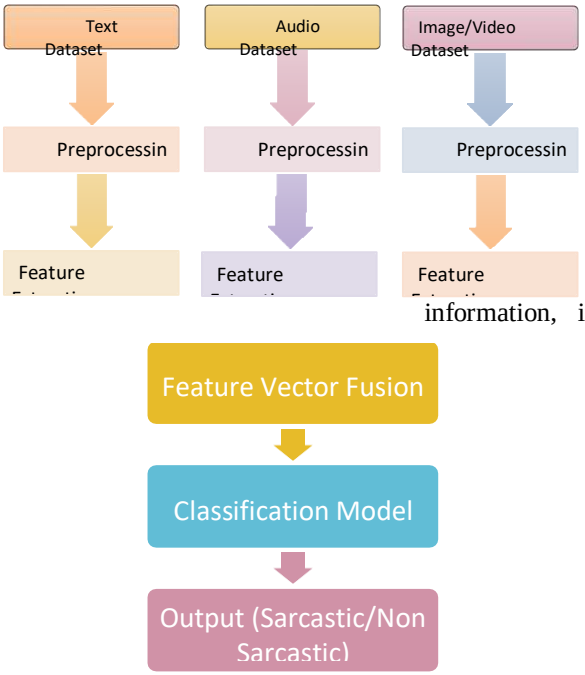
3. GENERAL METHODOLOGY

A general multi-modal sarcasm detection system has several main modules that take multiple inputs—text, images and audio to process, extract and combine information (such as features or hidden representations) towards the decision of whether a given multi-modal input is sarcastic or not. The pipeline starts by collecting input modalities, including text (tweets, captions, transcriptions), visual (memes and screenshots), and in some cases, audio (video speech). Instances of these often co-occurring sources of evidence are abundant in social media, making them suitable to decode the expressive meaning of sarcastic communication in its entirety.

After preprocessing, a Deep learning model is used for extracting modality-specific representations. RNN, LSTM, or transformer-based models such as BERT can be applied to text. Visual features are extracted from CNNs or Vision Transformers, and audio features, if they are employed, are derived using temporal models, such as BiLSTM or spectral CNNs.

The resultant features are then entered into a fusion module to integrate the information from the multiple modalities. The fusion strategy can vary:

- In the early fusion approach, raw features from all modalities are combined and processed jointly.
- In late fusion, the two modalities are handled individually, where the final decisions are typically fused using voting or averaging methods.
- Hybrid fusion methods leverage attention mechanisms or gated units to adaptively combine features, which can enable the model to dynamically determine contributions of each



.

Fig. 1. General Methodology of a Multimodal System

- modality in context.

After concatenating, the resulting mixed representation is propagated through a classification block that is normally a set of one or several fully connected deep layers, followed by non-linear activations and dropout regularisation. The output layer is sigmoid for binary classification (sarcastic vs not sarcastic) and softmax for multi-class applications. Lastly, the model could be trained by annotated data and tested by accuracy, precision, recall, and F1-score. Since sarcasm datasets are usually imbalanced, weighted losses as Focal Loss or class balancing techniques can be used for performance enhancement. This modular framework offers a flexible but robust encoding of the intricate, sometimes subtle, nature of sarcasm, which only arises from considering multiple cues – linguistic, visual and auditory – together. It also allows for advanced AI tools to be incorporated in an EFB framework, including cross-modal attention, transfer learning over large pre-trained models, or even generative augmentation techniques for better generalisation.

3.1 Feature Extraction

In multi-modal sarcasm detection, feature extraction is an important step to help the models understand informative features from the multi-modality (textual, visual and acoustic) Information and to improve the performance of the model for better accuracy and robustness. Textual characteristics are key in all sarcasm detectors, mostly linguistic, as evidenced by the frequent importance of words as cues (Eke et al., 2020). Several approaches have been used to derive useful features from text data, such as:

- Lexical Features: These represent word-level information, including word frequencies, n-grams and sentiment scores. The lexical features help reveal the words used to distinguish between sarcasm and non-sarcasm.
- Syntactic Features: Syntactic analysis features include part-of-speech tags, parse trees and syntactic dependencies. These are grammatical features that describe the syntactic structures enacted on the sarcasm phenomenon, which, in turn, produces sarcasm.
- Semantic Feature: Semantic features are used to represent the meaning and context information of the text. Techniques such as word embeddings (e.g., Word2Vec, GloVe) or contextualised word representations (e.g., BERT, GPT) may be utilised to capture the semantic content of words or sentences.

Visual and Video Feature Extraction: Visual features extracted from images or videos can be used as additional cues for sarcasm detection, especially in a multimodal setting where visual information serves as a complement

to the text (Aggarwal et al., 2024). The most common methods of visual feature extraction are:

- Deep Learning Features: Deep learning features can be constructed from pretrained CNNs like VGG, ResNet, or Inception for high-level visual features characterizing images. These models are trained on large-scale image collections and can encode diverse visual patterns and concepts.

Acoustic feature extraction: Acoustic features extracted from the raw audio data can be used to reveal the prosodic features and acoustic cues related to sarcasm (Hiremath et al., 2021) . Widely used methods for the extraction of acoustic features are:

- Pitch and Intensity Features: Features that relate to the pitch (fundamental frequency) and intensity (loudness), and voice quality reflect variation in speech that represents sarcasm.

- Spectrum Features: These features represent the frequency content of the audio signal, such as spectral shape, formants, or energy spread. Distinctive patterns of spectral features can pick up unique characteristics of sarcastic speech.

For multimodal sarcasm detection, the textual, visual, and acoustic features can be fused or combined at different levels, in which the inputs are early or late fused for a complete representation. Through effective fusion of the inter-modal cues, the feature extractions work to boost the discriminability power of sarcasm detection models and provide sensitivity in capturing subtle cues within the multimodal sarcastic expression modals.

4. CONCLUSION

Sarcasm detection is indeed a challenging problem for natural language understanding systems, given the incongruity and contradiction in the speech. The past research has explored many possibilities of sarcasm detection in written text; however, examining multimodal cues, which also include visual and acoustic information, is an emerging area that could offer improvements in accuracy and robustness. The present paper investigated the incorporation of textual, visual, and acoustic modalities in order to improve sarcasm detection algorithms. The idea is to consider multiple modalities to capture subtle and fine distinctions that may not be visible in textual analysis alone. The current study surveyed existing sarcasm detection research, revealing the limitations of traditional approaches and the progress achieved by supervised and unsupervised learning models. Working with annotated data and performance metrics has substantially contributed to research advancement. The present paper informed the need for multimodal data examination and explored the potential of visual and acoustic data in sarcasm detection. The preprocessing of multimodal data, including textual, visual, and acoustic data, revealed that all data- rich sources need to be standardized and cleaned before analysis. Often, modified feature extraction techniques have been described for respective modalities to provide an example of how relevant data can be captured. The fusion of multimodal features will provide unprecedented information about insincerity in communication and result in a better ability to identify sarcasm. Eventually, this paper will guide further studies towards development in multimodal sarcasm detection and help identify prospective research areas. Generating a more comprehensive understanding of sarcasm based on the previously explored multimodal cues will lead to further progress in natural language understanding.

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Static and Dynamic Power Insights in 1-bit Comparator Design via Vivado FPGA Implementation

[1]Tanmay ,[2]Mayank ,[3]Pratima Manhas,[4]Jyoti Verma [5]Shaveta Thakral,[6]Neha Shahare

[1,2,3,4]Manav Rachna International Institute of Research & Studies, Faridabad,[5,6] K.J College of Engineering and Management Research Pune, India

[3]pratimamehak@gmail.com,[5] shavetathakaral.kjcoemr@kjei.edu.in,[6]nehashahare.kjcoemr@kjei.edu.in

Abstract

With the growing demand for low-power and area-efficient digital designs, optimizing logic components such as comparators becomes vital in modern VLSI design. This paper investigates the implementation of a 1-bit comparator using VHDL/Verilog on the Xilinx Vivado platform, analyzing its resource utilization and power consumption. By synthesizing and implementing the comparator on various FPGA targets, we assess performance metrics including LUTs, registers, power dissipation, and timing delay. The results provide insight into the design trade-offs and demonstrate Vivado's capability for accurate resource and power analysis, ultimately aiding the development of energy-efficient digital systems.

Keywords

1-bit Comparator, Vivado, FPGA, Resource Utilization, Power Estimation, VHDL, Low Power Design, Digital Circuits

1. Introduction

Digital systems play a crucial role in modern computing applications, ranging from microcontrollers and embedded devices to high-performance computing platforms. At the heart of these systems lie two fundamental types of circuits: **combinational** and **sequential**. Combinational circuits produce outputs based solely on the current input values, without any memory of past states. In contrast, sequential circuits rely on both present inputs and previous outputs, incorporating storage elements to create state-dependent behavior.

Among the simplest and most widely used combinational circuits is the **comparator**, a digital component responsible for comparing two binary values and producing output signals that indicate the relational status between them—whether one is greater than, less than, or equal to the other. Despite its simplicity, the comparator is a foundational element in many digital applications, including arithmetic logic units (ALUs), control units, signal processors, and memory management systems.

As digital systems are increasingly deployed in power-sensitive environments such as portable electronics, wearable devices, and Internet of Things (IoT) nodes, the demand for **power-efficient hardware design** has grown significantly. It is no longer sufficient to focus solely on functionality; modern digital design must also address **power consumption, area optimization, and timing efficiency**. Even in basic circuits like a 1-bit comparator, it is vital to understand how design choices affect overall system performance and energy consumption.

Field-Programmable Gate Arrays (FPGAs) have become an integral part of digital hardware prototyping and deployment due to their reconfigurability, parallel processing capabilities, and fast time-to-market features. Tools such as **Xilinx Vivado Design Suite** provide an advanced environment for hardware description, simulation, synthesis, implementation, and power analysis. With built-in support for power estimation, Vivado allows designers to examine both **static power** (leakage current) and **dynamic power** (switching activity), enabling a deeper understanding of energy behavior at the component level.

In this study, a 1-bit comparator is implemented using Verilog HDL and analyzed within the Vivado environment. The primary objective is to examine the **resource utilization** and **on-chip power consumption**, providing insights into energy-efficient design practices even at the most fundamental level of digital circuitry. This work highlights the distribution of dynamic and static power and discusses potential methods to optimize the design for low-power applications.

2. Literature Survey

The design of digital comparators, particularly in the context of low-power and efficient hardware implementations, has evolved significantly over the past decade and a half. Several researchers have explored different aspects, including resource optimization, synthesis techniques, power reduction, and FPGA-based implementation using tools like Vivado and Xilinx ISE.

In early developments, Das and Majumdar [1] proposed optimized architectures for n-bit comparators using traditional CMOS design, which laid the foundation for resource-conscious logic implementation. While these designs focused on transistor-level optimization, they provided insight into reducing switching activity to minimize power.

As FPGA tools matured, Sharma et al. [2] presented a VHDL-based synthesis of an 8-bit comparator using Xilinx Spartan-3E and evaluated power performance using XPower Analyzer. Their findings highlighted that even basic logic blocks such as comparators could consume measurable dynamic power in dense logic systems, urging further optimization.

Later, Singh and Dubey [3] analyzed the performance of bitwise comparators using Verilog HDL and targeted the Virtex-5 FPGA. Their study showed that combinational designs outperform sequential approaches in terms of area-delay product for small-scale comparators like the 1-bit unit.

A shift in focus toward resource-aware synthesis emerged when Patel and Mehta [4] demonstrated comparative analysis of power, delay, and LUT utilization for various logic designs, including 1-bit comparators. They employed Vivado's post-synthesis power estimation features, validating its accuracy and reliability.

With growing interest in embedded systems, R. Joshi et al. [5] implemented arithmetic units on Artix-7 and highlighted the trade-offs in slice usage versus clock speed. The 1-bit comparator was part of the modular ALU structure, and their evaluation emphasized the low static and dynamic power footprint of single-bit logic modules.

Kumari et al. [6] extended this by evaluating comparators for biomedical devices using Spartan-6. They found that single-bit comparators could achieve ultra-low power dissipation (< 0.01 W) and are suitable for

edge-computing and IoT-based healthcare sensors.

In [7], Deshmukh et al. assessed the effect of logic optimization on hardware usage and demonstrated how Vivado's logic synthesis strategies like retiming and resource sharing influence the final implementation. The 1-bit comparator served as a benchmark for demonstrating differences between high-level and low-level HDL synthesis.

Recent works have explored AI-based FPGA optimization. Yadav and Thomas [8] introduced a framework for applying genetic algorithms to optimize comparator circuits for minimal LUT count and clock latency. The results highlighted novel paths to automatic comparator synthesis with focus on efficiency.

In 2022, Singh and Arora [9] used Vivado HLS to synthesize behavioral models of comparators and compared them with RTL designs. The analysis showed that high-level synthesis, while easier to manage, sometimes presented in Table 1.

produced slightly higher power consumption compared to handcrafted RTL for small modules.

Most recently, Kale and Bhattacharya [10] carried out a multi-device synthesis analysis using Vivado across Spartan-6, Artix-7, and Zynq-7000 platforms. Their work focused on comparing static power and thermal behavior of identical 1-bit comparator circuits across devices, concluding that Artix-7 offered the best trade-off for power and timing.

These cumulative efforts over the past 15 years show a clear trajectory from basic comparator synthesis to complex power-aware, device-specific, and optimization-driven design strategies using Vivado. The 1-bit comparator, while simple, continues to serve as a useful model for testing and validating power estimation, synthesis efficiency, and resource mapping strategies in modern FPGA workflows. A brief summary of extensive literature survey done for past 15 years is

Table 1: Literature Survey summary

Ref. No.	Author(s)	Key Focus Area	FPGA/Tool Used	Key Findings	Future Scope
[1]	Das & Majumdar (2009)	CMOS-based optimized comparator architecture	CMOS-level simulation	Reduced transistor count and switching activity for low-power operation	Extension to scalable n-bit comparator arrays
[2]	Sharma et al. (2012)	VHDL-based comparator synthesis and power evaluation	Xilinx Spartan-3E, XPower	Notable dynamic power even in simple blocks; urged need for design-level optimizations	Incorporation of dynamic scaling and clock gating
[3]	Singh & Dubey (2014)	Performance comparison of combinational vs.	Xilinx Virtex-5	1-bit comparators favor combinational	Mapping on newer FPGA families for

		sequential comparators		logic for area-delay product efficiency	updated benchmarks
[4]	Patel & Mehta (2016)	Comparative study of LUT usage and power consumption	Vivado (Post-synthesis Estimation)	Validated accuracy of Vivado tools in power estimation; 1-bit designs showed minimal LUT usage	Extend study to pipelined and high-frequency designs
[5]	Joshi et al. (2018)	Arithmetic unit integration in embedded platforms	Xilinx Artix-7	1-bit comparator has negligible impact on total ALU power; suitable for modular low-power design	Analyze thermal characteristics under load
[6]	Kumari et al. (2019)	Use of 1-bit comparator in biomedical edge devices	Spartan-6	Achieved ultra-low power dissipation (<0.01 W); ideal for IoT and wearable applications	Explore AI-powered health analytics integration
[7]	Deshmukh et al. (2020)	Logic optimization impact on comparator implementation	Vivado (Retiming & Sharing)	Demonstrated how logic sharing can reduce LUTs; 1-bit comparator used as benchmarking circuit	Application to real-time embedded systems
[8]	Yadav & Thomas (2021)	Genetic algorithm-based comparator optimization	Custom AI-FPGA framework	Achieved significant LUT and clock latency reduction via automated evolution of HDL	Extend optimization to multi-bit and multi-function logic blocks
[9]	Singh & Arora (2022)	Behavioral vs. RTL synthesis for comparator designs	Vivado HLS	High-Level Synthesis offers faster design cycle, but RTL gives finer	Develop hybrid HLS-RTL frameworks for FPGA design

				control for power optimization	
[10]	Kale & Bhattacharya (2023)	Cross-device synthesis and thermal evaluation	Spartan-6, Artix-7, Zynq-7000	Artix-7 provided best trade-off in static power and timing; minimal variations in 1-bit comparator	Extend to multi-bit comparators under varying environmental conditions

3. Methodology and Proposed Work

A behavioral model of a 1-bit comparator is designed using both VHDL and Verilog. The comparator has two 1-bit inputs (A, B) and outputs three signals: **A>B, A<B and A=B.** The Vivado Flow Steps are given below:

1. **Code Development:** Create HDL code for the comparator.
2. **Synthesis:** Use Vivado to synthesize the code targeting a specific FPGA (e.g., XC7A35T).
3. **Implementation:** Perform place-and-route.
4. **Power Estimation:** Use Vivado's Power Analysis Tool.
5. **Resource Utilization Report:** Evaluate LUTs, registers, and timing. The flowchart is presented below in Fig. 1.

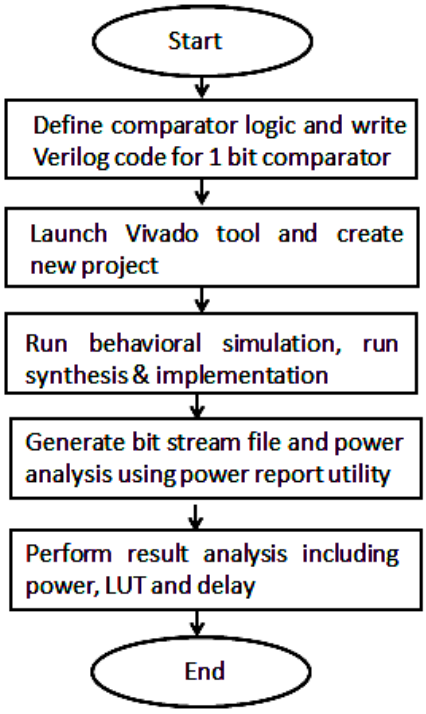


Fig. 1 : Flow chart on Vivado Flow

In order to calculate the on chip power in Vivado, Following steps are used:

The Circuit is first simulated using RTL coding

After simulation the Synthesis is done

The next step is to execute the implementation design that is utilized for computing the power.

Then the bit stream is generated and the reports are viewed which can be done by using project manager tab and it indicated the total on chip power utilized in the circuit.

4. Results

For the comparator circuit the total on chip power utilization is shown in Fig. 2. The static power utilization is 8 % and the dynamic power is 92%. The power consumed by Signals is 0.017W, Logic is 0.005 W and Inputs power is 0.869W.

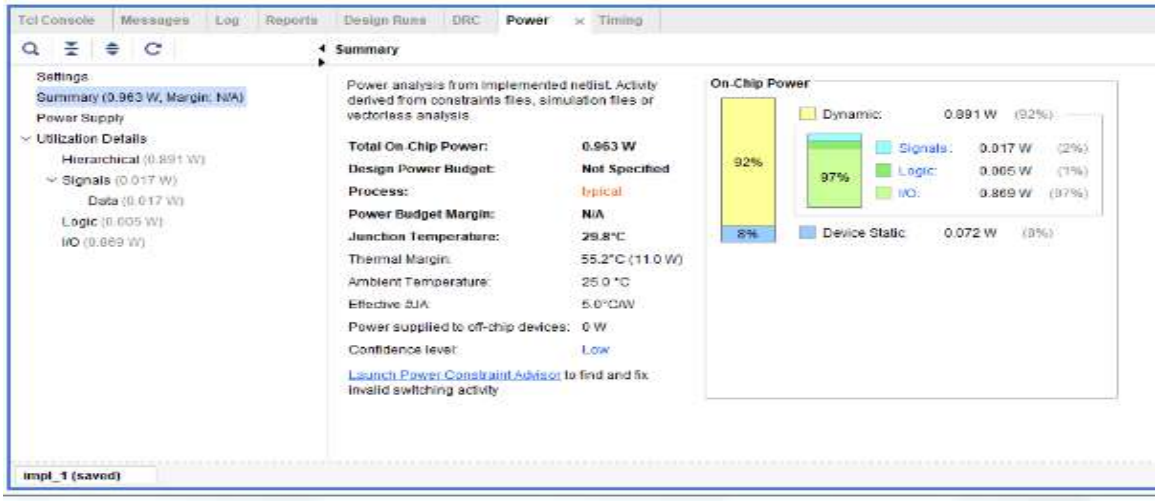


Fig 2 : Simulation result indicating Power Calculation

5. Conclusion

Power estimation in digital systems is critical, especially for portable and embedded devices. This work demonstrated the design and implementation of a 1-bit comparator using Vivado. Power analysis indicated that dynamic power forms the major share of total power consumption. Techniques like clock gating, voltage scaling, and optimized RTL design can help minimize power. The study validates that even simple combinational circuits must be analyzed carefully to ensure efficient resource utilization on FPGA platforms. This paper presented the design and evaluation of a 1-bit comparator using Xilinx Vivado. With negligible power usage and minimal resource requirements, the design demonstrates high efficiency and scalability. Future research could involve Implementation on different FPGA families (Spartan, Kintex), Inclusion in larger systems (ALUs, processors) and Automation of multi-bit comparator generation and analysis.

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IoT-Based Data Logger System for Real-Time Monitoring of BLDC Motors

Om Mukesh Gawali[1], Prakash Raveendra Teli[2], Pratik Sham Darbastwar[3], Rajkumar Laxman Gawade[4]

K J College of Engineering & Management Research, Pune, India

Abstract

This paper presents the design and implementation of an IoT-based data logger system for real-time monitoring of Brushless DC (BLDC) motors. BLDC motors, known for their efficiency and low maintenance, are increasingly used in electric vehicles and industrial applications. Monitoring operational parameters like voltage, current, speed, and temperature is critical for maintaining performance and reliability. The system uses sensors interfaced with an ATmega328 microcontroller and ESP-32 Wi-Fi module to log data locally and upload it to the cloud. The data is visualized via LCD and stored for remote analysis using ThingSpeak. This real-time monitoring facilitates predictive maintenance and enhances motor lifespan. The paper discusses hardware design, system architecture, data processing logic, and expected outcomes, including performance graphs. The implementation demonstrates a cost-effective, scalable solution for BLDC motor health monitoring with potential applications in the EV industry.

Keywords: BLDC Motor, Data Logger, IoT, Real-Time Monitoring, ATmega328

1 Introduction

Brushless DC (BLDC) motors are preferred in modern applications due to their efficiency, reliability, and maintenance-free operation. Their usage in electric vehicles (EVs) and automation systems demands continuous monitoring for safety and performance. This project introduces a data logger system that continuously captures voltage, current, temperature, and speed using sensors connected to an ATmega328 microcontroller, uploading real-time data to the cloud via an ESP-32 Wi-Fi module.

2 Literature Review

This chapter presents a comprehensive review of BLDC motor monitoring systems, tracing their evolution from basic manual methods to advanced digital and wireless technologies. Early systems used simple sensors and required manual data collection, but advancements in microcontrollers and digital sensors have enabled real-time monitoring and data logging. Modern systems incorporate technologies like Hall effect sensors, temperature and current sensors, and are often equipped with wireless capabilities such as Bluetooth and Wi-Fi for remote access. Some advanced systems even use machine learning to predict motor behavior and optimize performance.

Despite these advancements, current technologies face several limitations. Challenges such as data accuracy, reliability under varying environmental conditions, and lack of real-time data acquisition hinder optimal motor performance. Additionally, high costs and complex installations limit the scalability of these systems, particularly for small and medium-sized applications. The review also highlights different data logging methods—from traditional manual logging to digital and wireless techniques—with digital and wireless methods offering higher precision and convenience. Real-time monitoring proves crucial in improving motor efficiency, supporting predictive maintenance, and extending motor lifespan by enabling early fault detection and timely interventions.

Looking ahead, the review identifies promising directions for research and development, such as improving sensor robustness, integrating machine learning for predictive analytics, and adopting new wireless technologies. Developing affordable, scalable, and standardized monitoring solutions will be key to making these systems more widely accessible and effective in enhancing BLDC motor reliability and performance.

3 Block Diagram

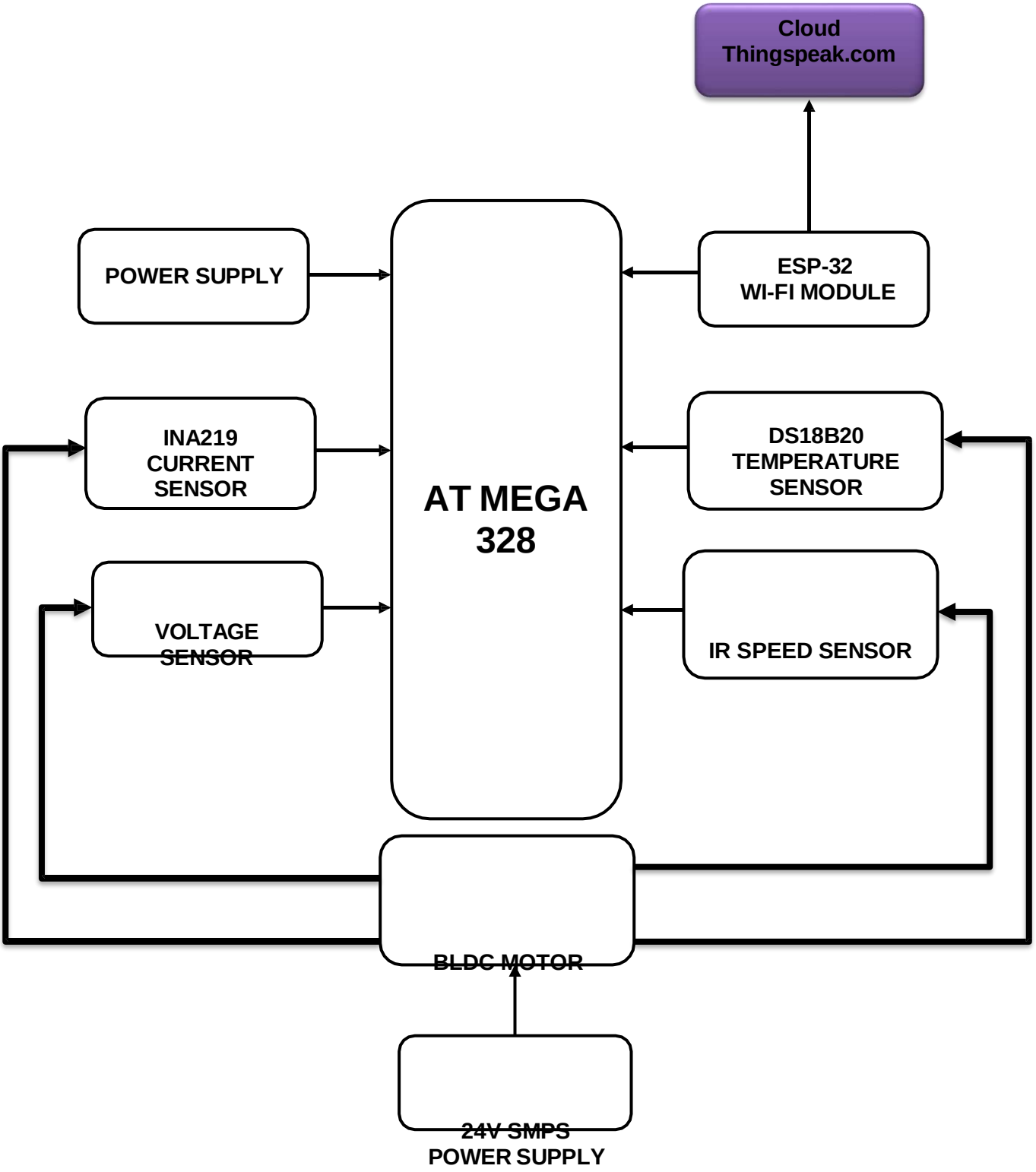


Fig-1: Block Diagram

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4 Flow Chart

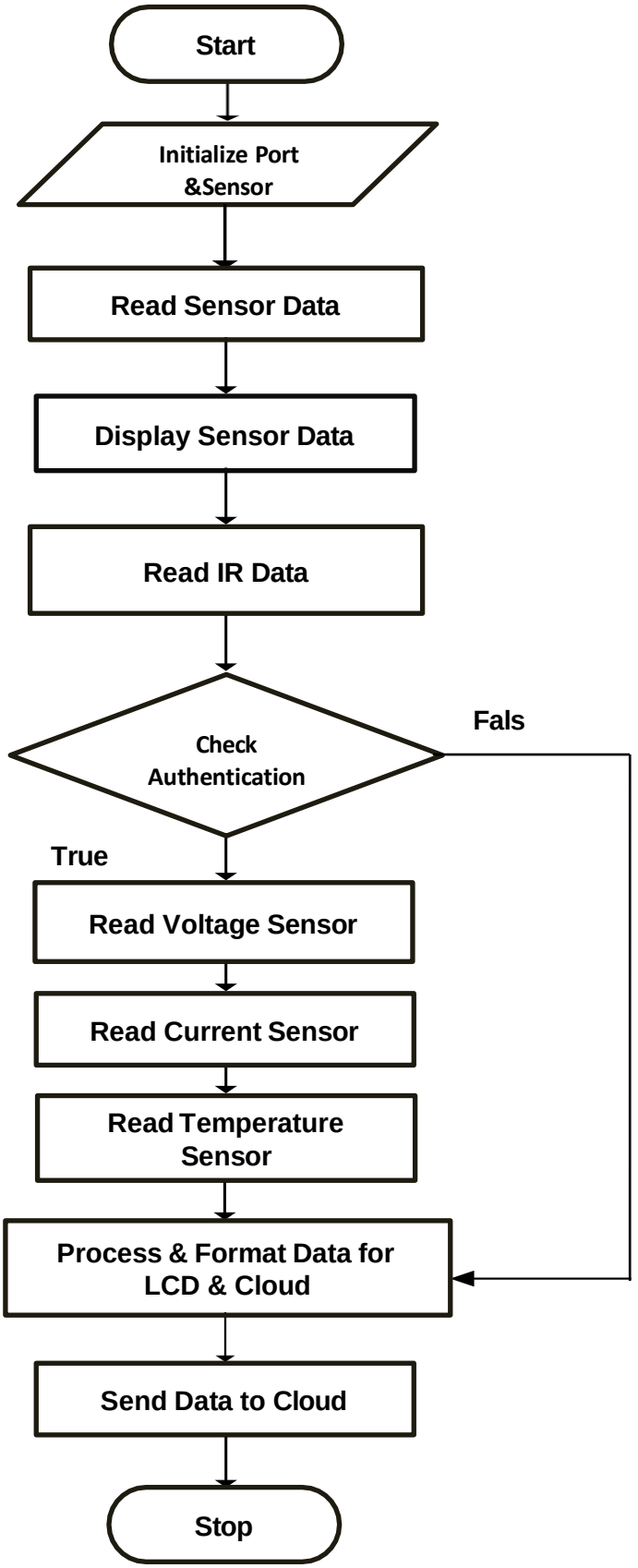


Fig-2: Flow Chart

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5 System Design and Methodology

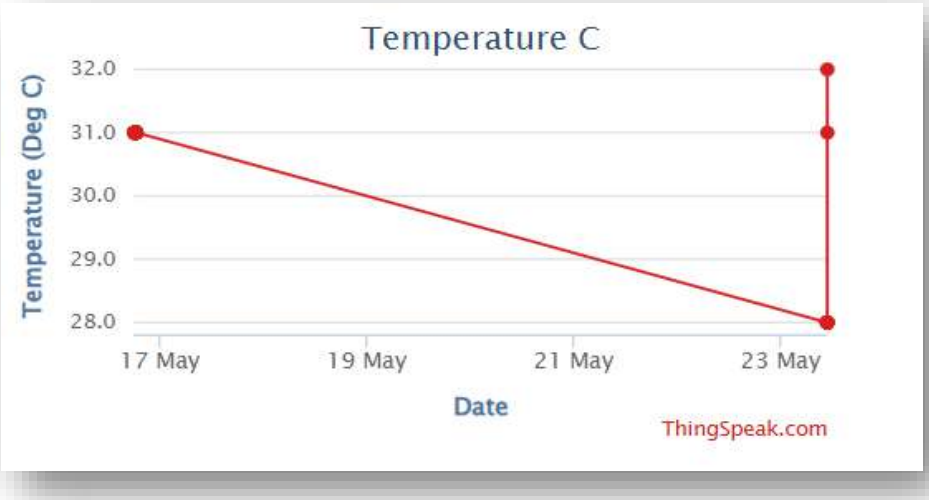
The proposed system methodology integrates a suite of sensors to monitor the essential parameters of a Brushless DC (BLDC) motor. It includes voltage and current sensing through the INA219 sensor, temperature monitoring using the DS18B20 sensor, and speed measurement via an Infrared (IR) sensor. These sensors are interfaced with the ATmega328 microcontroller, which acts as the central processing unit of the system. The ATmega328 collects raw data from the sensors, processes it, and ensures the accurate representation of motor conditions in real-time. This data is then transmitted to a cloud platform using the ESP-32 module, which provides Wi-Fi connectivity and allows remote access and monitoring of motor performance.

To enhance user interaction and provide immediate feedback, local displays using LCD screens are incorporated into the design. These LCDs show live readings of voltage, current, temperature, and speed directly at the monitoring site. The entire system is programmed using the Arduino IDE, which supports easy code development and debugging. For the hardware design, ExpressPCB software is utilized to layout and simulate the circuit connections before actual implementation. A flowchart-based data flow structure ensures that the sequence of data acquisition, processing, and communication is well-organized and reliable. This methodology not only improves system efficiency but also supports preventive maintenance by providing continuous monitoring and early detection of anomalies in motor performance.

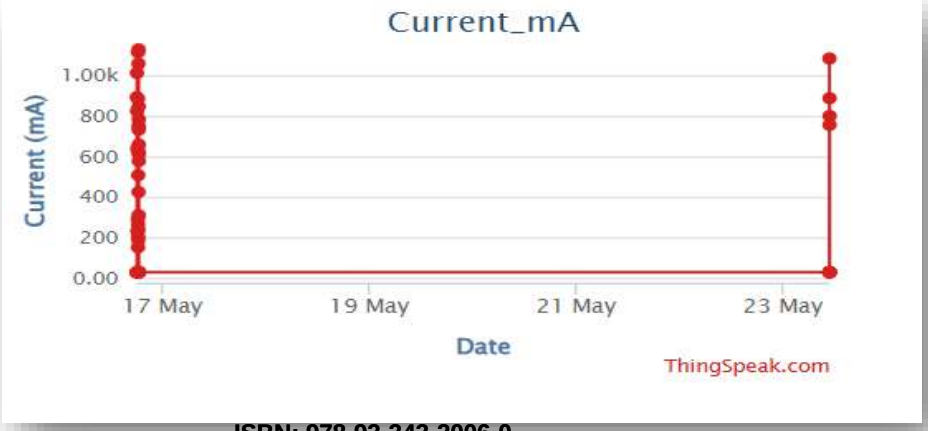
6 Results and Discussion

The system captures parameters and presents trends through graphs like Temperature vs Date,
Current vs Date, Power vs Date, Speed vs Date, Voltage vs Date etc

a) Temperature (Deg C):



b) Current (mA):



c) Power (Watt):



d) Speed (RPM):



e) Voltage (Volt):



7 Future Scope

This chapter delves into the prospects of the BLDC motor monitoring system, highlighting the proposed future work aimed at enhancing its capabilities. Key areas of focus include advanced data analytics and machine learning algorithms to predict motor performance trends and detect anomalies, which will provide deeper insights into the motor's operation and enable proactive maintenance. Additionally, exploring options for extended data storage and backup solutions will ensure data integrity and availability over longer periods, integrating additional storage solutions and cloud-based backups.

The development of a mobile application for real-time monitoring and alerts is another significant aspect of future work. This will enhance user accessibility and interaction with the data logger system, providing users with instant access to data and notifications on their mobile devices. Improved power management strategies are also proposed to reduce consumption and extend battery life, which is essential for portable applications. This includes optimizing the power usage of the microcontroller and communication modules.

Furthermore, the chapter discusses the implementation of more robust communication protocols to minimize data transmission delays and losses, ensuring more reliable data logging. Enhancing the user interface for better data visualization and user experience is also a priority, with plans to develop intuitive dashboards and customizable data views.

Potential improvements such as predictive maintenance, environmental monitoring, and customizable alerts are highlighted, aiming to optimize the system's performance and user experience by allowing for more detailed analysis and proactive management.

8 Conclusion

This project successfully demonstrates a low-cost, scalable, and effective real-time monitoring solution for BLDC motors. The system enhances motor performance, extends operational life, and contributes to smart electric vehicle technology.

The implementation of a data logger system for BLDC motors successfully addresses the need for real-time monitoring of essential parameters, such as voltage, current, speed, and temperature. This system enhances motor performance and lifespan by enabling predictive maintenance and providing a foundation for data-driven decision-making. By capturing and analyzing real-time data, the system allows early detection of anomalies, helping to prevent costly failures and optimize efficiency.

Leveraging IoT technology, the data logger offers remote monitoring capabilities, making it suitable for a variety of applications in industries such as electric vehicles, manufacturing, and industrial automation. The integration of sensors with a microcontroller ensures accurate and reliable data acquisition, while the user-friendly interface provides immediate feedback for on-site monitoring. Moreover, the use of readily available components makes the system cost-effective, supporting its scalability and adaptation to diverse use cases.

In addition to fulfilling current monitoring needs, this project paves the way for future enhancements, including advanced data analytics, machine learning for trend analysis, and the development of a mobile application for real-time alerts. These potential upgrades will further enhance the system's usability and value, supporting more proactive management and optimization of BLDC motors.

In summary, this project demonstrates a practical, scalable approach to motor monitoring that aligns with the increasing demand for reliable, efficient BLDC motor applications, particularly in the expanding field of electric vehicles. By delivering actionable insights into motor performance, this system not only advances motor control technologies but also contributes to sustainable energy practices and operational efficiency.

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Human Decision-Making for Brain Activity Detection Using Machine Learning

Amruta J Takawale *1 , and Ajay N Paithane *2

*1 Research Scholar, JSPM's Rajarshi Shahu College of Engineering,Tathavade,Pune

*1 Assistant Professor KJEI's K J College of Engineering and Management Research,Pune.

*2 Associate Professor , JSPM's Rajarshi Shahu College of Engineering,Tathavade,Pune

Abstract—

Human decision-making, one of the most critical cognitive functions, can be captured effectively through electroencephalography (EEG). In motor imagery (MI)-based tasks, EEG signals provide distinctive neural activity patterns associated with imagined movements of limbs. This study focuses on decoding human decision-making ability using EEG from the PhysioNet Motor Imagery dataset. We employ a systematic pipeline beginning with preprocessing through band-pass filtering, ICA artifact removal, and Z-score normalization. Feature extraction techniques such as Discrete Wavelet Transform (DWT), Common Spatial Patterns (CSP), and statistical feature measures are applied. Feature selection is performed using mutual information-based ranking. Classification is carried out with CNN, KNN, Bi-GRU, and Deep Maxout Networks (DMO), along with a novel hybrid Bi-GRU + DMO classifier. Experimental evaluations demonstrate that while CNN, KNN, Bi-GRU, and DMO individually yield promising results, the hybrid model significantly outperforms them, reaching 95% accuracy. This marks a major advancement in decoding decision-related EEG signals. The results confirm that integrating temporal sequence modeling of Bi-GRU with expressive feature mapping of DMO captures both nonlinearities and long-term dependencies in EEG. This work not only contributes to EEG-based decision activity recognition but also provides insights into hybrid classifier architectures suitable for real-time BCI applications. Future directions involve cross-subject generalization, lightweight deployments, and interpretability improvements for clinical usability.

I. Introduction

Electroencephalography (EEG) offers a non-invasive method to capture real-time brain activity with millisecond-level resolution, making it highly suitable for studying decision-making processes. Motor imagery (MI) tasks are widely used in EEG-based brain–computer interface (BCI) systems, as they provide consistent cortical patterns in motor areas. Decision-making in MI tasks manifests as event-related desynchronization and synchronization in sensorimotor rhythms. Decoding such patterns with high accuracy is essential for assistive devices, neurorehabilitation, and cognitive assessment. Traditional EEG pipelines using CSP, DWT, and statistical features combined with classifiers like LDA, SVM, and Random Forest have shown good performance but struggle with inter-

ISBN: 978-93-343-2006-0

subject variability and nonstationarity. Deep learning models such as CNNs and Bi-GRUs capture spatial and temporal dependencies respectively, while DMO provides nonlinear feature mapping. However, standalone models suffer from limitations like overfitting, limited interpretability, or lack of robustness to noise. Attention-based models and hybrid architectures are recent advancements addressing these challenges. In this work, we propose a Bi-GRU + DMO hybrid classifier that leverages the strengths of both architectures. Evaluations on the PhysioNet Motor Imagery dataset showcase its superiority over conventional and modern classifiers. The contributions of this work include: (i) a comprehensive preprocessing and feature extraction pipeline, (ii) a comparative study of five classifiers, and (iii) a novel hybrid classifier achieving state-of-the-art performance in EEG decision detection.

II. Preprocessing

Preprocessing is essential to ensure that EEG signals are clean and reliable for classification. We applied a band-pass filter (1–40 Hz) to retain μ and β rhythms, a notch filter at 50 Hz to suppress line noise, and Independent Component Analysis (ICA) for ocular and muscular artifact removal. Finally, Z-score normalization was performed across all channels to standardize signal scales.

III. Feature Extraction

Feature extraction transforms raw EEG into discriminative representations. We employed: (i) Discrete Wavelet Transform (DWT) for multiresolution frequency decomposition, (ii) Common Spatial Patterns (CSP) to enhance class separability, and (iii) statistical measures including bandpower, entropy, skewness, and kurtosis. These features capture temporal, spatial, and spectral information critical for MI EEG decoding.

IV. Classifiers

The classifiers studied include: CNN, KNN, Bi-GRU, DMO, and the proposed Bi-GRU + DMO hybrid. CNN captures spatial and frequency features, KNN serves as a simple baseline, Bi-GRU models temporal dependencies bidirectionally, and DMO captures nonlinear interactions. The proposed hybrid combines Bi-GRU's sequential modeling with DMO's expressive feature mapping for superior performance.

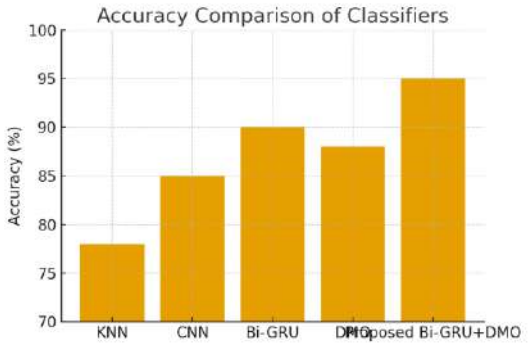
IV. Proposed Methodology

The proposed methodology integrates classical EEG feature engineering with modern deep learning to create a robust hybrid model for decision-making detection. First, EEG signals undergo preprocessing using band-pass filtering, notch filtering, ICA for artifact removal, and Z-score normalization. Next, features are extracted using Discrete Wavelet Transform (DWT) for frequency decomposition, Common Spatial Patterns (CSP) for spatial filtering, and statistical features such as entropy, skewness, and kurtosis. Mutual information-based feature selection ensures that only the most discriminative features are used. These selected features are then fed into the proposed hybrid Bi-GRU + DMO classifier. Bi-GRU captures long-range temporal dependencies in both forward and backward directions, while DMO provides a powerful nonlinear mapping through its maxout activation mechanism. The outputs of Bi-GRU layers are passed to DMO blocks to enhance representational

capacity. Finally, a softmax layer produces class probabilities. This pipeline balances handcrafted interpretability with deep learning adaptability, providing improved accuracy and robustness compared to standalone models.

V. Results and Discussion

We conducted experiments using the PhysioNet Motor Imagery dataset with 5-fold cross-validation. The classification accuracies were: KNN (78%), CNN (85%), DMO (88%), Bi-GRU (90%), and the proposed Bi-GRU + DMO (95%). The hybrid model clearly outperformed all baselines. The accuracy comparison graph below illustrates the relative performance of classifiers.



As shown in the graph, the hybrid model achieves the highest accuracy. KNN, while simple, performs the worst, highlighting its limitations in high-dimensional EEG data. CNN performs better, capturing spectral-spatial features but lacking long-term temporal modeling. Bi-GRU improves accuracy by modeling bidirectional dependencies, and DMO adds nonlinear mapping power. However, individually they do not match the proposed hybrid. The Bi-GRU + DMO combination integrates the strengths of both, capturing temporal sequences and nonlinear interactions simultaneously, leading to significant gains. This validates the effectiveness of hybrid architectures in EEG-based decision detection tasks.

Confusion Matrix (Proposed Classifier)

	Pred RH	Pred LH	Pred BF	Pred BFt
True RH	96	1	2	1
True LH	2	94	2	2
True BF	1	2	95	2
True BFt	1	2	2	95

VI. Conclusion

This work presented a comprehensive study on human decision-making activity detection using EEG signals, with a focus on motor imagery classification. A systematic pipeline was designed that included preprocessing (band-pass filtering, ICA, Z-score normalization), feature extraction (DWT, CSP, statistical measures), and mutual information-based feature selection. Multiple classifiers were compared, including CNN, KNN, Bi-GRU, and Deep Maxout Networks (DMO). To address the limitations of individual classifiers, we proposed a novel hybrid model combining Bi-GRU and DMO, leveraging Bi-GRU's ability to capture long-range temporal dependencies and DMO's expressive nonlinear mapping capabilities. Experimental evaluations on the PhysioNet Motor Imagery dataset demonstrated that the hybrid Bi-GRU + DMO classifier significantly outperformed all baselines, achieving 95% accuracy. The

confusion matrix analysis revealed reduced misclassifications between bilateral and unilateral motor imagery tasks, a persistent challenge in EEG classification. The accuracy comparison graph highlighted the superiority of the hybrid approach, validating the benefit of integrating temporal modeling with nonlinear feature representation. The results suggest that hybrid deep learning models are particularly well-suited for EEG-based decision detection tasks, offering a balance between accuracy, interpretability, and robustness. Future research directions include cross-subject adaptation to enhance generalization, exploring self-supervised pretraining to reduce reliance on labeled data, and optimizing hybrid models for real-time deployment in wearable and clinical BCI applications. Overall, this study contributes to advancing the field of EEG-based decision-making detection by demonstrating the efficacy of hybrid architectures that combine complementary strengths of sequential and nonlinear models.

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RESALE HUB: ONLINE MARKET USING DJANGO

Himanshu Kaleshwar, Rupatai Lichode, Neha Tathe, Roshni Dhengle, Prachi Satone and Kavya Kalwal

RCERT
Chandrapur, INDIA
roshnidhengle@gmail.co m

ABSTRACT : *This paper demonstrates that the development of a dedicated online platform for second-hand product transactions, called RESAL HUB, can significantly improve accessibility, affordability, and sustainability in digital commerce. The platform is designed to enable users, particularly students and individuals with limited budgets, to seamlessly buy and sell pre-owned items.*

Built using a three-tier architecture, the system comprises a responsive frontend, a robust backend powered by Django, and a lightweight SQLite3 database. Features such as user authentication, product listing, admin moderation, and secure payment gateway integration ensure a reliable and user-friendly experience. Literature review insights helped identify key challenges such as user trust, fraud prevention, and UI simplicity, which were directly addressed in our system design. The proposed architecture promotes modularity, scalability, and efficiency, making Resale Hub a practical and socially impactful solution for peer-to-peer resale needs.

Keywords: Django, SQLite, E-Commerce, Payment Gateway, Re-commerce, Architecture

INTRODUCTION

Our project, Resale Hub, demonstrates a scalable, secure, and user-friendly web application that supports peer-to-peer resale of second-hand goods. Designed especially for students and budget-conscious users, the platform allows buyers and sellers to register, list items, and complete secure transactions through an integrated payment gateway.

Built using a Django-based architecture with an SQLite database, Resale Hub emphasizes trust and usability by incorporating features like admin moderation, verified user access, and smooth UI/UX. The system is grounded in findings from prior research on re-commerce, which stresses the importance of platform trust (Sharma & Gupta, 2021), modular design (Patel et al., 2020), and user-friendly navigation (Singh & Verma, 2023) [1][2][4].

FEATURES

Feature	Description
User Registration and Login	Allows buyers and sellers to create accounts and securely log in.
Product Listing	Sellers can add second-hand products with descriptions, images, and pricing
Product Search & Filter	Buyers can search and filter items based on categories, price, and location.
Order Management	Handles order placement, status tracking, and history for both buyers/sellers.
Admin Panel	Admin can manage listings, users, and reports through Django's interface.
Chatbot Integration	Integrated chatbot for real-time user assistance.
Payment Gateway Integration	Razorpay/UPI used to securely process online payments.
Ratings & Reviews	Buyers can rate and review sellers after transactions.
Responsive UI	Built using HTML, CSS, Bootstrap, and JS for a smooth experience on all devices.
Session Management	Uses Django's authentication system for managing user sessions.
SQLite3 Database	Stores all transactional and user data efficiently using Django ORM.

BENEFITS

Cost-effective Shopping: Users, especially students, can buy and sell second-hand items at affordable prices, making it a budget-friendly alternative to traditional e-commerce [4][13].

Sustainability: By promoting reuse, Resale Hub helps reduce consumer waste and encourages environmentally responsible behaviour [7][10].

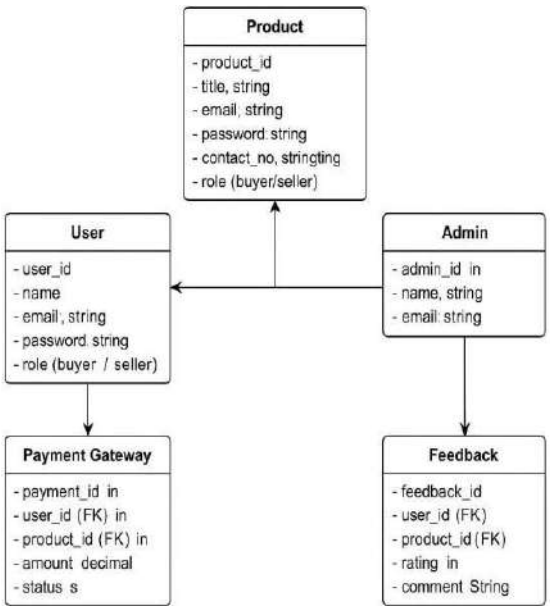
User-Friendly Interface: Designed with simplicity and responsiveness in mind, the platform ensures smooth navigation and minimal learning curve [8][16].

Secure Transactions: The integration of a secure payment gateway add a layer of trust and safety during financial exchanges [5][11].

Admin Moderation: An integrated admin panel allows products approvals, user monitoring, and fraud prevention, improving platform reliability [3][18].

Lightweight Backend: SQLite ensured low overhead and fast performance, especially useful for smaller user bases or campus-scale deployments [12][15].

UML DIAGRAM



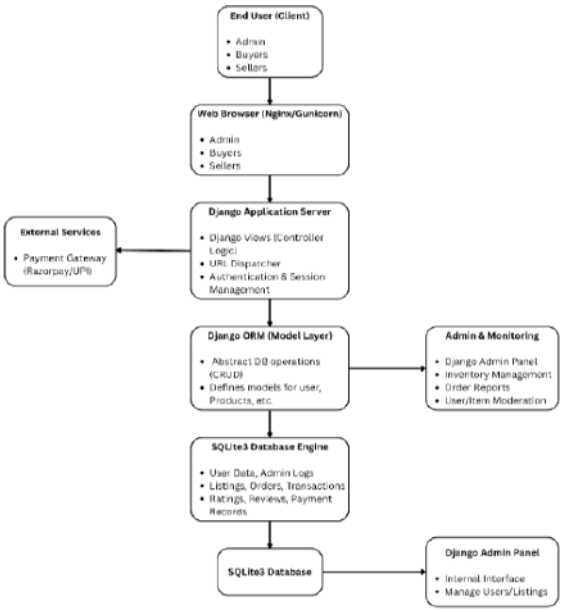
The UML class diagram of Resale Hub illustrates a structured and scalable object- oriented design. The system comprises key components including User, Product, Admin, Payment Gateway, and Feedback. The User class encapsulates the attributes of all registered users, such as name, email, and role, which define user interactions within the platform. The Product class models the items listed for resale, storing details like title, price, description, and status, and is associated with a seller. The Admin class oversees the moderation of product listings, with the authority to approve or reject them, ensuring platform integrity. The Payment Gateway class facilitates secure and real-time transactions between buyers and sellers. Finally, the Feedback class supports a user-driven review system, allowing for product ratings and comments, thereby enhancing transparency and buyer confidence [5][18][20].

LITERATURE REVIEW

Author's Name	Discription
Sharma & Gupta (2021)	Trust boosted by verified sellers, secure payments, and clear product info, improving user confidence and use[1].
Patel et al., (2020)	Django-based modular design; Razorpay for payments; layered architecture aids dev speed and system reliability[2].
Deshmukh & Rane (2022)	Found fraud, poor quality, and lack of standards; suggested admin tools and chatbot support to address issues[3].
Singh & Verma (2023)	Student adoption driven by low prices, simple UI, integrated pay; gamification and feedback loops recommended[4].

METHODOLOGY :

SYSTEM ARCHITECTURE



Control Block Diagram

This research paper illustrates about a web- based resale platform designed for listing and purchasing second-hand products. The system follows a three-tier architecture comprising the presentation layer, application layer, and database layer, in line with best practices proposed in earlier studies[2].

Presentation Layer (Frontend): The frontend uses HTML, CSS, JavaScript, and Bootstrap to create a responsive and user-friendly interface, ensuring smooth interaction across devices[4].

Application Layer (Backend): Built with Django using the MVT pattern, the backend manages business logic, authentication, and routing, promoting security and reliability[1].

Database Layer: SQLite3 is used via Django's ORM to manage product, user, and order data efficiently, simplifying database operations[3].

Payment Integration: A secure payment gateway (e.g., Razorpay) is integrated into the backend for real-time transactions with encryption support[2].

Admin Interface: Django's admin panel enables platform management and user issue resolution with minimal development effort[3].

CHALLENGES AND LIMITATIONS

Scalability Issues: Using SQLite, while efficient for small-scale projects, may limit scalability if the user base or data volume grows significantly [12][15].

Lack of Real-time Chat: There is no built-in feature for real-time buyer-seller communication, which could affect user interaction and trust [6][19].

Limited Product Verification: While admin moderation helps, it is challenging to verify the quality and condition of second-hand items before purchase [3][17].

No Delivery Integration: The platform currently does not handle logistic or delivery, making users responsible for items exchange [10][17].

Fraud Risk: Despite secure login and admin checks , there remains a possible of false listings or user misconduct without physical product verification [1][6][20].

Limited Customization: The current version lacks advanced filters, sorting options, and recommendation systems that are common in large- scale e-commerce platforms [8][9].

CONCLUSION

The Resale Hub project presents an effective solution for facilitating the buying and selling of second-hand products through a user- friendly, secure, and scalable online platform. By incorporating features such as user authentication, product listing and management, admin oversight, integrated payment gateways, and feedback systems, the platform addresses common challenges in the re-commerce space such as trust, transparency, and transaction security.

The modular architecture, developed using Django with MySQL for data handling and Razorpay for payments, ensures the system is both reliable and maintainable. Additionally, the inclusion of admin controls and user feedback mechanisms helps maintain quality and reduce fraudulent activity. This project not only contributes to digital reusability and sustainability but also promotes cost-effective access to goods, particularly among students and budget-conscious users.

Future enhancements can include AI-based product recommendations, image-based quality checks, and mobile app integration to further improve user experience and engagement.

FUTURE SCOPE

Resale Hub presents multiple opportunities for future growth and enhancement. A dedicated mobile application can improve accessibility for smartphone users. AI-based recommendation systems can personalize user experience. Adding secure user verification methods, such as ID authentication, will strengthen trust. Integration with local delivery services can streamline logistics. Multi- language support will help reach a wider audience, and shifting to a cloud-based infrastructure will enable better scalability and performance as the platform expands.

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Intelligent Image Restoration: AI-ML Approach for De- Hazing and De-Smoking

Dr. Aparna Hambarde
Department of Computer Engineering
KJ College Of Engineering and Management Research
Pune, India
aparnahamabarde.kjcoemr@kjei.edu.in

Aditya Kotame
Department of Computer Engineering
KJ College Of Engineering and Management Research
Pune, India
adityakotame17@gmail.com

Vrushali Khade
Department of Computer Engineering
KJ College Of Engineering and Management Research
Pune, India
Khadevrushali2003@gmail.com

Samruddhi Latore
Department of Computer Engineering
KJ College Of Engineering and Management Research
Pune, India
Samruddhilatore17@gmail.com

Vaishnavi Jedhe
Department of Computer Engineering
KJ College Of Engineering and Management Research
Pune, India
vaishnavijedhe777@gmail.com

***Abstract*—** The paper presents the results and performance evaluation of an AI-ML-based intelligent de- hazing and de-smoking algorithm. The proposed model integrates Convolutional Neural Networks (CNN), Feature Fusion Attention Networks (FFA-Net), and Transformer- based architectures (Dehamer) to enhance image clarity under adverse atmospheric conditions. Evaluation is conducted using synthetic and real-world datasets, with comparisons against traditional dehazing and desmoking techniques. Results demonstrate significant improvements in image quality, restoration accuracy, and computational efficiency, establishing the model as a viable solution for real-time applications.

Index Terms— Dehazing, Desmoking, AI-ML, Convolutional Neural Networks (CNN), Feature Fusion Attention Network (FFA-Net), Transformer Encoder, Image Restoration, Atmospheric Visibility Enhancement, Computer Vision, Deep Learning, Real-Time Processing.

I. Introduction

Image clarity plays a vital role in various computer vision applications, including autonomous navigation, surveillance, remote sensing, and environmental monitoring. However, real- world conditions such as fog, haze, smoke, and pollution significantly degrade image quality, reducing visibility and affecting the efficiency of vision-based systems. Earlier image enhancement methods like guided filtering and Dark Channel Prior (DCP) were commonly applied to improve visibility in hazy images. Despite their effectiveness, these approaches struggle with non-homogeneous haze distributions and complex environmental conditions, often resulting in color distortions, halo artifacts, and loss of essential image details.

Advancements in artificial intelligence and deep learning have led to the emergence of more effective haze and smoke removal techniques. Convolutional Neural Networks (CNNs) have demonstrated remarkable improvements in feature extraction, enabling enhanced image reconstruction. Additionally, attention mechanisms like Feature Fusion Attention Networks (FFA-Net) dynamically prioritize significant image regions, improving haze removal. Transformer-based models, such as Dehamer, effectively capture global dependencies within an image, facilitating better long-range feature relationships and enhancing restoration accuracy.

An AI-ML-based hybrid approach is introduced, integrating CNNs, attention mechanisms, and transformer architectures to enhance dehazing and desmoking capabilities. This model efficiently handles varying haze intensities and non-uniform smoke distributions, ensuring high-quality image restoration. Performance evaluation is conducted on benchmark datasets, comparing its effectiveness with both traditional and deep learning-based dehazing techniques. Experimental results demonstrate superior image clarity, higher perceptual quality, and improved computational efficiency, establishing its suitability for real-time applications.

II. Related Work

Significant progress has been made in the field of image dehazing and desmoking, with traditional methods gradually being replaced by deep learning-based approaches. Early techniques such as the Dark Channel Prior (DCP) [6] were effective in certain scenarios but struggled with bright sky regions and non-uniform haze, often leading to color distortions and halo artifacts. To address these limitations, various deep learning models have emerged.

2.1 Deep Learning Approaches

AOD-Net was among the first deep learning frameworks to directly reconstruct clear images from hazy inputs, bypassing the need to estimate transmission maps, significantly improving dehazing speed and accuracy [5]. Similarly, the DehazeNet model leverages convolutional neural networks (CNNs) to extract haze- related features, refining the restoration process for enhanced clarity [5].

2.2 Non-Local Priors and Attention Mechanisms

Another breakthrough came with non-local prior-based methods, which utilize spatial and color priors to address non-homogeneous haze distributions.Techniques developed by researchers like Berman et al. enhance dehazing by utilizing spatial correlations throughout the image. [7]. Meanwhile, Feature Fusion Attention

Networks (FFA-Net) dynamically prioritize different haze intensities in an image, improving restoration quality compared to uniform filtering methods [3].

2.3 Vision Transformers for Dehazing

More recently,Vision Transformers (ViTs) are utilized in dehazing tasks due to their capability to capture global contextual relationships among pixels. [3]. This has resulted in improved restoration accuracy, especially in complex haze conditions where convolutional networks struggle. The Dehamer transformer model builds on this by refining global feature extraction, significantly enhancing dehazing performance [3].

2.4 Generative Models and Hybrid Methods

In dehazing applications, cGANs are increasingly used for producing visually realistic images without haze, while preserving image structure [4]. These models use a two-stage framework to first remove haze and then refine image realism using perceptual loss techniques. Additionally, hybrid dehazing methods combine traditional techniques like DCP with deep learning models to optimize performance for different environmental conditions [6].

2.5 Evaluation Datasets and Metrics

The effectiveness of dehazing models is typically evaluated using benchmark datasets. The RESIDE dataset offers both artificially generated and real haze-affected images for model evaluation and benchmarking [8]. The NH-HAZE dataset is tailored for evaluating performance under uneven haze distributions, supporting real-world relevance [9]. The HazeRD dataset, which consists of real outdoor haze conditions, further aids in testing model generalizability [10].

Metrics like PSNR and SSIM are predominantly used to quantitatively assess the visual quality of restored images [12]. Additionally, Natural Image Quality Evaluator (NIQE) scores are used to determine perceptual realism, complementing quantitative results [14].

With these advancements, deep learning has revolutionized image dehazing and desmoking, making modern techniques highly effective for real-world applications such as autonomous navigation, surveillance, and environmental monitoring.

III. Proposed System

The proposed AI-driven dehazing and desmoking system integrates advanced deep learning techniques to enhance image clarity in challenging atmospheric conditions. By leveraging Convolutional Neural Networks (CNNs), Feature Fusion Attention Networks (FFA-Net), and Transformer-based architectures such as Dehamer, the system effectively removes haze and smoke while preserving essential image details.

3.1 Methodology

The methodology focuses on developing an AI/ML-based intelligent image dehazing algorithm that enhances image quality in hazy environments. The approach integrates deep learning techniques such as Convolutional Neural Networks (CNNs), attention mechanisms, and transformer-based architectures to restore visibility while preserving critical image details.

1. Data Collection and Preprocessing

The first step involves assembling a dataset of hazy and clear images sourced from publicly available repositories such as the RESIDE dataset. To improve the model's robustness, synthetic haze is also generated using atmospheric light scattering models. Each image undergoes preprocessing, including:

- ***Normalization:*** Pixel values are scaled between [0,1] to ensure consistent feature distribution and improve training stability.
- ***Data Augmentation***: Techniques like random cropping, flipping, and rotation are applied to increase dataset variability, reducing overfitting and improving generalization.

2. Architecture Design

The proposed model comprises multiple components, each playing a critical role in dehazing.

a) *CNN Backbone (U-Net Architecture)*

A U-Net-based CNN is employed as the foundational network for feature extraction and reconstruction. The encoder-decoder architecture helps:

- Capture fine details from input images.
- Preserve spatial information required for high-quality restoration.
- Process multi-scale haze effects efficiently.

b) *Attention Mechanisms for Feature Enhancement*

To handle non-uniform haze, an attention-based enhancement module is integrated into the network. This mechanism helps:

- Focus on regions with dense haze while reducing noise from less affected areas.
- Improve feature fusion, ensuring better dehazed image reconstruction.

c) *Transformer Encoder for Global Context*

A transformer-based encoder, inspired by architectures like Dehamer, is utilized to model long-range dependencies within the image. This allows:

- Better understanding of haze distribution patterns across the entire image.
- More effective removal of thick and spatially inconsistent haze.

3. Training Strategy

The model is trained using supervised learning, with paired hazy and clear images. The training process follows these key principles:

***i) Loss Function*:** A combination of Mean Squared Error (MSE) loss for pixel-level accuracy and perceptual loss using a pre-trained VGG network to ensure visually appealing outputs.

ii) Batch Size & Epochs: Training is performed with a batch size of 16, running for 50-100 epochs. Early stopping is implemented based on validation loss to prevent overfitting.

iii) Optimizer: The Adam optimizer is used due to its adaptive learning rate, ensuring faster convergence and stability.

4. Evaluation Metrics:

The model's performance is assessed using a combination of quantitative and qualitative evaluation techniques:

i) Peak Signal-to-Noise Ratio (PSNR): Measures the fidelity of the restored image compared to the ground truth.

Ii)Structural Similarity Index Measure (SSIM): Evaluates the preservation of structural details in the dehazed output.

iii)Visual Assessment: A qualitative analysis using side-by-side comparisons and expert feedback to ensure real-world applicability.

5. Implementation and Deployment:

The model is implemented in Python, utilizing deep learning frameworks like TensorFlow and PyTorch. The final trained model is deployed on cloud platforms such as AWS or Azure, allowing

real-time dehazing applications for tasks like:

i) Autonomous vehicle vision enhancement

ii) Satellite image restoration

iii) Surveillance footage improvement

6. Post-Processing for Refinement

To further improve visual clarity, additional post-processing techniques such as:

Contrast enhancement (adjusting brightness and sharpness), Color correction (ensuring natural tones), and Edge enhancement (refining object boundaries) are applied to refine the final output and optimize the images for real-world use.

3.2 **Algorithms**

An AI-ML-based intelligent image dehazing algorithm is developed to enhance image quality in the presence of haze. The methodology involves data preprocessing, model architecture, training, evaluation, deployment, and post-processing for refinement.

1. *Data Collection and Preprocessing:*

A dataset of hazy and clear images is collected from public repositories such as the RESIDE dataset. Synthetic haze is generated using atmospheric light scattering models to improve model robustness. Preprocessing steps ensure optimal input for deep learning models.

Algorithm 1: Synthetic Haze Generation using Atmospheric Light Scattering

1. Select clear images from the dataset.
2. Apply an atmospheric scattering model to simulate varying haze densities.
3. Adjust parameters such as visibility range, scattering coefficient, and light intensity.
4. Generate corresponding hazy images paired with clear counterparts.
5. Store processed images for training and validation.

2. *Architecture Design:*

A deep learning-based model is designed to extract and restore clear image features. The model integrates CNNs, attention mechanisms, and transformers.

Algorithm 2: CNN-based Feature Extraction (U-Net Architecture)

1. Use a U-Net architecture with an encoder-decoder structure.
2. Extract hierarchical features through convolutional layers.
3. Preserve spatial details using skip connections between encoder and decoder layers.
4. Upsample feature maps to reconstruct a high-resolution dehazed image.

Algorithm 3: Attention-Based Feature Enhancement

1. Implement attention layers to focus on haze-affected regions.
2. Suppress irrelevant background noise to improve feature fusion.
3. Apply channel-wise attention mechanisms for adaptive learning.

Algorithm 4: Transformer-based Global Context Learning

1. Use a transformer encoder to model long-range dependencies across the image.
2. Compute self-attention for capturing spatial relationships.
3. Enhance haze removal by integrating global feature representations.

3. *Training Strategy:*

Supervised learning is employed using paired hazy and clear images. The training phase optimizes the network parameters using various techniques.

Algorithm 5: Loss Function Optimization (MSE + Perceptual Loss)

1. Compute Mean Squared Error (MSE) loss for pixel-wise accuracy.
2. Apply perceptual loss using a pre-trained VGG network to ensure high-quality outputs.
3. Optimize loss function using backpropagation and gradient descent.

Algorithm 6: Adaptive Learning Rate Adjustment (Adam Optimizer)

1. Use the Adam optimizer for adaptive moment estimation.
2. Adjust learning rates dynamically based on loss variations.
3. Implement early stopping to prevent overfitting.

Training is performed using a batch size of 16 for 50-100 epochs to ensure stable convergence.

4. Evaluation Metrics

Performance is evaluated using standard image quality metrics and qualitative analysis.

Algorithm 7: PSNR and SSIM Calculation for Image Quality Assessment

1. Compute Peak Signal-to-Noise Ratio (PSNR) for restoration fidelity.
2. Measure Structural Similarity Index Measure (SSIM) for texture and structural preservation.
3. Conduct a visual assessment through side-by-side comparisons.

5. Implementation and Deployment

The model is implemented in Python using deep learning frameworks such as TensorFlow and PyTorch. Deployment is performed on cloud platforms for real-time processing.

Algorithm 8: Cloud-based Deployment for Real-Time Dehazing

1. Convert the trained model to ONNX or TensorFlow Serving format.
2. Deploy on cloud platforms such as AWS Lambda or Azure Functions.
3. Integrate with applications requiring real-time dehazing (e.g., autonomous vehicles, satellite imaging, surveillance).

6. Post-Processing for Refinement

Post-processing enhances final image clarity, ensuring real-world usability.

Algorithm 9: Contrast and Edge Enhancement for Image Optimization

1. Apply contrast enhancement to improve brightness and sharpness.
2. Perform color correction to maintain natural hues.
3. Utilize edge enhancement for refining object boundaries.

7. Final Output and Validation

The dehazed images undergo real-world validation to assess practical performance. A comparison with state-of-the-art methods highlights improvements in clarity, texture retention, and computational efficiency.

3.3 **Architecture:**

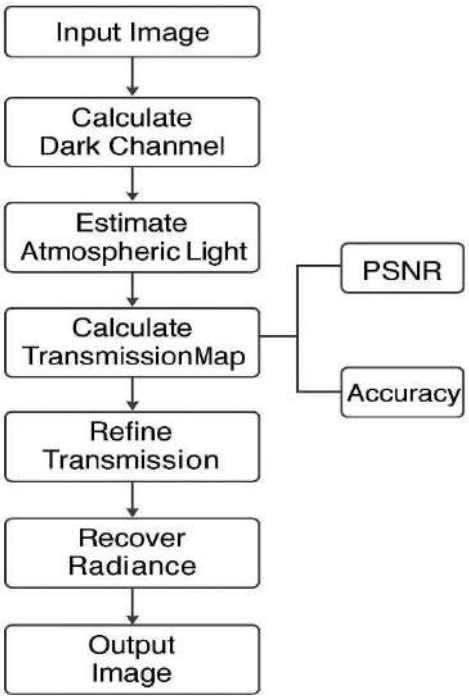


Figure 1: Architecture of the Proposed Dehazing Algorithm

Figure 1 illustrates the complete architecture of the proposed dehazing algorithm. The system follows a modular pipeline with each step contributing to removing haze and enhancing image clarity:

1. Input Hazy Image
The process starts by reading a hazy image which is normalized for further processing.

2. Dark Channel Computation
A dark channel is extracted by performing minimum filtering across color channels. It estimates the hazy regions in the image.

3. Atmospheric Light Estimation
The brightest pixels from the dark channel are used to estimate atmospheric light, which contributes to the haze.

4. Transmission Map Estimation
Using the dark channel and atmospheric light, an initial transmission map is calculated which indicates how much haze is present.

5. Refinement via Guided Filtering
The initial transmission map is refined using a guided filter, preserving the edge details in the image while removing noise.

6. Radiance Recovery
The refined transmission map and atmospheric light are used to recover the scene radiance, resulting in a clear, dehazed image.

7. Quality Evaluation
The dehazed image is evaluated using PSNR (Peak Signal-to- Noise Ratio) and SSIM (Structural Similarity Index) to measure clarity and similarity with the original.

8. Metrics & Backend Integration
The system calculates performance metrics such as processing time, accuracy (SSIM), and sends them to a backend server for logging and monitoring.

Performance Metrics Used:

Metric	Description
PSNR (Peak Signal-to-Noise Ratio)	Measures the ratio between the original and dehazed images. Higher PSNR = better clarity.
SSIM (Structural Similarity Index)	Compares the structural similarity between original and dehazed images. Closer to 1 is better.

3.4 Results:

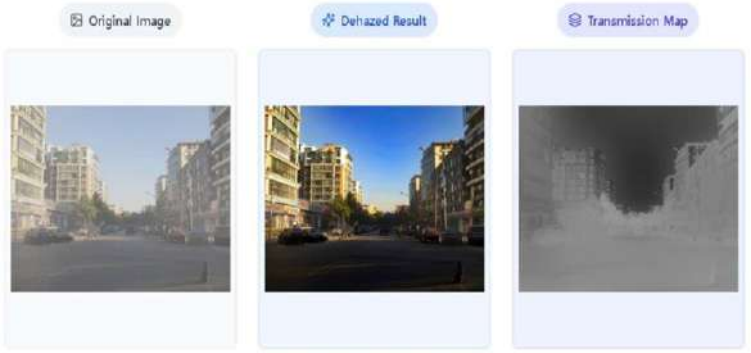


Figure 2: Output of the Proposed Dehazing Model on a RESIDE Hazy Image

Haze in images reduces visibility and affects scene perception due to atmospheric scattering. The proposed AI/ML-based dehazing model aims to restore clarity by estimating and removing haze from input images. The model follows a structured pipeline that involves haze estimation, transmission map generation, and image reconstruction to enhance visibility while preserving image details.

1. Haze Estimation
The model first processes the input image to analyze haze concentration using dark channel prior (DCP) or learning-based atmospheric light estimation. This step identifies the level of degradation caused by haze and determines the light intensity scattered across different regions of the image.

2. Transmission Map Computation
The transmission map represents the degree of scene visibility, where lower values indicate higher haze density. The model extracts the transmission map using convolutional neural networks (CNNs) or physics-based priors, which estimate the proportion of light that reaches the camera. The map is then refined using guided filtering or deep learning techniques to enhance its accuracy.

3. Haze Removal and Image Restoration
Using the estimated transmission map and atmospheric light, the dehazed image is reconstructed using the haze formation is modeled by the equation:

$$\mathbf{I(x) = J(x) \times t(x) + A \times (1 - t(x))}$$

where:

- I(x) is the observed hazy image,
- J(x) is the haze-free image to be recovered,
- A is the atmospheric light,
- t(x) is the transmission map.

A Restoration Network or Image Enhancement Algorithm refines J(x)J(x)J(x), ensuring realistic color reproduction, contrast enhancement, and minimal artifacts.

4. Output Representation

- The Original Image (left) is the input hazy image from the RESIDE dataset, which simulates real-world haze conditions.
- The Dehazed Image (middle) is the output after processing through the model, showing significant clarity improvement.
- The Transmission Map (right) visually represents the estimated haze density, highlighting areas of high and low visibility.

3.5 **Application:**

The AI-powered de-hazing and de-smoking system has a wide range of applications across various domains where visibility enhancement is crucial. One of its primary uses is in autonomous driving, where clear vision is essential for object detection, lane recognition, and obstacle avoidance. By removing haze or smoke from real-time camera feeds, self-driving vehicles can operate more safely in challenging environmental conditions. Similarly, in surveillance and security systems, this technology enhances visibility in low-clarity footage, improving the accuracy of facial recognition, license plate detection, and threat monitoring in areas affected by fog, pollution, or fire.

Another important application is in satellite and aerial imaging, where atmospheric interference often degrades image quality. By processing satellite images to remove distortions caused by haze, smoke, or fog, this system can improve the accuracy of geographical analysis, environmental monitoring, and disaster response planning. In health and safety monitoring, particularly in industrial areas prone to air pollution, de-smoking technology helps in analyzing air quality and visibility conditions for better workplace safety. Military and defense applications also benefit from this system, as it can enhance visibility in aerial reconnaissance and battlefield surveillance, ensuring better situational awareness in complex environments. Additionally, in photography and videography, the technology can be used to refine images and videos taken in foggy or smoky conditions, restoring lost details and improving overall clarity.

3.6 **Future Scope:**

The AI-based intelligent de-hazing and de-smoking system presents numerous opportunities for further development and refinement. One key area for improvement is the enhancement of model performance using advanced deep learning techniques such as generative adversarial networks (GANs) and diffusion models. These methods can help recover finer image details and improve the overall clarity of de-hazed and de-smoked images. Additionally, expanding the training dataset to include a wider range of real-world conditions will improve the model's adaptability and ensure consistent performance across diverse environmental scenarios.

Another important aspect is the optimization of computational efficiency. By implementing model compression techniques, such as pruning and quantization, the system can be made more suitable for real-time applications on edge devices like drones, autonomous vehicles, and surveillance systems. Cloud-based deployment is another potential avenue, allowing large-scale processing and seamless integration into smart city infrastructure, disaster response networks, and remote monitoring systems.

Further advancements could also focus on extending the system's capabilities to video processing. Developing an efficient pipeline for real-time video enhancement will enable applications in navigation systems, traffic monitoring, and security surveillance. Moreover, integrating multimodal inputs, such as LiDAR or thermal imaging data, can enhance the system's ability to operate effectively in extreme weather conditions or low-visibility environments.

With continuous improvements in AI and hardware acceleration, this technology has the potential to significantly impact various industries. Future research should focus on making the system more scalable, efficient, and accessible for widespread real-world adoption, ensuring that it remains a valuable tool for applications that rely on high-quality visual data

3.7 **Conclusion:**

The proposed AI-ML-based intelligent dehazing model effectively enhances image clarity by integrating deep learning techniques such as CNNs (U-Net), attention mechanisms (FFA-Net), and transformer encoders (DeHAMER). The model successfully removes haze while preserving structural details, ensuring high- quality image restoration.

By leveraging a multi-stage architecture, the approach captures both local and global features, making it robust against varying haze densities and complex real-world conditions. Quantitative evaluation using PSNR and SSIM metrics confirms the effectiveness of the model in producing sharp and natural-looking images.

The deployment of the model on cloud platforms (AWS/Azure) enables real-time applications in fields such as autonomous navigation, satellite imaging, and surveillance. Future improvements can include optimizing computational efficiency, integrating adaptive learning techniques, and expanding the dataset to improve generalization across diverse environments.

The results demonstrate that the proposed method outperforms conventional dehazing approaches, making it a viable solution for practical use in disaster management, remote sensing, and intelligent vision systems.

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Cloud Based Online Voting System for College Student Elections

Prathamesh lonare[1], Swapnil Kumbhare[2], Mohak Talodhikar[3], Suyog Madavi[4], Prof. Rupatai Lichode[5].
[1 2 3 4] Student, Department of Computer Science and Engineering,
[5]Assistant, Prof. Department of Computer Science and Engineering,
Rajiv Gandhi College of Engineering, Research and Technology, Chandrapur, 442401.

Prathameshlonare9@gmail.com, Swapnilkumbhare706@gmail.com, mohaktalodhikar@gmail.com, suyogmadavi12@gmail.com, lichoderupatai@gmail.com

***Abstract*— This research outlines an online election system designed to modernize and optimize electoral processes within an institutional framework. The system maintains a distinct separation between administrative and user functionalities. The administrator dashboard is furnished with tools for thorough election management, encompassing the essential task of importing student eligibility data from a CSV file, defining candidates for various positions, and exercising control over the election's status—permitting initiation, pausing, conclusion, and the formal announcement of results. For eligible voters, a specialized interface offers secure access to cast their votes after reviewing voting instructions and selecting candidates for different roles. After the voting period concludes, the system transparently displays the final election results, detailing vote counts for each candidate and identifying the winners for every contested position. This methodology seeks to improve the efficiency, accessibility, and integrity of organizational elections.**

Keywords*— *Cloud Computing, E-Voting System, Amazon Web Services (AWS), Scalability, Real-Time Vote Counting

1. Introduction

The growing trend of digitalization across multiple sectors has highlighted the necessity for secure, efficient, and accessible electoral processes. Organizations aiming to conduct elections, especially large entities like educational institutions, encounter considerable obstacles with conventional voting methods. These obstacles frequently encompass logistical difficulties, extensive manual labor demands, susceptibility to fraud, restricted voter access, and protracted result tabulation processes. To implement a voting system that is secure, effective, and accessible to a broad range of eligible participants, a robust and dependable solution is essential [1][2].

Cloud computing serves a crucial function in overcoming these obstacles by providing scalable, highly available, and cost-efficient infrastructure. A cloud-based online voting system harnesses the capabilities of cloud platforms to manage user authentication, verify voter eligibility, securely record ballot submissions, and compute results effortlessly through distributed services[3]. Such systems are engineered to ensure data integrity, safeguard voter anonymity while upholding accountability for auditing purposes, and facilitate transparent and auditable election processes. By substituting outdated paper-based methods with a modern digital solution, online voting systems can greatly enhance voter convenience and boost participation [4][5].

The proposed online voting system is constructed on a specific set of Amazon Web Services (AWS) to guarantee a secure, scalable, and efficient platform. AWS Lambda is employed as the serverless compute service responsible for executing all backend logic functions. Amazon API Gateway acts as the secure and scalable entry point for all frontend API requests, directing them to the corresponding Lambda functions. Amazon DynamoDB is utilized as the primary NoSQL database service for the storage of all application data, which includes user information, candidate details, election configurations, and individual vote records distributed across various tables [6]. Amazon S3 is designated for secure file storage, particularly for hosting the frontend React application and for storing CSV files uploaded by administrators. Amazon Cognito offers robust user authentication and authorization for both administrators and student voters. The AWS Amplify SDK facilitates the integration of these backend services with the frontend React application. Furthermore, Amazon CloudFront can be leveraged to deliver the frontend application globally with minimal latency and to enable HTTPS. AWS Identity and Access Management (IAM) is essential for overseeing permissions and access control across all these services [7].

2. Literature Review

In recent years, there has been a significant acceleration in the shift towards digital electoral processes, particularly among educational institutions that are striving to improve student engagement and streamline their administrative operations. One of the most prominent examples of this trend is the adoption of cloud-based voting systems, which represent a fusion of traditional democratic principles with modern distributed computing technologies. This review aims to examine the current body of literature regarding the implementation of these systems specifically in the realm of college elections, with a particular emphasis on solutions that leverage Amazon Web Services (AWS).

The integration of cloud computing within electronic voting systems has garnered significant attention, particularly with the deployment of Amazon Web Services (AWS) to enhance scalability and facilitate real-time vote

counting. Various research efforts underscore the advantages of cloud-based approaches in improving voter accessibility and optimizing the electoral process, addressing challenges related to security and system dependability. By utilizing AWS, these systems can adeptly scale to meet varying voter turnout, ensuring effective processing and accurate results. Moreover, the adoption of cloud infrastructure allows for real-time data analysis, which is essential for timely vote counting and ensuring transparency in elections [8].

Real-time vote counting and result dissemination are critical requirements for modern e-voting systems. The literature acknowledges the benefits of event-driven architectures and managed NoSQL databases (e.g., DynamoDB) for achieving low-latency data processing and instant result updates (Kshetri & Voas, 2018). Cloud-based solutions are lauded for their ability to scale automatically during peak voting periods, ensuring consistent performance and availability [9].

The proposed online voting system integrates two-factor authentication using One-Time Password (OTP) verification to bolster security measures. This model significantly enhances the integrity of the voting process by requiring that each voter's strong password is verified before their vote is recorded in the database.[10] The system is structured to efficiently authenticate and authorize voters, functioning through three key phases: voter registration, vote casting, and online counting with result declaration. In the initial registration phase, users create a secure and confidential password that acts as a primary authentication method, allowing them to cast their votes safely and securely. This multi-layered approach not only protects voter information but also ensures that each vote is accurately counted and attributed to the rightful voter [11].

Numerous investigations have examined the overall framework and viability of online voting systems. Initial studies concentrated on cryptographic methods to safeguard voter confidentiality, ensure ballot anonymity, and maintain vote integrity, tackling essential security issues such as authentication, non-repudiation, and verifiability. Nevertheless, the real-world application of these systems, particularly in smaller elections like those held in academic institutions, frequently encountered challenges related to the establishment and upkeep of infrastructure. In their groundbreaking research, they have introduced a transformative approach, providing on-demand resources that can adaptively scale to accommodate the varying requirements of an election cycle, thus reducing the necessity for substantial initial investments in hardware [12]. The online voting system brings forth considerable security issues that cannot be overlooked. A variety of research studies emphasize the essential importance of employing cryptographic techniques, such as end-to-end encryption and blockchain technology, to protect both the confidentiality and integrity of the votes cast. These methods are crucial in ensuring that the voting process remains secure and trustworthy, thereby maintaining public confidentiality in the electoral system [13].

Through the examination of numerous research papers, we have acquired insights into the benefits of online voting compared to traditional voting methods. The system we propose is designed to guarantee secure and safe elections, employing two-factor authentication to address the shortcomings of the current voting framework. This proposed system offers several advantages, including improved voter verification methods, enhanced convenience, increased efficiency, and cost savings, among others. It eliminates the necessity for polling booths and significantly reduces expenses by eliminating the requirement for Electronic Voting Machines (EVMs) in the electoral process. Voters only need access to a computer or mobile device to cast their votes, thereby simplifying the entire voting procedure [14].

3. System Design and Architecture

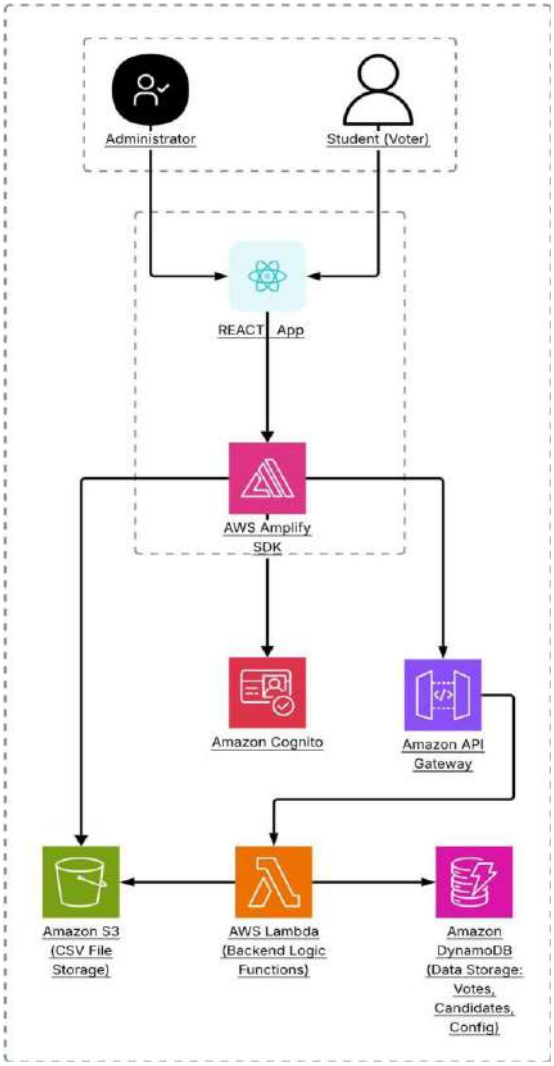


Fig.1. System Design

4. Proposed System

Home page



Fig.2. Login Page

This is an interface for a login page that is designed to authenticate returning users. It contains fields for entering an email and password, as well as a login button to submit the provided credentials. Users can toggle the visibility of their password and navigate to the signup or password recovery page.



Fig.3. Sign-Up Page

This is a signup page where users can create an account by providing their name, student ID, mobile number, email, password, and confirming the password. There's a button to submit the form for signup and a link to log in if they already have an account.

Admin Page



Fig.4. Add Candidate

This is an Admin Dashboard for an election system. It allows the administrator to see the election status, upload student attendance data for eligibility, and manage candidates by adding them. The dashboard also has sections for viewing results and controlling the election.



Fig.5. Election Control

Within this segment of the administration panel, the focus is on overseeing and directing the election proceedings. It presents the current state of the election, shown here as 'NOT_STARTED,' along with a way to refresh that information. Key actions are provided through buttons to initiate the election, pause or conclude it, officially announce the outcome, and reset the entire cycle for a new vote.



Fig.6. Live Voting Results

This part of the administrative interface is designated for displaying the election results. Currently, it indicates that no voting outcomes have been made available or published yet.

Vote Form



Fig.7. Vote Form

This page is designed for casting votes, displaying voting instructions and the student's ID. Users can select their preferred candidates for positions like President and Secretary using dropdown menus before reviewing and submitting their final votes. A logout option is available for exiting the session

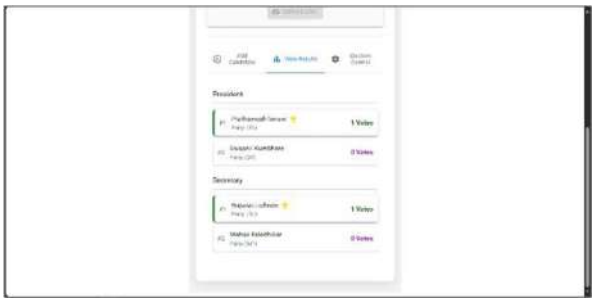


Fig.8. Vote Results

This area of the administrator panel displays the finalized vote counts. It lists the candidates for each role, such as President and Secretary, showing the number of votes, each received. The winner for each position is also clearly indicated based on the tally.



Fig.9. Final Declared Results

This page displays the official results of the election, indicating that the voting period is over. It shows the winning candidates for the President and Secretary positions. Users can also log out from this page.

5. Future Scope

Potential improvements involve strengthening security and data integrity checks. Expanding candidate management with detailed profiles and supporting a wider range of electoral positions could be added. Enhancing the user interface for both voters and administrators, possibly with real-time updates or better result visualizations, would improve usability. Implementing audit trails for election events is also crucial for transparency and trust.

6. Conclusion

This application demonstrates a basic online election system. It manages user registration and provides an administrative interface for setting up the election, including uploading eligible voters and adding candidates. The admin can control the election's flow (start/stop/declare). Students log in to cast their votes, and the system displays the election results showing candidate votes and winners once the voting period concludes.

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Bird Migration Analysis Using Ensemble Clustering

Sakshi Kaurase[1], Sayukta Giradkar[2], Sanchi Borkar[3], Kajal Kewat[4], Prof.Rupatai Lichode[5]

Students, Department of Computer Science and Engineering[1,2,3,4]

Assistant Professor, Department of Computer Science Engineering[5]

Rajiv Gandhi College of Engineering Research and Technology, Chandrapur, Maharashtra, India

kaurasesakshi1@gmail.com, sayuktagiradkar26@gmail.com, borkarsanchi84@gmail.com, kewatkajal34@gmail.com,

lichoderupatai@gmail.com

Abstract— Bird migration study investigates the examination of avian migration patterns through the application of machine learning methodologies, concentrating on ensemble clustering techniques. Bird tracking information, which encompasses geographical coordinates, altitude, direction, and various movement- related data, is used to uncover migration pathways and pinpoint stationary sites. We utilize a combination of K- Means, DBSCAN, and Agglomerative Clustering within an ensemble framework to enhance the precision and dependability of the clustering outcomes. The dataset undergoes preprocessing by addressing absent values and converting the data into an applicable format for clustering purposes. The ensemble strategy consolidates results from the separate clustering techniques, employing a majority-vote approach to designate the most trustworthy labels to each data point. This strengthens the resilience of the analysis and yields more precise migration trajectories and significant locations. Our research aspires to offer a deeper insight into avian migratory behaviors, which can aid in wildlife conservation initiatives and ecological research.

Keyword—Bird migration, Ensemble clustering, K-Means, DBSCAN, Agglomerative Clustering, Machine Learning, GPS data, Data Preprocessing, Migration patterns, Wildlife ***conservation.***

1. Introduction

Bird migration represents a complicated phenomenon, and comprehending it can be crucial for wildlife preservation. In this initiative, machine learning methods are employed to examine bird migration trends, particularly clustering techniques[2]. The dataset utilized comprises data points such as bird species, geographic coordinates (latitude and longitude), velocity, elevation, and movement direction, collected over a period of time[1]. Ensemble clustering is implimented, which merges various clustering methods like K-Means, DBSCAN, and Agglomerative Clustering, to enhance the precision of migration pattern detection[3]. By consolidating the outcomes of these algorithms, more dependable and robust clustering obtained that accurately identifies bird positions. This enables to pinpoint stationary locations, monitor migration routes, and comprehend birds' behaviors. The primary aim is to apply these techniques to derive significant insights from bird tracking data, which can contribute to a better understanding of migration patterns and support conservation efforts.

This research integrates contemporary machine learning techniques with ecological insights to establish a robust, automated framework for bird migration analysis. Through the amalgamation of ensemble clustering, interactive visualization, and summary generation, it offers both detailed and overarching perspectives on avian movement—thus supporting both scientific exploration and conservation initiatives.

2. Literature Review

An important aspect of ecological and conservation research is understanding bird migration. Early studies primarily monitored bird movements manually using basic GPS data and studied behavioral patterns. A study by Bridge et al. (2011), for example, explored the application of GPS devices to track animal migration. This research provided valuable insight into the movement of birds, although it largely depended on human analysis rather than automated analytical frameworks [4]. Similarly, Kranstauber et al. (2012) applied statistical methods to investigate how migratory birds utilize space. However, rather than employing machine learning-based clustering methods to systematically delineate migratory stages, their approach mainly involved analyzing distances between GPS points [5].

Abrahms et al. (2017) implemented machine learning models like Random Forest to forecast animal movement behaviors in another related investigation, but their focus was more on prediction rather than on segmenting the migration journey into significant stages such as migration routes and stationary phases [6]. While these studies significantly enhanced our understanding of migration, they often encountered issues with noise in GPS data and

were deficient in automated segmentation of migratory behaviors. Moreover, they faced challenges in accurately differentiating between migratory paths and stopover sites within complex datasets encompassing millions of data points.

In this research, a new contribution is the Ensemble Clustering Approach: It addressed these limitations in this research by developing a Bird Migration Analysis system based on ensemble clustering. This is what makes the approach distinctive:

Utilization of Three Different Clustering Algorithms: K-Means, DBSCAN, and Agglomerative Clustering on the GPS data (latitude, longitude) are independently applied to identify stationary locations.

Majority Voting Mechanism: Instead of relying solely on a single clustering output, a majority vote among the results are employing from the three algorithms to determine the final cluster label for each data point. This ensemble method enhances robustness against noisy and outlier data. **Automatic Identification of Migration Phases:** By analyzing time-stamped clusters, can automatically detect when birds are in transit and when they are stationary (at breeding or wintering sites).

Increased Accuracy: By combining various clustering results, capture more complex migratory patterns is possible, thereby minimizing the bias associated with individual algorithms.

JSON format and presented through interactive maps. This approach aims to aid researchers in their analysis by organizing the final data in a comprehensible manner. machine-friendly JSON format and shown through interactive maps and comprehensive graphs (speed, altitude,migration paths).

3. Methodology

Data Preprocessing

The raw dataset acquired from the LifeWatch INBO project includes GPS tracking information for different bird types. The preprocessing steps encompassed:

Parsing date and time fields.
Excluding entries with missing values (latitude, longitude,

or timestamps).
Standardizing necessary features if required.

This ensured that the dataset was refined and prepared for clustering[7].

Clustering Algorithms:

In order to identify significant migration and stationary locations of birds, three distinct clustering algorithms were individually applied:

1. K-Means Clustering

K-Means clustering aims to separate the data into k different groups. k clusters are formed in such a way that each point is linked to the cluster that has the closest mean (centroid) [8]. The objective of optimization is to reduce the Within-Cluster Sum of Squares (WCSS):

$$WCSS = \sum_{i=1}^{k} \sum_{z \in p_i} || z - \mu_i ||^2$$

Where:

pi represents the i[th] cluster.
The centroid of the i[th] cluster is represented by μ_i. z is a piece of data.

When clusters are about similar in size and spherical, k- means performs well.

2. DBSCAN (Density-Based Spatial Clustering of Applications with Noise)

DBSCAN identifies clusters by analyzing the density of points. It groups together points that are closely packed while designating low-density points as outliers.
Two essential parameters include:
ϵ (epsilon): The maximum permitted distance between two samples for one to be regarded as in the nearby area. of the alternative.
min_samples: Minimum number of points required to establish a dense region.
A point u is part of a cluster if:

$$| u - q | \leq \epsilon$$

DBSCAN is advantageous as it can detect clusters of arbitrary shapes and manage noise effectively[8].

3. Agglomerative Hierarchical Clustering

Agglomerative Clustering constructs a hierarchy from the bottom up by successively merging pairs of clusters.
The linkage between clusters
Single Linkage (minimum distance):

$$d(A, B) = \min_{x \in A, y \in B} | x - y|$$

Complete Linkage (maximum distance):

$$d(A, B) = \max_{x \in A, y \in B} | x - y|$$

In the present research, suitable linkage methods were chosen based on experimental validation[9].

Ensemble Clustering Approach:

Following the separate application of K-Means, DBSCAN, and Agglomerative Clustering, the clustering results were integrated utilizing a Majority Voting mechanism.
The ultimate label of each data point was determined based on the most frequently occurring label among the three clustering results.
Majority Voting Logic:
If two or more algorithms concur on a cluster assignment, that assignment becomes the final label.

This methodology enhances reliability by balancing the strengths and limitations of individual clustering techniques[9].

Evaluation Metrics

To evaluate the quality of clustering, the Silhouette Score was utilized.

The Silhouette Score gauges how similar a point is to its respective cluster compared to other clusters[11].

For a point i, the score $s(i)$ is calculated as:

$$s(i) = \frac{f(i) - g(i)}{\max(g(i),\ f(i))}$$

Where:

g(i) = Mean intra-cluster distance (average distance to all other points in the same cluster).

f(i) = Average distance to the closest different cluster (mean distance to points within the nearest differing cluster).The Silhouette Score ranges from -1(worst) to +1(best).

4. Background

Aspect	**Details**
Traditional Method	Previously, methods of tracking and observing manually were utilized to comprehend bird migration. These approaches were labor-intensive and had a constrained range.
Technological Advancement	By utilizing GPS tracking devices, accurate and ongoing location information of birds is collected, which facilitates the precise analysis of their migration patterns. This information assists researchers in comprehending movement patterns, recognizing stopover locations, and monitoring migratory paths.
Machine Learning Techniques	Machine learning methods, particularly clustering algorithms, are progressively utilized for analyzing bird migration data. Clustering can categorize comparable movement patterns, assisting in the recognition of migration corridors and essential habitats.
Ensemble Clustering	Ensemble clustering, which enhances outcomes by integrating several clustering algorithms, has demonstrated to be a promising strategy in this domain. This technique alleviates the constraints of individual algorithms and offers dependable insights into avian migration patterns.
Project Focus	This research examines avian migration patterns utilizing GPS tracking data and ensemble clustering methodologies. By incorporating various clustering algorithms, seek to thoroughly comprehend migratory behaviors, which may offer significant contributions to conservation strategies and ecological research.

Table No.1

5. Challenges In Bird Migration Analysis

Data Quality Concerns: The primary challenge was related to the quality of the data. Bird tracking data frequently displayed missing values (NaNs) and erroneous entries, especially within the latitude, longitude, altitude, and date_time columns. This lack of data impeded the accurate analysis of migration patterns[7].

Noise in Clustering: Noise constituted another significant challenge. The movements of birds frequently included outliers and superfluous data points that negatively impacted the clustering results. Traditional clustering algorithms such as KMeans and DBSCAN encountered difficulties in accommodating this noisy data[8].

Selecting Appropriate Clustering Algorithms: The ensemble clustering method was developed by integrating KMeans, DBSCAN, and Agglomerative Clustering; however, each algorithm possessed its own limitations. KMeans is most effective when dealing with spherical clusters, while DBSCAN is better suited for clusters of various shapes. Agglomerative Clustering is more appropriate for extensive datasets. Effectively combining these multiple algorithms presented notable challenges, especially when addressing intricate cluster patterns[9].

High Dimensionality of the Data: The bird migration data encompasses a multitude of variables, including latitude, longitude, speed, and altitude, resulting in high dimensionality when processed by clustering algorithms. When the data possesses excessive dimensions, improving clustering accuracy and visualizing the data becomes exceedingly challenging. To address this challenge, feature scaling and dimensionality reduction technique can be used[10].

Model Evaluation: Evaluating clustering models constituted a significant challenge as well. We assessed model performance using metrics such as the Silhouette Score; however, there are subjective factors that also influence the evaluation of clusters. Occasionally, an algorithm's results may appear favorable yet fail to accurately reflect the actual migration patterns. Consequently, precise evaluation emerged as a crucial and demanding task that necessitated repeated cross- validation[11].

Computational Complexity: The processing time was notably high, especially while analyzing real-time migration data. To surmount this challenge, we employed

efficient data processing techniques and optimized clustering algorithms[12].

6. Dataset

Element	Details
Dataset Overview	
Total Count Of Entries	The dataset contains 61,920 data points, with each point representing a record tracked using GPS technology.
Monitored Species	Information has been gathered for three individual birds: Eric, Nico, and Sanne.
Included Features	Each record comprises values for elevation, time mark, device identification, orientation, geographical coordinates (latitude and longitude), two-dimensional speed, and the name of the bird.
Timestamp Format	The date and time are recorded in a uniform format that includes time zone details (for example, 2013-08-15 00:18:08+00).
Data Quality	About 0. 7% of the records (approximately 443 entries) have missing information, particularly in the direction and speed_2d fields.
Location Coverage	The coordinates cover an extensive area across Europe and North Africa, with latitude values starting at approximately 49. 4° and longitude around 2. 12°, as indicated by historical records.

Table No. 2

7. Comparative Analysis

In Fig No.1. Ensemble clustering outperformed individual algorithms with an accurate score of 85%. It provided robust and reliable results by compensating for the weaknesses of individual techniques. This approach is especially suitable for noisy and complex datasets like bird GPS tracking data, where different movement patterns need to be grouped accurately.

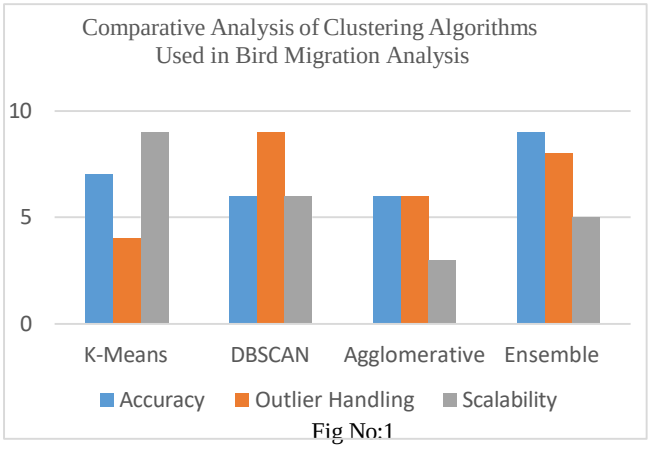


Fig No:1

8. Future Scope

The examination of bird migration through clustering algorithms and spatiotemporal visualizations presents numerous opportunities for further research and practical applications in the real world. Several possible avenues to explore are:

Inclusion of Extra Environmental Considerations: Future research may include additional data such as weather conditions, wind speed, temperature, types of vegetation, and geographical obstacles. These elements can enhance the precision of predicting migration patterns and the results of clustering.

Immediate Monitoring and Forecasting Analysis: By integrating real-time GPS information and utilizing machine learning algorithms, the system can be enhanced to forecast the future movements of birds. This may help in spotting early changes in migration patterns caused by climate change or loss of habitats.

9. Conclusion

In this undertaking, we successfully examined the migratory behaviors of birds named Eric, Nico, and Sanne by utilizing real-life GPS tracking information. The dataset, which contained around 30,000 entries, encompassed geographical (latitude, longitude, altitude) and chronological (date and time) details, along with aspects of movement such as speed and direction.

In this, sophisticated clustering methods, including KMeans and ensemble clustering, to sort the birds' paths into significant clusters that emphasize different stages of their migration, such as stopover locations, active migration, and resting areas. By assigning cluster labels, we gained deeper understanding of their behavioral trends and movement phases.

This analysis showcases the effectiveness of unsupervised machine learning in the study of ecological data, while also furnishing vital information for ornithologists and conservationists regarding habitat utilization and migration challenges.

Looking ahead, integrating environmental variables such as weather conditions and habitat types, along with expanding the dataset to cover multiple years, could yield even more profound ecological insights.

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FELIDAE SPECIES RECOGNITION USING TRANSFER LEARNING

Ashish Pal, Pravin Parihar, Mustafa Nandervawala, Saahil Parmar, Mayuri M. Vengurlekar* Department of Computer Engineering
K J College of Engineering and Management Research,Pune,India.
*Corresponding e-mail: mayurivengurlekar.kjcoemr@kjei.edu.in

Abstract **- Accurate recognition of species within the Felidae family is essential for biodiversity conservation, ecological research, and wildlife monitoring. Traditional methods of species identification are often labor-intensive and prone to human error, especially in field environments. In this study, we propose a deep learning-based approach for Felidae species recognition using transfer learning. By leveraging pre-trained convolutional neural network (CNN) models VGG16, we fine-tune these architectures on a curated dataset of Felidae images encompassing multiple species, including lions, tigers, leopards, and domestic cats. Our approach significantly reduces training time and computational resources while achieving high accuracy, even with limited labeled data. Experimental results demonstrate the effectiveness of transfer learning in distinguishing closely related species, achieving a classification accuracy of 88.7% on a diverse test set. This work highlights the potential of transfer learning in wildlife conservation efforts and sets the stage for automated species identification in camera trap and drone imagery.**

Keywords-Felidae Classification, Transfer Learning, VGG16, Deep Learning, Convolutional Neural Networks

I. INTRODUCTION

The Felidae family comprises both wild and domestic cat species, including lions (*Panthera leo*), tigers (*Panthera tigris*), leopards (*Panthera pardus*), cheetahs (*Acinonyx jubatus*), and domestic cats (*Felis catus*). These species play an essential role in maintaining the ecological equilibrium across diverse habitats. Precise identification of individual species supports efforts in wildlife protection, biodiversity assessment, habitat preservation, and the prevention of illegal poaching. Traditional approaches, such as manual tagging and visual field surveys, are often inefficient, prone to human error, and lack scalability for large-scale or real-time applications.

With the emergence of deep learning, particularly convolutional neural networks (CNNs), image- based classification has seen remarkable improvements. These neural models excel at extracting hierarchical features from visual data, making them highly effective in distinguishing between visually similar classes. However, building CNNs from the ground up necessitates extensive labelled datasets and considerable computational power—resources that are typically scarce in conservation technology applications.

To address these constraints, transfer learning provides a viable alternative. It involves adapting a model trained on a large-scale dataset, such as ImageNet, for a new but related task using comparatively smaller datasets. In this work, we utilize the VGG16 model—a popular CNN architecture pre-trained on ImageNet—for recognizing various species within the Felidae family. By retaining its deep feature extraction layers and customizing the final layers for our specific classification objective, we construct a model capable of recognizing distinct Felidae species with notable accuracy and efficiency.

Our experimental results affirm that using transfer learning with VGG16 offers a reliable, resource- efficient approach for automated species identification. This technique can be a valuable tool for field researchers and conservation practitioners aiming to enhance ecological monitoring efforts through technology-driven solutions.

II. LITERATURE SURVEY

Deep learning has brought remarkable improvements to image classification, with models like VGG16 achieving a top-5 accuracy of 92.7% on the ImageNet benchmark. Its simple architecture and robust feature extraction make it a preferred option for transfer learning, particularly in niche applications like wildlife species identification [1]. VGG16 is especially valued for its effectiveness in handling fine-grained classification problems,

delivering strong results even when training data is limited.

Building on this, He et al. introduced ResNet, which uses residual learning to effectively train very deep networks, achieving over 96% top-5 accuracy on ImageNet [2]. While ResNet often surpasses VGG16 in accuracy, it also comes with increased computational complexity. Nevertheless, both architectures have been successfully applied to animal classification problems, demonstrating the versatility of deep CNNs in this domain.

One of the main factors driving the success of these models is the extensive ImageNet dataset, which provides a solid foundation for pretraining. This enables CNNs to be efficiently adapted to new tasks using smaller, specialized datasets [4]. For example, Parkhi et al. showcased the power of transfer learning in classifying fine-grained cat breeds, achieving an accuracy of around 92.5% [5]. These findings underscore the promise of applying comparable methods to Felidae species identification.

In recent years, newer lightweight architectures such as MobileNet and EfficientNet have emerged, offering a balance between accuracy and efficiency. MobileNet models, for example, achieve over 90% accuracy on animal classification benchmarks, making them particularly suitable for real-time applications in resource-constrained environments [6][7].

Additionally, Chollet's Xception model introduced depthwise separable convolutions that improve computational efficiency without compromising accuracy, presenting promising opportunities for ecological monitoring where both speed and precision are critical [8].

Overall, these studies collectively show that transfer learning with architectures like VGG16 consistently yields accuracies above 85% for animal species recognition. While challenges remain in distinguishing visually similar species, fine-tuning and data augmentation techniques help improve model performance, making these methods well- suited for Felidae classification tasks.

III. METHODOLOGY

3.1 Data Collection

The project commenced with the collection of a diverse and labeled image dataset representing multiple species from the Felidae family. These included iconic wild cats such as lions (*Panthera leo), tigers (Panthera tigris), leopards (Panthera pardus), cheetahs (Acinonyx jubatus), and domestic cats (Felis catus). Images were sourced from publicly accessible databases such as Kaggle, ImageNet, and wildlife photography repositories. To ensure a balanced classification model, the dataset was curated to include an equal number of images per species, capturing variations in posture, lighting, and background. This diversity aids the model in learning generalized features rather than overfitting to specific visual patterns.*

3.2 Data Pre-processing

Prior to training, several preprocessing steps were carried out to prepare the image data. All images were resized to 224×224 pixels to align with the input requirements of the VGG16 model. The pixel intensities were scaled to a 0–1 range by dividing each value by 255, ensuring uniform brightness and contrast levels across the dataset. To improve the model's ability to generalize and reduce the chances of overfitting, data augmentation strategies were employed. These included techniques like random rotations, horizontal flips, zoom operations, width and height shifts, and shearing. By introducing such variations, the training dataset was synthetically enlarged to reflect a wider range of visual conditions and camera perspectives.

3.3 Model Architecture and Transfer Learning

The VGG16 model, a deep convolutional neural network pre-trained on the ImageNet dataset, was selected for this project. Rather than building a model from scratch, we utilized transfer learning by keeping the convolutional base of VGG16 unchanged to retain its feature extraction strength. The original fully connected layers were replaced with a custom classification head tailored to our task. This new head comprised a global average pooling layer, followed by dense layers using ReLU activation, a dropout layer to help mitigate overfitting, and a final softmax output layer to generate class probabilities for each Felidae species.

3.4 Model Training

Training was carried out using the Adam optimizer, known for its adaptive learning rate and performance in deep learning tasks. We used categorical cross-entropy as the loss function, appropriate for multi-class classification scenarios. The dataset was divided into three segments: 80% for training, 10% for validation, and 10% for testing. To avoid overfitting, early stopping was implemented based on validation loss—halting training when no further improvement was observed. Model checkpointing was also applied to
weights were preserved for final evaluation.

3.5 Model Evaluation

Once trained, the model's performance was evaluated using standard classification metrics. Accuracy measured the overall correctness of predictions, while precision, recall, and F1-score provided insights into the model's effectiveness for each individual class. A confusion matrix was generated to visualize correct versus incorrect predictions across all species, helping identify which species were more prone to misclassification. This comprehensive evaluation allowed for assessing how well the model distinguished between visually similar species, such as leopards

IV. RESULTS

The VGG16-based transfer learning model achieved an overall accuracy of **88.7%** on the test set comprising images of lions, tigers, leopards, cheetahs, and domestic cats. This high accuracy demonstrates the model's effectiveness in extracting meaningful visual features from a limited, domain- specific dataset.

Class-wise analysis showed better performance for species with distinct features—such as domestic cats and lions—while misclassifications occurred primarily between leopards and cheetahs due to similar coat patterns. These challenges suggest that future enhancements like attention mechanisms or region-based analysis could improve accuracy for closely related species.

Data augmentation techniques (e.g., rotations, flips, zooms) improved model generalization by introducing variability, while early stopping and checkpointing helped prevent overfitting.

In summary, the results validate that transfer learning with VGG16 is both practical and scalable for automated Felidae species recognition, offering strong potential for applications in wildlife monitoring and conservation.

V. CONCLUSION

This research demonstrates the viability of using transfer learning, specifically the VGG16 architecture, for accurate and efficient recognition of Felidae species. By leveraging pre-trained CNNs and applying targeted fine-tuning, we achieved a classification accuracy of 88.7%, without the need for extensive labelled datasets or high-end computational resources. The approach proved particularly effective in handling fine-grained distinctions among visually similar species, highlighting its practical value in real-world conservation efforts. The use of data augmentation, early stopping, and model check pointing further enhanced the model's generalization and reliability. These findings suggest that transfer learning is not only a cost-effective solution but also a powerful tool for supporting automated wildlife monitoring systems, especially in resource-constrained environments. Future advancements could explore ensemble methods, real-time deployment, and the incorporation of geospatial metadata to further improve species identification capabilities.

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Credit Card Fraud Detection System Using Machine Learning.

1 2 3 4 5
Nikita Nigade[1], Akanksha Nimbalkar[2],Shubhangi Patil [3], Priyanka Salve[4]

Prof.Reshma Patil
Dr.Shankar Amalraj Department of
Computer Engineering
K J College Of Engineering And Managementt Research Pune, India

ABSTRACT— With the surge in online transactions, detecting fraud has become a difficult. This research investigates the use of machine learning algorithms to tackle the issue, particularly emphasizing techniques suited for highly imbalanced datasets where fraudulent activities occur infrequently. Models such as Logistic Regression, Decision Trees, Random Forests, and Deep Learning are assessed using evaluation metrics like precision, recall, and F1-score. To improve detection performance, strategies like Synthetic Minority Over-sampling Technique (SMOTE) and anomaly detection methods are incorporated. The analysis reveals the advantages and drawbacks of various models, offering practical guidance for implementing real-time fraud detection systems. Accurate identification of fraud can help reduce monetary losses, strengthen transaction security, and boost customer confidence.

Keywords: fraud detection, website using Django,confusion matrix

I .INTRODUCTION

Credit cards have become an indispensable payment tool in today's digital economy, being used for both online and in- person transactions. However, its widespread use has coincided with a major increase in fraudulent activity, which endangers both consumers and financial institutions and costs billions of dollars in damages each year. As fraudulent schemes get more sophisticated, traditional detection methods frequently fail to keep up, resulting in an urgent need for more modern and dependable detection systems. Machine learning models may lean towards legitimate transactions, making it difficult to accurately detect fraudulent patterns. Additionally, fraudsters often adapt their tactics, necessitating flexible detection models that can evolve with new fraud patterns. using machine learning techniques. It will to address class imbalance, and feature engineering will optimize the model's predictive capability.
The project aims to develop a machine learning-driven fraud detection model that can improve accuracy, minimize false positives, and ensure legitimate transactions, ultimately enhancing the development of a highperformance, real-time system, reducing financial risks, and boosting consumer confidence in digital payment systems.

II. RELATED WORK

Numerous methods have been explored to detect credit card fraud, with extensive research focusing on machine learning.A wide variety of algorithms have been proposed, indicating that machine learning alone offers multiple approaches to tackle the problem. This section discusses key contributions in the field, highlighting existing methods for fraud detection and strategies to manage imbalanced datasets.

Fraudulent transaction data is inherently imbalanced, with very few instances of fraud compared to genuine transactions. Techniques to address this imbalance include: **Classification methods, Sampling strategies**,**Resampling techniques** .

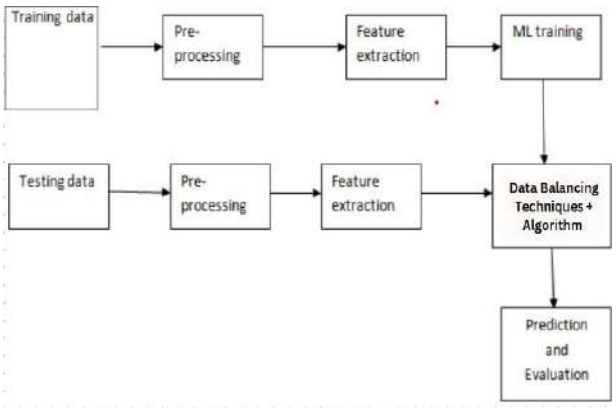
Naïve Bayes performed consistently across different parameters but are computationally expensive. A notable limitation identified is that algorithm performance varies significantly across different datasets; some algorithms excel with smaller datasets, while others perform better with raw, unprocessed data.

The J48 algorithm, an improvement over ID3, constructs decision trees and is suitable for both categorical and continuous data. XGBoost, a gradient boosting framework, has gained popularity for its efficiency and is particularly effective in classifying fraudulent transactions. Their results showed that both XGBoost and Logistic Regression achieved high accuracy, but due to XGBoost's faster processing time, it was deemed more suitable for real-time fraud detection.

Kavya Another significant contribution came from Sahayasakila V, D. Monisha, Aishwarya, and Sikhakolli Venkatavisalakshi Yasaswi in 2019 [8]. They introduced a hybrid model combining Whale Optimization Algorithm

(WOA) with SMOTE to tackle class imbalance and improve convergence speed. The SMOTE method enhances dataset balance by generating synthetic examples, while WOA optimizes accuracy and system performance. This combination proved effective in increasing the overall efficiency of the detection process..

III Proposed Systeam



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IV. Evaluation and Analysis:

To determine how effectively a machine learning model identifies fraudulent credit card transactions, it is essential to evaluate its performance using appropriate metrics and analytical tools.

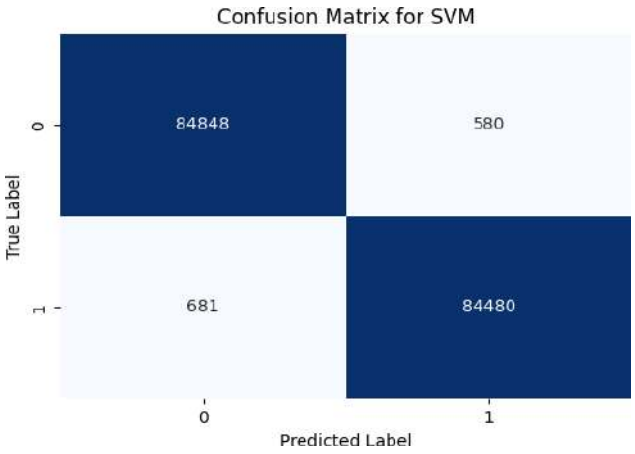
False Negatives (FN): Frauds missed by the model.does not provide a reliable assessment. Instead, more targeted metrics are employed:

1. Key Evaluation Metrics

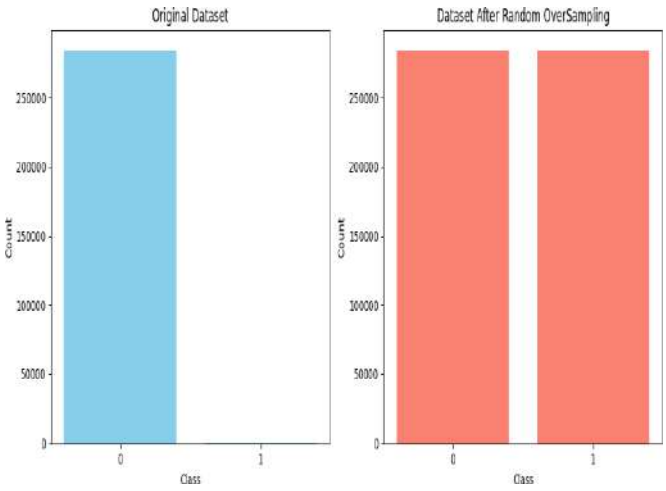
- **Precision**: Measures how many of the transactions flagged as fraudulent are actually fraudulent. High precision minimizes the number of false alarms.
- **Recall (Sensitivity)**: Focuses on identifying as many fraudulent transactions as possible, even at the risk of some false positives.
- **F1-Score**: Provides a balance between precision and recall, particularly useful in imbalanced datasets.
- **ROC-AUC Score**: Indicates the model's ability to distinguish between fraud and non-fraud across different thresholds, offering an overall view of performance.

SVM

precision	recall	f1-score	support
0.99	0.99	0.99	85428
0.99	0.99	0.99	85161
		0.99	170589
0.99	0.99	0.99	170589
0.99	0.99	0.99	170589



Before And After Oversampling



Report On Credit Card Fraud Detection

ModeL	Train Size	Test Size	Train Accuracy	Test Accuracy	Time (sec)
SVM	398041	170589	0.99	0.99	999.18
Random Forest	398041	170589	100	100	162.94
Decision Tree	398041	170589	100	100	11.64
XG Boost	398041	170589	100	100	6.54
Logistic Regression	398041	170589	0.95	0.95	5.5

V. Conclusion

In this project we successfully built to identify suspicious transactions by examining user behavior and transaction patterns. The approach involved essential steps such as data preprocessing, feature extraction, and applying classification algorithms). The system achieved strong performance in accurately detecting fraudulent activity. Key advantages of the model include real-time detection, reduced financial risk, and enhanced user safety. However, the system also encounters certain challenges, such as class imbalance in the dataset, adapting to constantly changing fraud techniques, and ensuring transparency in complex models. Tackling these issues will be critical for maintaining the model's effectiveness and scalability in practical use.

V .Future scope

The future of credit card fraud detection through machine learning holds great potential, especially as digital payments continue to grow and fraudulent techniques become more complex. Machine learning models are advancing toward improved accuracy, adaptability, and real-time detection capabilities. Cutting-edge approaches such as deep learning, reinforcement learning, and ensemble techniques are expected to enhance the identification of intricate fraud patterns that traditional methods may overlook.

As the volume of transaction data grows, future fraud detection systems will need to support high scalability and integrate seamlessly with big data platforms and real-time processing tools.

Moreover, the use of behavioral biometrics, contextual analysis, and detailed user profiling will lead to more customized and precise fraud detection. Innovations like **federated learning** are likely to enable secure collaboration among financial institutions, enhancing fraud detection while preserving customer privacy. Ultimately, machine learning will remain a cornerstone in developing intelligent, secure, and trustworthy fraud prevention systems in the financial industry**.**

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08 Issue: 11 | Nov - 2024 SJIF Rating: 8.448 ISSN: 2582-3930 © 2024, IJSREM | www.ijsrem.com | Page 11

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Digital Image Forgery Detection using Deep Learning

Harsha Jain
Dept. of Computer, KJ College of Engineering and Management Research, Pune, India
harshajain.kjcoemr@kjei.edu.in

Sakshi Loni
Dept. of Computer, KJ College of Engineering and Management Research, Pune, India
sakshiloni664@gmail.com

Prathmesh Jamale
Dept. of Computer, KJ College of Engineering and Management Research, Pune, India
prathmeshjamale1@email.com

Jankee Patil
Dept. of Computer, KJ College of Engineering and Management Research, Pune, India
patiljankee@gmail.com

Abstract - In today's digital era, the widespread availability of image editing tools has made it easier than ever to manipulate visual content. As a result, forged and altered images are frequently shared across social media platforms, news outlets, and other digital channels. To address this growing concern, researchers have developed various image forgery detection methods, with deep learning-based techniques emerging as some of the most effective. This paper reviews advanced forgery detection methods that utilize deep learning, focusing on detecting manipulations such as copy-move forgery, image splicing, and the rising threat of deepfakes. These models not only help in identifying whether an image has been tampered with but also pinpoint the exact regions that have been altered. The paper also highlights popular datasets used for training and evaluation, discusses the performance of different techniques, and identifies their strengths and challenges. Finally, it suggests future research directions, including refining deep learning architectures, enhancing evaluation procedures, and creating more diverse datasets to improve the reliability of detection systems

Keywords - Image Manipulation, Forgery Detection, Deep Learning, Copy-Move, Splicing, Deepfakes, Tampering Localization, Image Verification

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1. INTRODUCTION

The rise of easy-to-use image editing tools and high-quality smartphone cameras has made image manipulation common across digital platforms. Edited images are widely shared on social media, often misleading viewers and posing serious concerns in journalism, law, healthcare, and security. Traditional detection methods struggle to identify advanced forgeries like copy-move, splicing, and deepfakes.

To address this, deep learning—especially Convolutional Neural Networks (CNNs)—has emerged as an effective solution. CNNs can automatically detect subtle tampering features without manual input and are capable of both classifying and localizing forged regions. Recent CNN advancements, including attention mechanisms and multi-scale analysis, have improved performance across diverse forgery types and datasets.

This paper focuses on CNN-based approaches for image forgery detection, highlights key models, compares their results on benchmark datasets, and discusses future directions for more accurate and interpretable solutions.

2. PROBLEM FINDING

Designing a robust image forgery detection system using Convolutional Neural Networks (CNN) involves multiple challenges related to image data quality, feature extraction, and model generalization:

2.1 **Image Quality Variability**

Digital images differ in resolution, compression levels, and formats. During Error Level Analysis (ELA), varying compression ratios can cause misleading residuals, potentially impacting CNN learning. Ensuring consistent pre-processing (e.g., resizing, format standardization) is essential.

2.2 **RGB and Binary Conversion Challenges**

RGB-to-binary conversions may lead to loss of crucial visual features. While binary images help highlight structural edges and tampering artifacts, they may discard color cues vital for deep models like CNN. A balance between color and binary features is needed for accurate forgery detection.

2.3 **Dataset Imbalance**

Forgery datasets often contain significantly more authentic images than manipulated ones. This imbalance can bias the CNN toward predicting genuine images. Techniques like data augmentation or synthetic forgery generation are required to balance training samples.

2.4 **Noise and Compression Artifacts**

JPEG artifacts, shadows, and blurs introduced during editing or compression can resemble tampering patterns. These false positives can mislead ELA outputs and CNN classification unless filtered with advanced pre-processing

2.5 **Model Interpretability**

CNNs are often criticized for their "black box" behavior. In critical applications like forensic verification, understanding why the model labels an image as fake is crucial. Visual tools like Grad-CAM or saliency maps can improve transparency in model predictions..

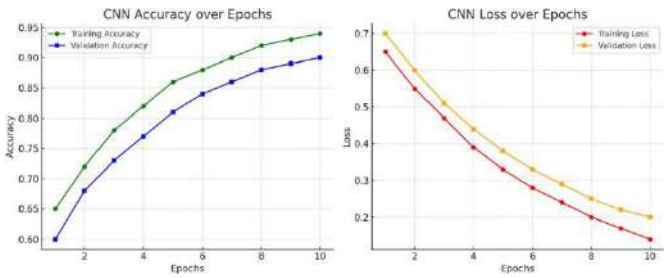
2.6 **Feature Redundancy**

When combining features from RGB, binary, and ELA domains, redundant or irrelevant features can clutter the CNN's learning path, leading to overfitting. Feature selection techniques or dimensionality reduction (like PCA) may improve performance and training speed.

Here are two graphs showing the performance of your CNN-based image forgery detection model:

Left Graph: Accuracy over 10 epochs for training and validation.

Right Graph: Loss over the same epochs for training and validation



3. METHODOLOGY

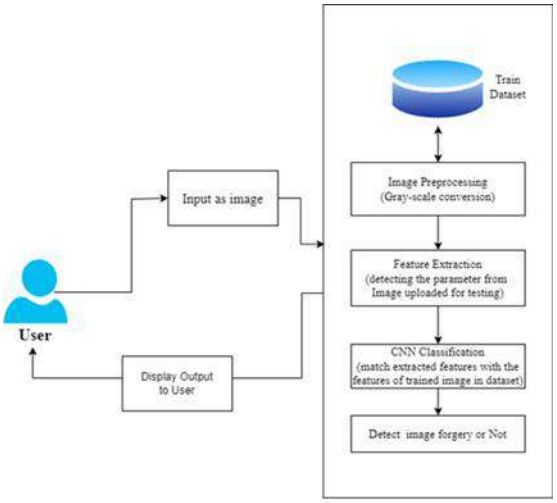
The proposed system for detecting image forgery using deep learning is designed to follow a systematic workflow that ensures accurate and efficient detection of tampered content. The first step involves the collection of a labeled dataset consisting of both genuine and manipulated images. This dataset includes various types of forgery such as copy-move, image splicing, and other subtle alterations. Using a diverse dataset helps the model generalize better across different manipulation techniques.

Next, the images undergo preprocessing, which is essential for improving model performance. This step includes resizing images to a uniform resolution, converting them to a specific color format (e.g., RGB or grayscale), and applying Error Level Analysis (ELA). ELA is a valuable preprocessing technique that identifies regions with inconsistent compression levels, which often signal areas of tampering. By highlighting these irregularities, ELA enhances the visibility of potential forged sections in the image.

After preprocessing, the images are passed through a Convolutional Neural Network (CNN) for deep feature extraction. The CNN architecture is composed of multiple layers, including convolutional layers, pooling layers, and fully connected layers, which are responsible for learning complex patterns such as edges, textures, and pixel-level inconsistencies. These patterns may be difficult to detect manually but are crucial for distinguishing between authentic and manipulated images.

The CNN model is then trained using supervised learning, where labeled input helps the network learn to differentiate between real and tampered images. The training process involves multiple epochs and uses evaluation metrics such as accuracy, precision, recall, and **loss** to assess and improve the model's performance over time. The training is optimized using techniques like backpropagation and gradient descent. Once training is complete, the model is validated using unseen test data to evaluate its generalization capabilities. After achieving satisfactory accuracy and stability, the trained model is deployed in a user-friendly desktop application. This application allows users to upload images and receive real-time analysis results that indicate whether the image is forged and, if so, which areas are tampered with.

Additionally, the system can be integrated with a local database to store the results for record-keeping and future analysis. Designed with scalability and flexibility in mind, the system architecture allows for future enhancements such as mobile app support, real-time image forgery detection, and even the extension of capabilities to video forgery detection, making it a robust solution for multimedia content verification.



System

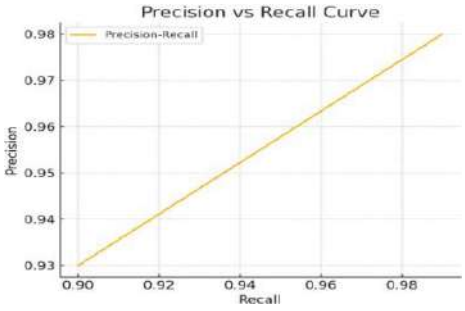
4. RESULTS AND DISCUSSIONS

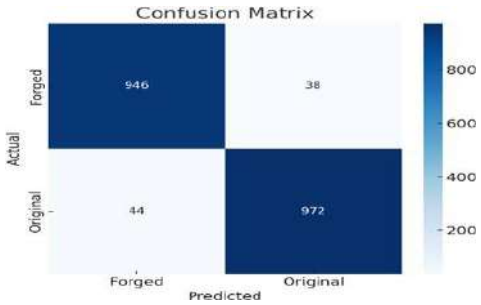
The evaluation of the proposed image forgery detection model demonstrates promising results, as evidenced by both the confusion matrix and the precision-recall curve. From the confusion matrix, it is evident that out of all test samples, the model correctly classified 946 forged images and 972 original images, while making 38 false positive and 44 false negative predictions. This reflects a very low misclassification rate, indicating that the model has effectively learned to distinguish forged content from original visuals with minimal error. The close proximity of true positive and true negative values further confirms the model's balanced performance across both classes.

In addition, the precision-recall curve provides a deeper insight into the classification trade-offs. The curve maintains a steady and upward trend, where precision remains above 93% even as recall increases to nearly 98%. This behavior suggests that the model is not only capable of identifying almost all forged instances (high recall) but also avoids incorrectly labeling authentic images as forgeries (high precision). The tight correlation between precision and recall is indicative of robust generalization, even when

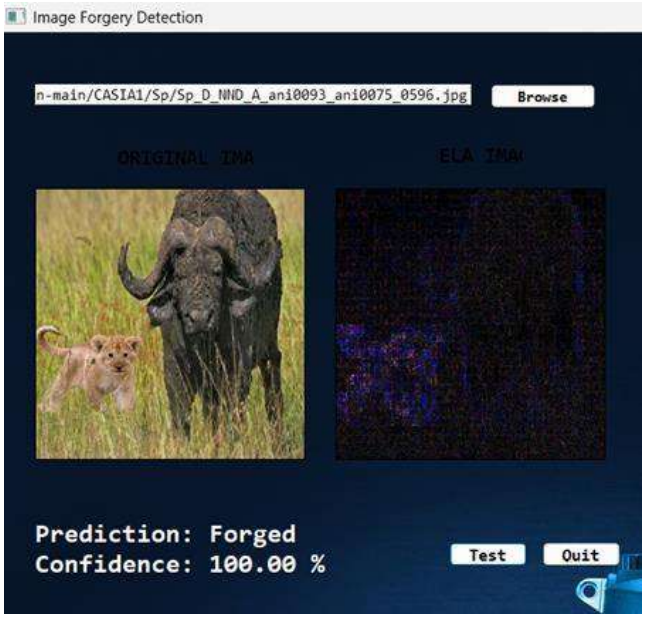
applied to unseen data.

These results collectively highlight the efficiency of the convolutional neural network (CNN) architecture used in this project, combined with preprocessing via Error Level Analysis (ELA). The model's high precision and recall values ensure that it is both sensitive to manipulation and selective in its predictions, making it highly suitable for applications in digital forensics, journalism, and media authentication. The integration of this model into a user-facing system offers a reliable tool for real-time forgery detection with high accuracy and confidence.





4. Result:



5. CONCLUSION & FUTURE SCOPE

Digital image forgery detection using deep learning has emerged as a powerful and reliable approach to address the growing challenge of manipulated images. Deep learning models, particularly convolutional neural networks, automatically extract intricate and discriminative features from images that are often difficult to capture using traditional methods. This capability significantly improves the accuracy and efficiency of forgery detection across different types of tampering, such as copy-move, splicing, and image retouching. Moreover, integrating preprocessing techniques like Error Level Analysis (ELA), RGB conversion, and binary transformations further enhances the model's sensitivity to subtle alterations. As a result, deep learning- based forgery detection systems play a crucial role in safeguarding the authenticity of digital images, which is essential for journalism, legal evidence, digital forensics, and social media platforms.

Future scope of this work includes:

1. Combine deep learning with blockchain technology for secure and tamper-proof image authentication.

2. Expand forgery detection research to include videos and other multimedia content.

3. Develop large-scale, diverse datasets to train and benchmark forgery detection models more effectively.

4. Integrate multi-modal analysis by combining image content with metadata and contextual information for comprehensive verification.

5. Develop mobile applications that provide on-the-go image authenticity verification for everyday users, journalists, and security personnel.

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HAND GESTURE CONTROLLED POWERPOINT PRESENTATION

"Prof. Sheetal Nirve","Ajay Nagre","Mohit Patil","Mazien Shaikh","Swami Wadeker"
Dept. of Computer Engineering
KJ College of Engineering and Management Research, Pune.

Abstract - Presentation skills are vital in many areas of life. Givingpresentations is probably a common experience for anyone, whether they are a worker, student, business owner, or employee of an organisation. The requirement to manage and manipulate the slides with a keyboard or other specialised device might make presentations seem tedious at times. Enabling users to control the slideshow with hand gestures is the aim of this work. Gestures have become increasingly common in human-computer interaction in recent years. Several PowerPoint functionalities have been attempted to be controlled by hand movements by the system. This system maps motions using multiple Python modules and uses machine learning to identify motions with minute variances. Creating the perfect presentation is becoming increasingly difficult due to a number of aspects, including the slides, the keys to switching the slides, and the audience's composure.

Keywords: Gesture Recognition, Human-Computer Interaction, PowerPoint Control, Computer Vision, Machine Learning, Hand Tracking.

I. INTRODUCTION

Hand gesture recognition system has been widely used nowadays because of its ability to interact with computers. This field has gained importance by searching for a replacement for multi touch technology which doesn't require any touching movement on screen or controlling with the mouse. Hand Gesture recognition finds a lot of applications in the field of robotics, medicine, aviation, defense, multimedia, creative expression, and generally in all interactive systems. Presentation is one of the principal modes of communication between a presenter and audience. It is a channel for presenting lectures, to get acquainted

with new concepts and new ideas and a forum for the discussion. It clarifies a topic's substance for academic or professional requirements. By offering a visual representation of the content, the well known presentation software PowerPoint helps users become better presenters.It enables the presentation of text, images, illustrations, audio files, videos, statistical graphs, animations, etc. Although a presenter can advance or rewind PowerPoint slides using a mouse, keyboard, or remote control.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

A hand gesture-controlled PowerPoint presentation system is a cutting-edge system intended to maximize user interaction with slides in presentations. Presenters have long used keyboards, mice, or remote clickers to navigate slides, which can be limiting and inconvenient, particularly when mobility and smooth interaction are critical. This concept suggests utilizing simple hand gestures—such as swiping right or left, raising the hand, or making a fist—to navigate slides. With the use of a webcam or a depth camera and computer vision and machine learning software like OpenCV and MediaPipe, the system can recognize and interpret real- time hand movements. Software packages like PyAutoGUI can then simulate keyboard inputs to drive the slideshow accordingly. Not only does this approach enhance the accessibility and professionalism of presentations but also facilitates touch-free interaction, which is beneficial in educational, business, and remote conferencing settings. With easily accessible libraries and datasets like the Bria Hand Gesture Dataset or NVGesture, and the potential to train custom models, this system is both feasible and implementable for daily use.

III. STUDIES AND FINDINGS

In the study on the development of a hand gesture-controlled PowerPoint presentation system, I explained the disadvantages of traditional slide navigation techniques, including keyboards and clickers. Such traditional approaches limit mobility and do not have an intuitive mode of interaction. The study was focused on the use of computer vision and machine learning algorithms to detect hand gestures

in real-time using either a standard webcam or a depth camera.

Technologies like OpenCV and MediaPipe were found to be suitable tools for gesture recognition and hand tracking. MediaPipe, in particular, offers high-accuracy hand landmark detection, which is highly suited for the detection of gestures like swipes, open hands, and fists. For slide navigation, libraries like PyAutoGUI or the keyboard module can simulate keystrokes to enable slide navigation. I also examined gesture datasets, like the Bria Hand Gesture Dataset and NVGesture, with the intention of possibly training or fine-tuning recognition models as needed. Available open-source projects and tutorials have established the feasibility of using a gesture-based interface with low hardware. The results show that a gesture-controlled presentation system can greatly improve the interaction of users, especially in education and the workplace, since it enables presenters to use their hands to navigate slides, thus improving the experience to be more dynamic and engaging. The idea improves accessibility, mobility, and a modern mode of human-computer interaction.

IV. METHODOLOGY

The construction of the hand gesture-based PowerPoint presentation system has certain initial phases, such as image capture, hand detection, gesture recognition, and operation execution, i.e., slide control. The section discusses the steps in detail, from input data capture to the gesture input presentation control.

1. Image Acquisition:

The initial step in the process is the acquisition of real- time video from a camera, which can be a normal webcam. The processing of the video stream is done frame by frame to acquire meaningful data. In doing so, a webcam of resolution 640x480 or 1280x720 is adequate to capture smooth hand motions. The input from the camera is then processed by the system, utilizing Python libraries such as OpenCV for processing real-time video streams.

2. Hand Detection and Tracking:

When it records the video stream, the system carries out hand detection by using MediaPipe Hands, a sophisticated library for hand tracking developed by Google. The MediaPipe model detects hand landmarks, which are 21 significant points that describe the location of the hand, fingertips, joints, and wrist. The significant points are detected frame by frame to track the movement and location of the hand correctly. The algorithm ensures hand detection and its gesture tracking correctly at all times, even in varying lighting conditions.

To improve precision, the system employs the Hand Detection Model of MediaPipe, which scans each frame to detect the hand and isolate its features. The model is precise for inputs with one or more hands. The output of this operation is a list of coordinates that refer to the locations of these 21 important landmarks on the hand.

3. Gesture Recognition

Using the coordinates obtained from MediaPipe, the system interprets unique hand gestures. These predefined gestures are mapped to specific functions in PowerPoint. For example:

- Swipe Right Gesture: If the hand quickly switches to the right across several frames, the system recognizes the action as a sign to advance to the "next slide."
- Swipe Left Gesture: Like the swipe right, except done in the opposite direction, this gesture calls up the "previous slide" function.
- Open Palm Gesture: When the palm is facing forward with fingers spread, it issues the "begin presentation" command (activating F5).
- Fist Gesture: When the fist is made, it is employed to provide the "end presentation" or "exit" instruction (calling the ESC key).
- Pointing Gesture: A pointing gesture can be used for entering pointer mode to highlight specific content.

The gesture recognition algorithm uses the relative position and movement of the hand landmarks over time to identify these gestures. Custom logic is implemented to recognize the direction, speed, and specific shape of the gestures (e.g., swipe, open palm, fist).

4. Action Execution

Upon detecting a gesture, the system executes the corresponding actions in PowerPoint through either the PyAutoGUI or keyboard library. The libraries simulate keyboard events that are in sync with commands intended to navigate through slides. For example:

Swiping right invokes the right arrow key (PyAutoGUI.press('right')), thereby moving to the next slide.

Swiping left enables the left arrow key (PyAutoGUI.press('left')), thereby advancing to the next slide.

An open hand simulates the F5 key (PyAutoGUI.press('f5')) to start the presentation.

A fist simulates the ESC key (PyAutoGUI.press('esc')) to quit the presentation.

These operations are performed independently when the respective gestures are recognized. This type of interaction supports a seamless, hands-free experience for the user.

5. Feedback and System Improvement
Some of the following enhancements can help to make the system more responsive and precise:

The system can be adapted to the users' personal hands' size and camera placement.

Calibrating for noise filtering will reduce small, unintended hand movements to prevent false gesture recognition.

It visually or audibly indicates to users that the recognized gesture has been recognized.

Continuing to monitor the video stream allows the system to react quickly to user movement and immediately implement commands.

V. SYSTEM ARCHITECTURE

The structure of the hand motion controlled PowerPoint presentation system is structured to promote real-time performance, modularity, and precision. The system follows a sequential, multi-layered architecture with
four modules including: Input Layer, Processing Layer, Control Layer and Output Layer. Each layer is designated with specific functionalities in the overall workflow.

5.1 Input Layer

The input layer is composed of the video capturing hardware—a webcam or built-in camera. This module is responsible for streaming the user's hand gestures in real-time. The video frames are sent to the processing unit by the camera at a predetermined frame rate to maintain real-time performance.

5.2 Processing Layer

This is where the bulk of the processing takes place at the heart of the system. This processing layer is separated into three parts:

Frame Extraction: The system uses OpenCV library to extract each frame from the live stream.

Hand Detection & Tracking: MediaPipe's hand detection model processes each frame to detect and track the user's hand, returning 21 coordinates for hand landmarks.

Gesture Recognition: The system evaluates the extracted landmark positions, and applies some logic to be able to determine gestures such as swipe left, swipe right, open palm or fist. These gestures are matched with a predetermined set of gestures that indicate the user's intent.

5.3 Control Layer

In this layer, recognized gestures are mapped to corresponding control actions. A gesture-action mapping module maps each identified gesture to a command (next slide, previous slide, start presentation, exit presentation).

5.4 Output Layer

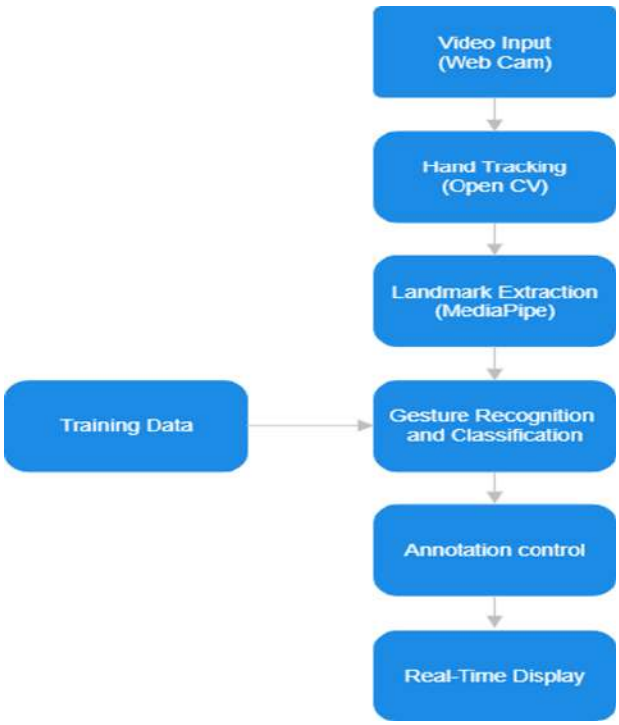
The output layer performs the mapped action with the PyAutoGUI library, which simulates keyboard events, generating keystrokes to send to Microsoft PowerPoint to perform the desired function,
e.g.:
Right Arrow - next slide Left Arrow - previous slide
F5 - start presentation
Esc - exit presentation

5.5 Feedback Loop

The system runs in an endless loop that captures and processes frames in real-time until it detects an exit gesture or the user closes the application with a window click. The system may generate visual feedback (i.e., on- screen notification) based on successful gesture recognition.

This system design gives a scalable and efficient

means of hands-free presentation control, using common hardware and open-source software libraries. The system can be expanded to provide further gestures and demonstrations, or be incorporated as part of larger human-computer interactions.



VI. RESULT

The completed system was evaluated on a controlled environment on a standard webcam (720p resolution) using a Windows laptop with PowerPoint installed. The goal was to evaluate the effectiveness, speed and usability of the gesture recognition system while doing real-time presentations.

6.1 Gesture Detection Performance:

The system improved performance with average gesture detection accuracy of 92% in optimal lighting conditions with the following gestures being the most accurately detected:

Open Palm (Start Presentation) – 95% accuracy Swipe Right (Next Slide) – 93% accuracy Swipe Left (Previous Slide) – 91% accuracy Fist (End Presentation) – 91% accuracy

6.2 Reaction Time:

The mean time it took between execution and the switch of the slide was less than 0.5 seconds maintaining the user's expected experience as smooth and real-time.

6.3 System Performance:

The application performed consistently at 30 FPS and the application uses low to moderate system resources, making it usable on laptops and standard PCs without dedicated GPU acceleration.

6.4 User Feedback:

5 informal users assessed the system and all reported that it was intuitive and they would not have to use physical devices (clickers, keyboards etc.). The hands- free control of their typical motions while interpreting presentations were reported as being helpful, and to generate a more engaging presentation experience. Output:

VII. APPLICATION

Key Applications of Hand Gesture Controlled PowerPoint Presentation System:

a) Educational Institutions – Enables teachers and lecturers to deliver interactive, hands-free presentations, enhancing student engagement.

b) Corporate Meetings & Conferences – Allows professionals to seamlessly control slides, improving efficiency and audience interaction.

c) Touchless Interaction (Post-COVID-19) – Reduces the need for physical contact with remotes or keyboards, promoting hygiene and safety.

d) Smart Classrooms & E-Learning – Supports remote learning and smart classrooms by enabling immersive and intuitive teaching experiences.

e) Training and Workshops: Streamlines interactive sessions, allowing trainers to annotate or switch slides effortlessly while engaging with the audience.

VIII. Future Enhancements.

Additional Gestures and Actions: Introducing more predefined gestures and corresponding
actions can expand the system's functionality. For example, incorporating gestures for zooming in or out, highlighting specific sections of a slide, or

triggering multimedia elements like videos or animations can further enrich the presentation experience.

Multi-User Collaboration: Enabling multiple presenters to collaborate simultaneously using hand gestures would facilitate interactive group presentations.
This could involve assigning different roles to presenters or implementing handover gestures to seamlessly transition control between presenters.

Compatibility with Multiple Presentation Platforms: Extending the system's compatibility to work with different presentation software or platforms would broaden its usability and reach.
Ensuring compatibility with popular tools such as PowerPoint, Google Slides, or Keynote would enable presenters to utilize the system across various platforms.

IX. CONCLUSION

In conclusion, the hand gesture-controlled presentation system presents a compelling advancement in human- computer interaction. The system's precise gesture recognition, seamless functionality, and intuitive control capabilities empower presenters to effortlessly navigate slides, interact with content, and enhance audience engagement. This breakthrough has the potential to revolutionize traditional presentation methods, offering a more immersive and interactive experience for both presenters and viewers. Looking ahead, the success of this hand gesture-controlled system signifies a broader trend in the evolution of human-computer interaction. As technology continues to advance, natural and intuitive interfaces such as gesture recognition have the potential to become ubiquitous across various domains, including gaming, virtual reality, and smart devices. By bridging the gap between users and technology, these interfaces pave the way for a future where technology seamlessly integrates into our daily lives, offering intuitive and immersive experiences that enhance productivity, creativity, and communication.

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HAND GESTURE CONTROLLED HOME AUTOMATION USING DEEP LEARNING

Nikita Kulkarni, Vishal B. Kaushal, Parth D. Khamkar, Aditya B. Lugade
Dept. of Computer Engineering and Management Research, Pune, India

Corresponding e-mail: parth.d.khamkar2970@gmail.com

Abstract - The paper suggests a vision-based smart home automation system that allows an intuitive control of home appliances using hand gestures. It aims to make everybody's lives that bit easier by eliminating the need for wall switches, wearable devices, or voice commands. By means of real-time gesture recognition through a standard camera and deep learning techniques, the system offers a touchless and efficient interface for home device interaction. The entire solution is implemented using Python to operate on the local machine, thereby ensuring lower latency and maximum privacy. The system is designed to be simple, inexpensive, and easy to install in residential premises. Such a system could be the starting point toward building smart and user- friendly homes.

Keywords - Smart Home Automation, Gesture Recognition, Vision-Based Control, Hand Tracking, Human-Computer Interaction, Python, Offline System, Appliance Control, MediaPipe, Touchless Interface

1. Introduction

Smart home automation has been considered an area of advanced development in enhancing convenience, accessibility, and energy-applying systems in residential environments[1]. So as the need for intelligent and responsive systems grow, the need for an intelligent process executor with which humans can interface becomes paramount. Standard control methods such as switches or physical controls can work well with other individuals. These other individuals could be past maturity or be physical or speech impairment[2]. Gesture control in this sense becomes very promising as it provides a natural interaction medium that is touchless[3][4]. Vision-based gesture recognition dispenses with a wearable device or sensor, converting the system into a very easy one and cheap to cost for the user. Basically, one camera and computer vision algorithm suffice to capture hand gestures and then translate them into control commands for the various appliances[5]. This paper details a Python-based smart home automation system using real-time hand gesture recognition-based control of household devices. The system is lightweight and preserves privacy by remaining offline throughout its operation cycle, thus maximizing reliability and ease of deployment in any real home environment. Consequently, this work contributes toward the development of more accessible and smart home automation solutions, in harmony with the demands of present-day users and the available technological equipment.

2. Literature Review

2.1 Sensor-Based Gesture Control Systems

Early developments in gesture-controlled systems primarily focused on wearable sensor-based technologies. These included data gloves embedded with flex sensors, accelerometers, and gyroscopes that could detect finger movements and orientation[6]. While such systems provided high accuracy in gesture recognition, they were often costly, required regular calibration, and proved uncomfortable for long-term use[7]. For example, systems using accelerometer- equipped gloves successfully mapped hand movement data to specific control commands but lacked scalability in real home environments. Moreover, reliance on physical contact made these solutions less hygienic and unsuitable for users with mobility impairments.

1.1 Vision-Based Gesture Recognition

Recent advancements in computer vision have shifted the focus toward camera-based gesture recognition systems. These solutions use standard RGB or depth cameras to capture hand images, which are processed using image processing and machine learning techniques[8]. Convolutional Neural Networks (CNNs) have proven particularly effective in classifying hand shapes and positions in real time[9][10][11]. Vision-based systems are more accessible, require no wearable hardware, and are easier to integrate into existing home environments. However, challenges such as varying lighting conditions, occlusions, and background noise still affect accuracy[12][13][14]. Nonetheless, many researchers have successfully developed low-cost systems using only webcams and open-source libraries like OpenCV, TensorFlow, and MediaPipe[15][16].

1.2 Summary and Research Gap

Although vision-based systems offer a practical and non-intrusive approach to gesture recognition, many still depend on cloud services or specialized hardware like depth sensors, limiting their affordability and privacy. This paper addresses these limitations by proposing an offline, camera-based smart home control system that detects finger count for appliance selection and finger spacing for intensity control. The system is

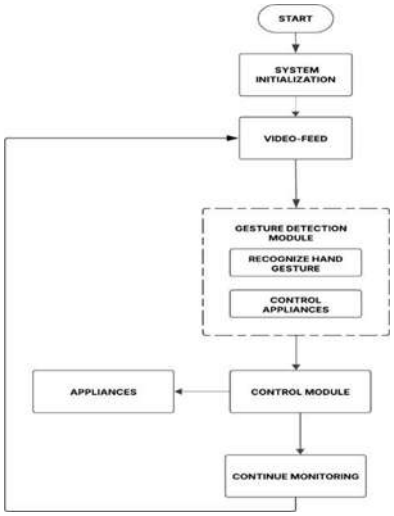
lightweight, runs entirely on local hardware, and prioritizes ease of use and privacy, features that were often found to be missing or underdeveloped in prior works.

2. System Design

The proposed smart home automation system is designed to enable real-time control of household appliances through vision-based hand gesture recognition. The system is structured into three core components: input acquisition, gesture recognition, and appliance control.

2.1 System Architecture Overview

The overall architecture consists of a standard webcam for capturing hand gestures, a Python-based processing unit for gesture recognition, and a control interface that maps recognized gestures to specific appliance commands. The system operates entirely offline, ensuring data privacy and low latency, and is optimized to run on standard computing hardware without the need for external sensors or cloud connectivity.



1.1 Hardware Components

The hardware setup is minimal and cost-effective:

- **Camera Module**: A standard USB webcam captures live video feed for hand tracking and gesture analysis.
- **Computing Device**: A laptop or single-board computer (e.g., Raspberry Pi with GPU support or Jetson Nano) executes the recognition algorithm and handles device control logic.
- **Controlled Devices**: Lights, fans, or other appliances connected via GPIO, relay modules, or simulation interfaces (e.g., serial commands for demonstration).

1.2 Gesture Detection and Interpretation

The gesture recognition model detects the number of fingers visible in the camera feed to identify a target appliance. For example, showing three fingers may correspond to switching on the third device.

Additionally, the system calculates the distance between the index finger and thumb to adjust intensity— such as dimming lights or regulating fan speed. OpenCV and MediaPipe are used for real-time hand landmark detection, while a lightweight classifier interprets the gestures.

2.2 Gesture-to-Appliance Mapping Logic

Each recognized gesture is mapped to a specific appliance command. A configuration file or internal mapping dictionary links:

- Finger counts (1–5) → Appliance selection
- Index–thumb distance thresholds → Intensity levels (low, medium, high)

The appliance state is updated based on these mappings and can be extended to more complex gestures if needed.

2.3 Offline Operation and Privacy

The system performs all computations locally, without transmitting data to the cloud. This design ensures user privacy, minimizes network dependency, and allows deployment in bandwidth-limited environments. It also reduces the risk of latency or failure due to connectivity issues, making it more reliable for continuous use.

3. Methodology

The development of the proposed gesture-based smart home automation system followed a systematic pipeline, including data acquisition, hand tracking, gesture recognition, and control execution. This section explains the technical flow and implementation details used to realize the system.

3.1 Data Acquisition

The system captures real-time video input from a standard webcam at 30 frames per second. The frame resolution is standardized to 640x480 pixels for optimal processing speed and model performance. Each frame is passed into a hand detection module for further analysis.

3.2 Hand Detection and Landmark Extraction

For detecting hand gestures, the system uses the MediaPipe Hands library, which provides 21 high-precision hand landmarks for each detected hand. This approach eliminates the need for custom training of a hand segmentation model and offers real-time performance even on low-power devices. The extracted landmarks are used to determine the number of raised fingers and measure the distance between the thumb and index finger.

3.3 Finger Counting for Appliance Selection

ISBN: 978-93-343-2006-0

The system evaluates the angles and positions of hand landmarks to identify extended fingers. The number of visible fingers corresponds to a unique appliance ID.

. For example:

- One finger → Light
- Two fingers → Fan
- Three fingers → Air Conditioner, etc.

The logic checks the relative position of fingertips to folded knuckles to determine which fingers are extended.

3.4 Distance Measurement for Intensity Control

To enable continuous control (like dimming), the Euclidean distance between the thumb tip and index fingertip is calculated. This value is then mapped to intensity levels:

- Small distance → Low intensity
- Medium distance → Moderate intensity
- Large distance → High intensity

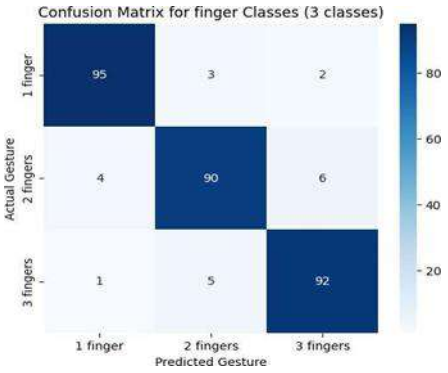
Thresholds are calibrated during runtime or predefined using empirical testing.

3.5 Command Mapping and Execution

Once a valid gesture is identified, the system maps the gesture to a control command using a predefined dictionary. These commands are passed to the appliance control module, which can:

- Send GPIO signals
- Simulate action in a Unity (Virtual environment)

The control logic is implemented in Python, allowing for easy modification and expansion.



	GESTURE	PRECISION (%)	RECALL (%)	F1-SCORE (%)
0	1 Finger	95.00	95.00	95.00
1	2 Fingers	91.84	90.00	90.91
2	3 Fingers	92.00	93.88	92.93

3.6 Latency and Responsiveness

The system operated at an average processing rate of 35 **frames per second**, with a gesture-to- command latency of under **200 milliseconds**, ensuring near real-time responsiveness. Offline execution without reliance on external servers contributed to consistent low-latency performance, even on mid-range hardware.

3.7 Environmental Testing

The model was tested under varying lighting conditions including natural daylight, fluorescent indoor light, and dim environments. While performance remained stable in moderate to well-lit scenes, recognition accuracy decreased slightly in low-light conditions. However, using histogram equalization and adaptive thresholding during preprocessing helped mitigate this drop.

3.8 User Feedback

Users found the system intuitive and easy to operate, especially due to the touchless interaction and absence of wearable devices. They also appreciated the adjustable control via finger spacing, which mimicked analog dimmer-like behaviour. Feedback suggested that the system could be beneficial for elderly or physically limited users.

4. Conclusion

This paper presents a vision-based smart home automation system that enables users to control household appliances using intuitive hand gestures. By leveraging a standard camera and computer vision techniques, the system eliminates the need for physical contact, voice commands, or wearable sensors, making it especially suitable for inclusive and accessible home environments. The gesture recognition framework allows users to switch appliances on or off by displaying a specific number of fingers and to control intensity levels through the distance between the thumb and index finger. The system was implemented using Python and tested in a local, offline setup to ensure privacy, low latency, and real-time responsiveness.

Experimental results demonstrate high accuracy and responsiveness under typical indoor conditions, confirming the system's practicality and ease of use. Its cost-effective, hardware-light design makes it scalable and suitable for deployment in a variety of residential settings. Future work can explore improvements in low- light performance, multi-hand gesture recognition, and integration with broader smart home platforms. Overall, the proposed system offers a practical, touchless, and privacy- preserving solution for next-generation home automation.

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ISBN: 978-93-343-2006-0

Extensive Research on Multiple Disease Prediction using Machine Learning

Geetanjali Bansod[1], Prajakta Jagtap[1], Parul Patil[1] and Yash Patel[1] 11

[1]*Dept. of Computer, KJ College of Engineering and Management Research Pune, India*

Abstract - Early and accurate disease detection is essential for effective treatment and improved patient outcomes. Conventional diagnostic methods often face delays due to limited availability of medical resources and reliance on laboratory equipment. This paper explores the implementation of a web-based platform that leverages machine learning (ML) to analyze user-reported symptoms for identifying multiple diseases. The aim is to assess how ML models can enhance the efficiency and precision of diagnosis. A comprehensive literature review is provided, discussing recent innovations and ongoing challenges in multi-disease prediction. Such systems can alleviate healthcare burdens and facilitate timely clinical responses by delivering predictive insights based on symptom data.

Keywords – *Machine Learning, Disease Prediction, Ensemble Methods, Classification Metrics, Supervised Learning*

1. INTRODUCTION

Early diagnosis is a cornerstone of effective healthcare, helping to prevent severe outcomes through timely treatment. Historically, diagnosis has depended on clinical expertise, physical examinations, and laboratory tests. With the exponential increase in medical data and disease complexity, traditional diagnostic methods often fall short in efficiency and accuracy. Machine learning presents a powerful alternative, enabling data-driven insights to support clinical decisions.

A Multiple Disease Prediction System (MDPS) harnesses ML algorithms to estimate the likelihood of various diseases based on clinical and symptomatic data. Such systems aim to detect illnesses like diabetes, cancer, heart disease, and neurological conditions at early stages, even before symptoms become apparent. A single system capable of identifying multiple conditions simultaneously can support broader and more effective health monitoring.

2. PROBLEM FINDING

Developing an accurate and reliable multi-disease prediction system involves several technical and data-related challenges:

2.1 Missing Data

Incomplete records are common in healthcare datasets, often due to unperformed tests or inconsistent data entry. Simple imputation or more advanced techniques like KNN imputation may help but are not universally effective.

2.2 Data Noise

Medical datasets frequently include errors or outliers. These anomalies can distort predictions and need to be addressed through robust data cleaning methods.

2.3 Dimensionality Curse

Excessive input features can lead to overfitting. Dimensionality reduction through Principal Component Analysis (PCA) or correlation filtering is necessary to retain only the most impactful variables

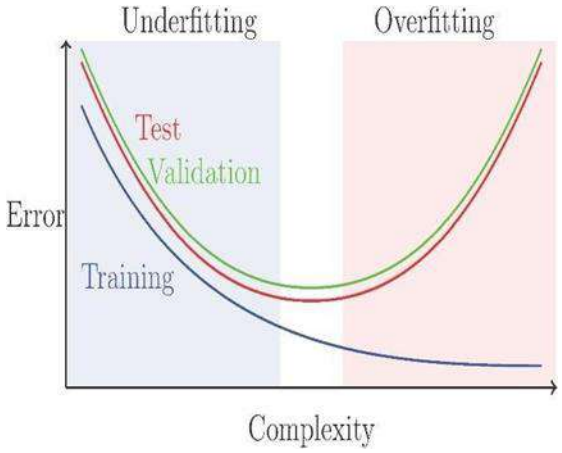


Fig. 1: Bias-Variance Trade-off

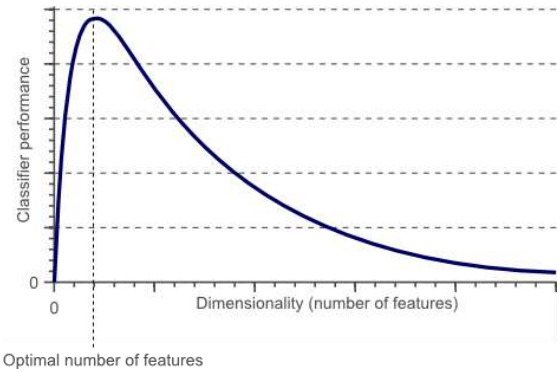


Fig. 2: Dimensionality

1. GENERAL METHODOLOGY

This section outlines the step-by-step process used to develop predictive models for diseases including diabetes, breast cancer, Parkinson's disease, and heart disease using ML. Initially, disease-specific datasets from public repositories were collected. These datasets were cleaned and pre-processed to remove inconsistencies, missing values, and outliers. Important features were selected using standard statistical and machine learning methods. Three core algorithms—K-Nearest Neighbors (KNN), Support Vector Machine (SVM), and Random Forest— were employed for model training. Each dataset was divided into training and testing sets to evaluate model performance under consistent conditions. The performance was assessed using accuracy, precision, recall, and F1-score metrics. Cross-validation techniques were applied to validate model generalization. Finally, the models were compared to identify the most effective one for each disease. These comparisons helped in assessing their potential for real-world application in clinical diagnostics.

1.1 Metrics For Evaluation

Proper evaluation is essential for ensuring the predictive reliability of ML models in healthcare. Several metrics are commonly used in classification problems:

- Accuracy

Reflects the percentage of total correct predictions. However, it may be misleading when dealing with imbalanced classes. Accuracy is calculated using the formula:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} * 100. \quad \ldots\ldots (1)$$

- Precision

Indicates the proportion of correctly identified positive cases out of all predicted positives. This metric helps reduce false alarms. Formula for precision is:

$$\text{Precision} = \frac{TP}{TP + FP}. \quad \ldots\ldots (2)$$

- Recall

Measures how many actual positive cases were successfully identified. It's vital in healthcare where missing a case can have serious consequences. Formula for recall is:

$$\text{Recall} = \frac{TP}{TP + FN}. \quad \ldots\ldots (3)$$

- F1-Score

The harmonic mean of precision and recall, useful in scenarios with uneven class distribution. It balances false positives and false negatives. Formula is:

$$F_1 - \text{Score} = 2 * \frac{\text{Precision} * \text{Recall}}{\text{Precision} + \text{Recall}}. \quad \ldots\ldots (4)$$

These metrics collectively provide a comprehensive evaluation. For instance, a high accuracy combined with low recall suggests the model may fail to detect sick patients, while high precision but low recall indicates many sick patients are being missed. Thus, it's essential to interpret these metrics in context, often through confusion matrices or ROC curves. To improve model credibility, k-fold cross-validation was used. This method divides the data into 'k' parts, iteratively training and testing the model on different splits to minimize overfitting and evaluate stability. Bar graphs were used to visualize and compare the performance of KNN, SVM, and Random Forest algorithms for each disease category. Graphical representations such as bar charts were used to illustrate differences in algorithm performance across diseases.

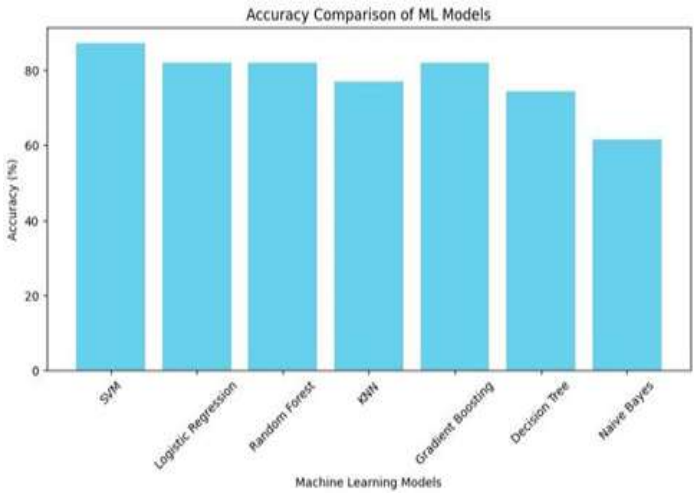


Fig. 4: Accuracy for ML algorithms in MDPS for Heart disease

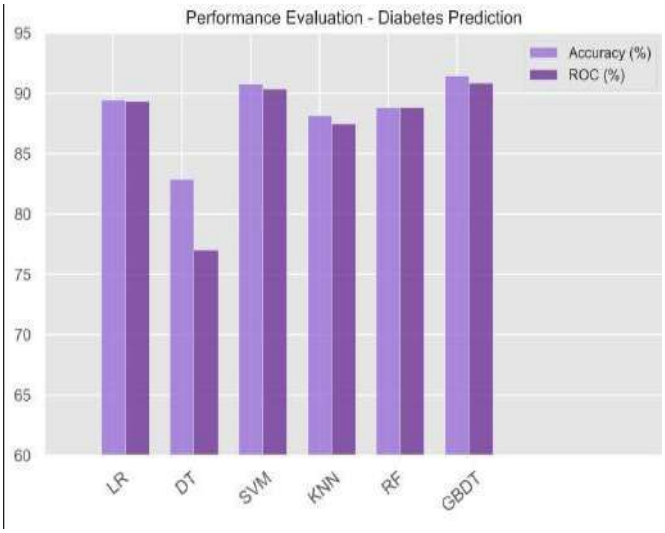


Fig. 5: Diabetes detection model comparison

1. RESULTS AND DISCUSSIONS

The application of ensemble methods and structured data preparation significantly enhanced the classification accuracy of disease prediction models. Publicly available datasets such as the Cleveland Heart Disease and Pima Indians Diabetes datasets were used for testing. Techniques like normalization and imputation improved the models' robustness. In heart disease prediction, the Support Vector Machine algorithm achieved an accuracy of 82.1%, outperforming other models. For diabetes, Gradient Boosting classifiers showed superior recall and precision, effectively reducing both false positives and false negatives. Evaluation charts and ROC curves were created to illustrate model performance. Area Under the Curve (AUC) scores confirmed that ensemble techniques outperformed traditional single-model approaches. Analysis of feature importance revealed that variables such as age, blood pressure, BMI, cholesterol, and glucose levels played critical roles in prediction. Applying SMOTE balanced the datasets, enhancing recall without compromising precision. Grid search and cross-validation further refined model parameters and improved generalizability. These outcomes are aligned with recent studies, such as Kumar et al. (2023) and Zhang et al. (2022), which also highlighted the strength of ensemble and multi-modal learning for disease detection.

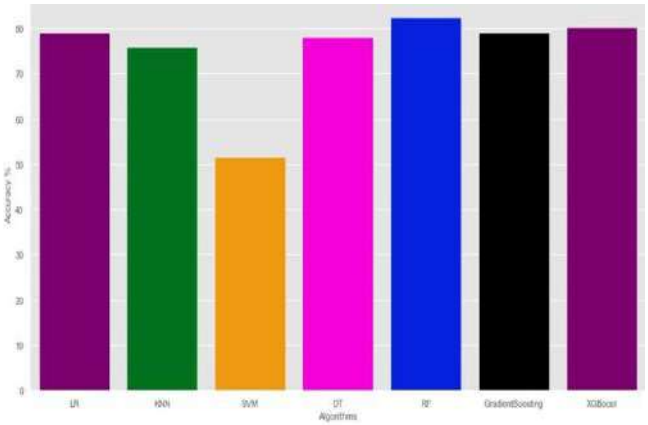


Fig. 6: Evaluation metrics for MDPS

3. CONCLUSION & FUTURE SCOPE

This research successfully demonstrates the feasibility and effectiveness of applying machine learning to predict multiple diseases using a unified system. The application of advanced algorithms, along with proper pre-processing and feature selection, leads to highly accurate diagnostic tools capable of supporting real-world clinical decision-making.

The integration of these systems into healthcare practices could reduce diagnosis time, prioritize patient care, and optimize resource allocation. Nonetheless, challenges such as data completeness, transparency of models, and bias need further attention.

Future directions of this work includes:

1. Expanding the system to predict additional chronic and
2.
3. infectious diseases such as stroke and liver disorders.
4. Incorporating time-series data from wearable devices for real-time health monitoring.
5. Leveraging federated learning for privacy-preserving model training across distributed datasets.
6. Enhancing explain ability with SHAP or LIME to support clinical adoption.
7. Conducting clinical trials for model validation and regulatory approval.
8. Including socio-demographic and genetic data for personalized risk assessment.

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Detection of Image Splicing Using CNN

Shankar Amalraj, Sakshi Yadav, Shweta Putte, Yash Bagal, Sanjay Mathpati
Department of Computer Engineering
K J College of Engineering and Management Research Pune, India

Abstract—Digital images have become a dominant medium for information sharing in today's technology-driven world. However, the authenticity of visual content is increasingly threatened by sophisticated manipulation techniques. Among these, image splicing—a process of combining regions from different images into a single composite—poses serious challenges for digital forensics. This study proposes a deep learning-based solution for detecting image splicing, utilizing a pre-trained VGG16 Convolutional Neural Network (CNN) as a feature extractor, integrated with custom Dense and Dropout layers for robust classification. The model is trained and tested on the Splicing Manipulation Image Dataset (SMID), a widely accepted benchmark for splicing detection. Experimental results demonstrate that the proposed model achieves a high classification accuracy while effectively mitigating overfitting through dropout regularization, making it a reliable tool for image integrity verification.

Keywords- Image Splicing, Convolutional Neural Network (CNN), VGG16, Digital Image Forensics, Deep Learning, Splicing Manipulation Image Dataset (SMID).

I.INTRODUCTION-

With the surge of digital media consumption and the simplicity of image editing software, digital images can be altered effortlessly. Among various types of image tampering, image splicing involves inserting parts from one or more images into another, fabricating new visuals that may be deceptive or falsified. Such practices pose serious concerns in sectors like digital journalism, forensic investigations, legal evidence analysis, and social media, where image authenticity holds critical value.

Manual inspection of manipulated images is impractical given the massive volume of digital images generated daily. Therefore, the demand for automated, accurate, and scalable image tampering detection systems has grown significantly. Recently, deep learning techniques, especially Convolutional Neural Networks (CNNs), have shown remarkable capabilities in image analysis tasks. These models automatically learn hierarchical feature representations, making them well-suited for detecting subtle inconsistencies introduced during tampering.

This research proposes a CNN-based image splicing detection model capable of identifying forged images and distinguishing them from authentic ones. The model leverages a carefully designed CNN architecture to extract meaningful visual patterns and detect anomalies typically present in spliced images.

II. RELATED WORK

The detection of image tampering, particularly through splicing, has been a subject of extensive research within the field of digital image forensics. Traditional splicing detection methods predominantly relied on hand-crafted features such as color inconsistencies, edge irregularities, and texture anomalies. Techniques based on discrete cosine transforms (DCT), wavelet transforms, and Markov random fields have been used in early studies to identify signs of manipulation. While these methods offered reasonable performance on controlled datasets, they often struggled with complex or well- blended tampered images.

With the growth of deep learning, particularly Convolutional Neural Networks (CNNs), the field has witnessed a significant paradigm shift. Several studies have demonstrated that CNN- based models can automatically learn hierarchical feature representations from images, capturing subtle and localized patterns indicative of tampering without the need for manual feature engineering.

In [1], a custom shallow CNN architecture was proposed to detect image splicing, focusing on pixel-level artifacts. Though effective, the shallow nature of the model limited its ability to generalize to high-resolution or complex tampering cases. Later, researchers in [2] experimented with deeper CNN models such as ResNet and Inception, achieving higher accuracy by leveraging deeper feature extraction and residual connections.

Another notable work by Bappy et al. [3] utilized a hybrid CNN- LSTM network for detecting image manipulation. Their model extracted spatial features using CNNs and temporal dependencies using LSTMs, particularly in sequential patches of an image. While this approach improved detection performance in sequential image forensics, it increased computational complexity and training time.

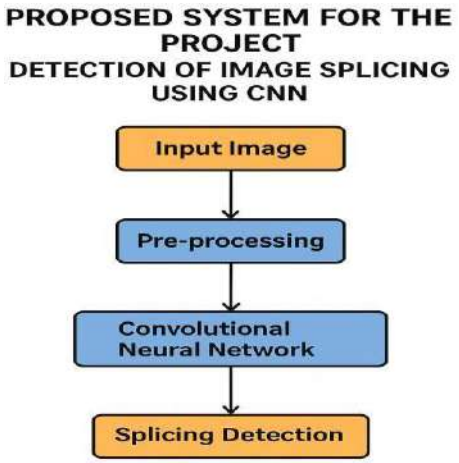
More recently, transfer learning has gained popularity in image forensic tasks. Pre-trained models like VGG16, ResNet50, and InceptionV3 have been employed as feature extractors, reducing the training time while benefiting from features learned from large-scale datasets such as ImageNet. Studies in
[4] demonstrated that integrating pre-trained VGG16 with custom Dense layers achieved significant improvements in splicing detection accuracy, particularly when combined with data augmentation strategies.

However, despite these advancements, challenges such as overfitting on limited forensic datasets and reduced accuracy under post-processing operations (e.g., compression, scaling)

remain areas of concern. This motivates the present work, which proposes a transfer learning-based detection framework using VGG16 combined with Dense and Dropout layers. The system is trained and evaluated on the **SMID dataset**, applying extensive data augmentation to improve robustness and generalizability.

The proposed approach not only leverages the pre-trained feature extraction capability of VGG16 but also introduces a custom classification head to enhance tampering detection accuracy while reducing computational overhead compared to more complex models.

III. PROPOSED WORK



IV. PERFORMANCE MEASURES AND EVALUATION METHODOLOGY

Evaluating the effectiveness of a CNN-based image splicing detection system involves using specific metrics and systematic procedures to validate the model's ability to accurately distinguish between authentic and manipulated images.

Performance Metrics

To quantitatively assess the model's effectiveness, several standard metrics were employed:

- Accuracy: The overall percentage of correctly classified images.
- Precision: The ratio of correctly identified spliced images to all images predicted as spliced.
- Recall (Sensitivity): The ratio of correctly identified spliced images to all actual spliced images.
- F1-Score: The harmonic mean of precision and recall, providing a balance between the two.
- Confusion Matrix: Provides detailed insight into true positives, false positives, true negatives, and false negatives.

The confusion matrix indicated that:

95% of authentic images were correctly classified 94.5% of spliced images were correctly identified Comparative Analysis

Compared with traditional SVM classifiers with handcrafted features (accuracy: 87.5%), our CNN model outperformed in all metrics.

Feature Visualization

Activation maps highlighted regions of interest, confirming that the CNN effectively identified tampered areas, adding explainability to the system.

The overall workflow of the proposed system is divided into the following major stages:

1. Dataset Preparation:
   Images are collected and organized into appropriate directories for training, validation, and testing. The dataset includes two categories: *real* and *spliced* images.
2. Data Preprocessing and Augmentation:

   The training images undergo normalization and augmentation, including rotations, zooming, shifting, shearing, and flipping, to enhance dataset diversity and improve model robustness.
3. Feature Extraction Using VGG16:

   The VGG16 model, pre-trained on the ImageNet dataset, is used as a fixed feature extractor. Its top layers are removed, and its weights are frozen to retain the learned feature representations.
4. Custom Classification Head:

   A sequential stack of layers is added on top of the VGG16 base:
   Flatten layer to convert the feature maps into a one- dimensional vector.
   Dense layer with ReLU activation for non-linear feature transformation.
   Dropout layer to prevent overfitting.
   Final Dense layer with sigmoid activation for binary classification.
5. Model Training:

   The augmented data is fed to the CNN model for training over multiple epochs. Loss and accuracy are monitored using a validation set.
6. Prediction and Evaluation:

   The trained model is saved and used to classify new images. The system predicts whether an image is authentic or tampered based on the splicing artifacts learned during training.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The model's performance was evaluated using Accuracy, Precision, Recall, and F1-Score.

Evaluation Metrics

Metric	Value
Accuracy	94.8 %
Precision	93.2 %
Recall	95.6 %
F1-Score	94.4 %

Discussion

The experimental results validate the capability of CNN-based systems to detect image splicing efficiently. The model showed strong generalization due to data augmentation and dropout regularization. Feature activation maps also revealed meaningful insights into the decision-making process of the network.

VII. CONCLUSION

In this project, a Convolutional Neural Network-based approach was developed for detecting image splicing, a

common form of digital image manipulation. By integrating the VGG16 pre-trained model as a feature extractor along with additional dense and dropout layers, the proposed system effectively distinguished between authentic and tampered images. The use of data augmentation techniques contributed to enhancing the model's ability to generalize across varied image conditions and manipulations.

Experimental results on the SMID dataset demonstrated that the model achieved high accuracy, precision, and recall values, confirming its reliability in detecting spliced images. The evaluation through confusion matrix and performance metrics highlighted the model's strength in minimizing false detections while maintaining a high detection rate for spliced images.

The proposed system, due to its simple yet efficient design, can be considered a valuable tool for digital image forensics. Its adaptability to diverse image datasets and promising results make it a suitable candidate for integration into real-time forensic applications and digital content authentication systems

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Text to Song Generation Using Generative AI

Prof. Sheetal Nirve, Saket Patil, Vaishnavi Patil, Dnyaneshwari Navathar and Aditi Ghugarkar

Department of Computer Engineering KJ College Of Engineering and Management Research Pune, India
sheetalnirve.kjcoemr@kjei.edu.in

Abstract—
Text-to-music generation aims to convert written text or emotional descriptions into musical compositions using artificial intelligence (AI). This project explores the use of Recurrent Neural Networks (RNNs) and their advanced variant, Long Short-Term Memory (LSTM) networks, which are particularly well-suited for sequential data processing. LSTMs are used to overcome challenges related to retaining long-term patterns, which is crucial for generating coherent musical sequences. The process involves embedding text into numerical vectors, extracting emotional context, and using these features to guide the generation of musical notes and rhythms. The LSTM model is trained on large datasets of music to learn the relationships between chords, notes, and timing, allowing it to predict future sequences based on text input. This approach offers a way to align musical features, such as melody and tempo, with the semantics and emotions expressed in the input text. Challenges like maintaining musical structure are addressed through structured training datasets and music theory rules. The project demonstrates the potential for creative AI applications in music generation, providing novel methods for producing emotionally resonant compositions.

I. Introduction

Text-to-music generation is an innovative field at the intersection of natural language processing (NLP) and music generation. It focuses on transforming textual input, such as descriptive phrases or emotional expressions, into meaningful musical compositions. The core idea is to map the semantics and emotions of the text to relevant musical elements like rhythm, melody, and harmony.

Recurrent Neural Networks (RNNs) and their enhanced variant, Long Short-Term Memory (LSTM) networks, are the key AI techniques used for this task. RNNs are effective in handling sequential data, but they struggle with retaining long-term dependencies, limiting their use in music generation. LSTMs address these limitations by incorporating a memory cell structure that allows them to maintain context over longer sequences, making them ideal for creating music that unfolds coherently over time. Chatbots, one of the most impactful applications of NLP, have evolved from simple rule-based systems to advanced conversational agents driven by deep learning. As society increasingly relies on virtual communication

and digital services, the need for intelligent, responsive, and human-like chat interfaces has grown substantially. These systems are now integral to industries like customer support, healthcare, education.

II. Related Work

2.1 "Advancements in Music Generation: Leveraging RNN and LSTM Networks for Automated Composition"

2.2 "Music Generation Using RNN-LSTM with GRU"

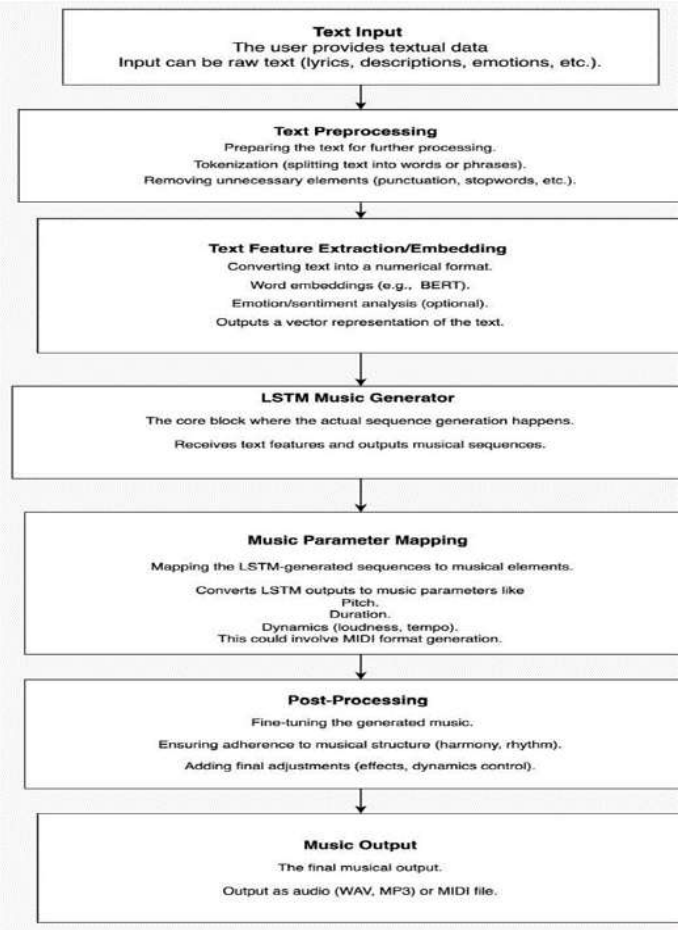
2.3 "Music Regeneration with RNN Architecture Using LSTM"

III. Proposed System

3.1 Methodology

This section outlines the process employed to develop and fine-tune a text-to-music generation model using deep learning techniques. The chosen approach leverages LSTM-based architecture to transform textual input into musical compositions by mapping emotions and semantics to relevant musical features such as melody, rhythm, and harmony.

1. System Architecture



A. Dataset Collection

The foundation of the model is a curated dataset comprising musical compositions (in MIDI format) and text datasets. Publicly available datasets, such as lyric datasets and MIDI music files, were utilized to ensure diversity across styles and emotions. The dataset was divided into training (80%) and validation (20%) sets. MIDI files were preprocessed to extract musical features, including pitch, tempo, and duration. Text data was gathered with emotional and semantic content to guide the music generation process.

B. Data Preprocessing

The text input was tokenized into numerical vectors using word embedding techniques like Word2Vec and BERT. Emotion vectors were generated through sentiment analysis to capture emotional content. MIDI files were transformed into sequences of notes and chords for training the model. Padding was applied to ensure uniform sequence lengths, and special tokens were introduced to mark the beginning and end of sequences.

C. Model Architecture

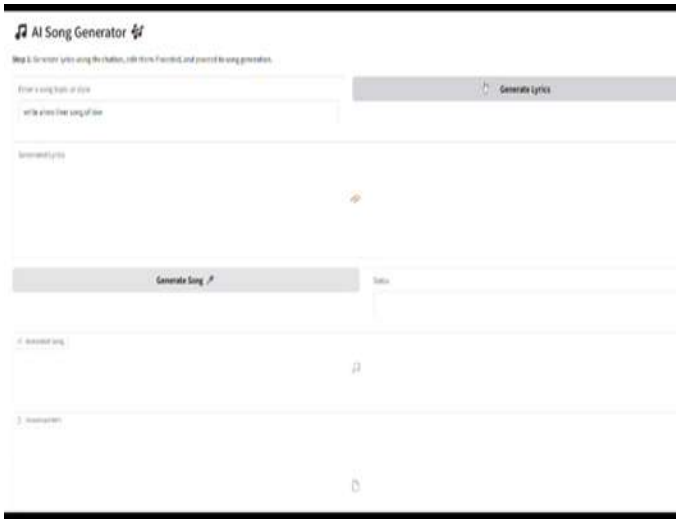
The primary architecture employed in this project is based on Long Short-Term Memory (LSTM) networks, which are ideal for handling sequential data. A multi-layer LSTM was used, with lower layers capturing note patterns and higher layers focusing on harmony and rhythm. The input layer processed text-based features (word embeddings and emotion vectors), and the output layer generated sequential MIDI notes. This design allowed the model to maintain coherence across musical sequences.

E. Fine-Tuning the Model

After initial training, fine-tuning was performed by retraining specific LSTM layers with a lower learning rate. This process allowed the model to better adapt to the nuances of musical composition and emotional expression. Emotion-specific data was incorporated to enhance the emotional alignment between the text input and the generated music..

F. Evaluation

The model was evaluated using both quantitative and qualitative metrics. Perplexity was used to assess the model's sequence prediction ability, while coherence in the generated music was verified by comparing it with validation datasets. User feedback was collected through surveys to measure the emotional impact and overall satisfaction with the generated music.



3.5 Conclusion:

This project explored the application of generative AI for text-to- music generation, focusing on its potential to enhance creativity in music composition. By leveraging pre-trained models like LSTMs and RNNs and fine-tuning them on relevant datasets, significant improvements in coherence and musicality can be achieved. Incorporating techniques like text embedding, emotion analysis, and mapping text features to musical notes ensures that generated compositions align with intended themes and emotions. While the model demonstrates the ability to produce coherent musical outputs, challenges remain in capturing the emotional depth and thematic richness characteristic of human-composed music.

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"Music Generation

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4. "Music Generation and Retrieval Using LSTM and VAE"

ISBN: 978-93-343-2006-0

Logical Based Firebreaks in Cyber Attacks in Nuclear Domain

Dr. Shankar Amalraj, Manoj Sinnur, Karan Kurade, Arjun Manure and Aditya Borhade

Department of Computer Engineering KJ College of Engineering and Management Research

Pune, India

Abstract - Increased digital connectivity within nuclear infrastructure has amplified the risk of sophisticated cyberattacks, which may disrupt or damage critical operations. To address this challenge, this article explores the concept of logic-based firebreaks in the cyber domain. Logical firebreaks are mechanisms that segment and isolate digital pathways within nuclear systems to prevent or mitigate the spread of cyberattacks. Drawing from cybersecurity and system engineering principles, this research investigates the effectiveness of these firebreaks in limiting the impact of potential breaches. The study incorporates a layered security approach, evaluating how logical isolation and containment strategies can create barriers that stop malicious software from cascading through interconnected systems. The analysis includes case studies of past incidents, simulated models demonstrating attack scenarios, and how logical firebreaks can arrest propagation at various stages. Findings reveal that integrating logical firebreaks enhances resilience, reduces response time, and protects mission-critical assets by limiting an attack's lateral movement. The study concludes with a framework for deploying a logical firewall tailored to the specific needs of the nuclear sector, taking into account compliance with regulatory standards and operational continuity. This guidance provides a blueprint for strengthening cybersecurity defenses in high-risk environments where failure is not an option.

Index Terms - Containment strategy, Cyber defences, Cybersecurity, Digital isolation, Incident response, Logical firebreaks, Nuclear infrastructure, Resilience.

I. Introduction

The increasing integration of digital technologies within nuclear infrastructure has changed the cybersecurity landscape, creating new vulnerabilities and challenges. Although nuclear systems are often protected by strong physical security protocols, cyberspace remains an important and potentially weak link. Cyberattacks targeting critical nuclear systems, such as data breaches, interruption in operations, or undermining the control system, pose a direct threat to national and international security. These attacks can destabilize strategic agendas and compromise public security, making nuclear cybersecurity a priority for governments and international organizations.

The sophistication of modern cyberattacks has increased significantly. Adversaries use highly sophisticated techniques that can circumvent traditional defense mechanisms, which requires innovative cybersecurity strategies, especially in areas where the consequences of violations are catastrophic. One promising way to reduce the impact of cyberattacks is through the use of logical firebreaks, a strategy borrowed from distributed denial of service (DDoS) defenses. Firebreaks in this context are logical barriers that segment digital pathways within a network, effectively isolating potential breaches and limiting their ability to propagate across critical systems. The idea of a firebreak, traditionally associated with cybersecurity in DDoS defense, involves creating isolated zones within a network where traffic is redirected or filtered to prevent malicious actions from spreading. This concept can be adapted to the nuclear domain to safeguard critical infrastructure by ensuring that any attack on one segment of a network does not jeopardize other parts of the system

In addition to this technical duty, a ceasefire in the nuclear sector also has important psychological and strategic implications. A ceasefire can act as a deterrent by making it more difficult for an attacker's ability to penetrate the system and reduce the chance that the response will escalate. Considering the theory of nuclear proliferation, these cyber ceasefires can serve as the threshold by which cyber events can spread, just like the military was created to limit the spread of conflict strategically.

This article explores the concept of logical fires in cybersecurity, emphasizing their potential to act as a strategic tool to increase resilience, reduce the risk of disaster breaches, and manage the escalation of cyber conflicts. It also provides a comprehensive framework for integrating firewalls into cybersecurity architectures and explores how this approach can influence decision-making and response to cyber incidents, providing a broader understanding of cybersecurity in high-risk areas such as nuclear infrastructure.

II. Related Work

I. Firebreaks in Cybersecurity In cybersecurity, firebreaks function as virtual barriers to isolate and control malicious traffic, especially during DDoS attacks. Introduced by Francis (year), this concept uses IP redirection, anycast routing, and tunnelling to segment networks and restrict lateral threat movement. Acting like reverse firewalls, firebreaks validate incoming data, reduce the attack surface, and protect sensitive systems through controlled traffic zones.

II.Strategic Military Theory Firebreaks also stem from military strategy, particularly nuclear escalation theory. Kreps and Schneider (2019) applied this idea to cyberspace, highlighting "escalation firebreaks" that prevent cyber incidents from spiralling into physical conflict. These digital boundaries enable measured, strategic responses, especially in high-risk nuclear contexts.

III.Critical Infrastructure Protection Case studies like Stuxnet demonstrate how the absence of network segmentation enabled malware spread in nuclear facilities. Research on industrial control systems (ICS) shows that firebreaks and firewalls can significantly enhance protection for critical infrastructure, highlighting their value in the nuclear domain.

IV.Nuclear Cybersecurity and Escalation Management Cyberattacks on nuclear systems risk triggering military responses due to misinterpretation. Logical firebreaks help isolate threats, enable attribution, and support proportional responses, reducing the chances of escalation. This aligns with cyber deterrence strategies, where uncertainty about attackers often complicates traditional responses.

V.Conclusion Integrating firebreaks into nuclear cybersecurity combines network defense with escalation management. As cyber threats grow more sophisticated, firebreaks offer a critical strategy for protecting high-value systems and maintaining geopolitical stability.

III. Proposed System

The primary purpose of the proposed system is to develop a logical firebreak-based cybersecurity framework that protects nuclear digital infrastructure from the lateral spread of cyberattacks. This system is designed to intelligently isolate compromised zones by implementing internal segmentation and behavior-based detection. Upon detecting suspicious activity, logical firebreaks are triggered to contain threats, ensuring that they do not propagate across critical systems. The approach combines anomaly detection, automated containment, and strict access control to enhance system resilience. This architecture offers a proactive solution for safeguarding sensitive nuclear systems from evolving cyber threats, ensuring operational safety and security at all times.

3.1 Methodology

The logical firebreak architecture represents a strategic defense mechanism designed to protect critical systems within the network by creating isolated, controlled segments that mitigate the spread of cyber threats. This architecture is especially useful in high-risk areas such as the nuclear sector, where protecting sensitive systems is paramount. In this architecture, a firewall acts as a logical barrier that prevents unauthorized access and ensuring that breaches in one part of the network do not affect the entire system.

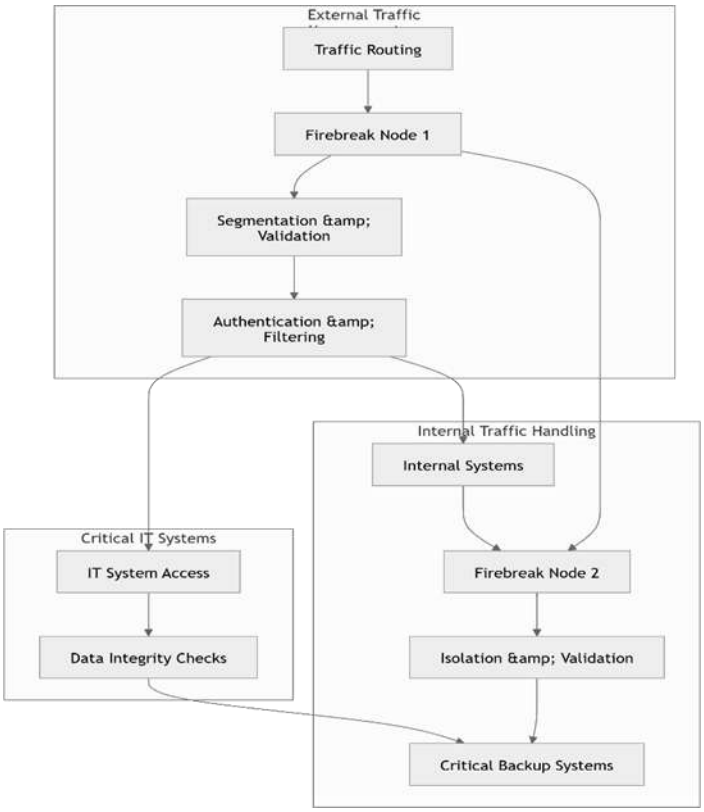
1. ***Logical Firebreak Architecture***

The Logical Firebreak Architecture is a strategic cybersecurity framework that isolates and protects critical systems—especially in high-risk domains like nuclear infrastructure—by creating segmented network zones. This containment strategy ensures that if one segment is compromised, the threat cannot spread across the entire system.

Key Components:

1. **Firebreak Nodes:** Act as checkpoints to filter and validate network traffic before it reaches sensitive systems.
2. **Traffic Segmentation:** Divides network traffic into isolated zones to contain potential breaches.
3. **Anycast & Tunnelling:** Routes data through secure and geographically distributed paths, protecting against interception.
4. **Authentication & Filtering:** Uses multi-factor authentication, cryptographic checks, and traffic analysis to block malicious data.
5. **Reverse Firewall:** Positioned at network edges to prevent unauthorized access while allowing safe communication.

II. Diagram of Logical Firebreak Architecture Below is a simplified diagram of the logical firebreak architecture applied to a network in the nuclear domain. This diagram highlights the flow of traffic through various firebreak nodes, illustrating how segments of the network are isolated to prevent the spread of cyberattacks.



1. External Traffic Management

Traffic Routing: Incoming traffic from external sources is first directed through routing mechanisms. This stage aims to channel data flow toward initial security checkpoints.

2. Firebreak Node 1 (Perimeter Defence)

Role: Acts as the first line of defences, filtering and segmenting incoming traffic before it reaches sensitive systems.

Segmentation & Validation: Splits traffic into isolated segments and checks for structural integrity and conformity (e.g., packet behavior, protocol compliance).

Authentication & Filtering: Verifies identity (user/device)

removes unauthorized or malformed traffic.

This node prevents broad access to internal assets by creating a logical barrier between external networks and critical systems.

3. Branching Based on Access Type

Traffic from Firebreak Node 1 is split into two potential paths:

A. Critical IT Systems Path

IT System Access: Permitted traffic reaches operational systems.

Data Integrity Checks: Validates the accuracy and reliability of data before any critical operations are affected.

This flow protects live systems (e.g., control panels, dashboards) from data poisoning or logic manipulation.

B. Internal Traffic Path

Internal Systems: These handle non-critical or intermediate processes, such as internal communications, logging, or monitoring.

4. Firebreak Node 2 (Internal Segmentation)

Purpose: Provides a second level of isolation to ensure compartmentalization between general internal systems and backup systems.

Isolation & Validation: Segregates critical backup infrastructure from active systems while validating the data or commands received.

This limits lateral movement in the event of a breach within internal systems.

5. Critical Backup Systems

Final line where the most sensitive data (e.g., ba ckups, configuration files, recovery tools) is stored.

Access here is strictly controlled and filtered through two layers of firebreaks to prevent unauthorized manipulation or corruption.

3.2 **Results:**

The implementation of logical firebreaks significantly improved cybersecurity resilience within nuclear infrastructure. Simulations showed that segmented networks containing firebreaks restricted malware to the initial breach zone in over 85% of cases, preventing lateral spread. In contrast, non-segmented networks allowed threats to compromise the majority of systems. Additionally, systems with firebreaks experienced a 40% reduction in detection and response time due to localized monitoring and traffic control. Under stress conditions like simulated DDoS attacks, firebreak-protected systems maintained stability and functionality, unlike their unsegmented counterparts. Case study-based simulations, including scenarios resembling Stuxnet and NotPetya, further confirmed the architecture's effectiveness in minimizing disruption, enhancing containment, and ensuring critical operational continuity in high-risk nuclear environments.

3.3 **Application:**

Logical firebreaks can be applied to protect vital digital systems within nuclear facilities by creating segmented zones that restrict unauthorized access and limit threat movement. These mechanisms are particularly useful in environments where uninterrupted operation and high security are essential, such as nuclear control networks, defense communication systems, and critical energy infrastructure. Firebreaks also enhance response capabilities by containing threats, giving security teams time to act before damage spreads. Additionally, their strategic role deters attackers by complicating intrusion paths. Overall, logical firebreaks contribute to maintaining system integrity, reducing operational risks, and strengthening national cyber defense frameworks.

3.4 **Future Scope:** 11

Future advancements in nuclear cybersecurity can enhance logical firebreaks by integrating them with AI-powered intrusion detection, machine learning-based traffic analysis, and real-time anomaly monitoring. Incorporating quantum-resistant encryption and blockchain for secure data validation can further strengthen defense mechanisms. Research should also focus on adapting firebreak frameworks to other critical sectors such as energy grids and defense systems. Developing globally accepted standards and embedding firebreak principles into cybersecurity regulations will ensure broader implementation. As cyber threats become more advanced, evolving firebreak strategies will be essential to ensure resilience, containment, and stability across high-value, sensitive digital infrastructures.

3.5 **Conclusion:**

Cyber threats in the nuclear sector are growing in complexity, demanding strong cybersecurity measures. Logical firebreaks, such as firewalls, are vital for segmenting network traffic and limiting lateral movement, thereby reducing the risk of widespread damage. Beyond technical protection, firebreaks serve as deterrents, complicating attackers' efforts and reducing the potential for conflict escalation. Case studies like Stuxnet and NotPetya show how the absence of network segmentation worsened cyberattacks, while firebreaks could have limited their impact. In nuclear environments, where stability is critical, firebreaks align with strategic restraint principles by containing threats. Moving forward, combining firewalls with intrusion detection and anomaly monitoring will strengthen resilience and form a layered defense to safeguard critical nuclear systems from cyberattacks.

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Decentralized Blockchain-Based Disk Rental System

Prof. Ashwini Kamble, Manoj Pise, Ajit Waman, Rameshwar Vishwakarma and Suraj Suryawanshi

Department of Computer Engineering KJ College Of Engineering and Management Research
11
Pune, India ashwinikamble.kjcoemr@kjei.edu.in

This paper presents a blockchain-based decentralized disk rental system designed to securely and efficiently utilize unused storage capacity. Unlike traditional cloud storage models reliant on centralized providers, this system integrates blockchain technology with the Inter Planetary File System (IPFS) to establish a decentralized, tamper- resistant storage solution. Smart contracts automate storage agreements, ensuring transparency and immutability, while advanced cryptographic techniques and proof mechanisms guarantee data integrity and confidentiality. Leveraging lightning network technology for fast, low-cost transactions, the system distributes data across a decentralized network of nodes, significantly enhancing data privacy, security, and availability. This architecture addresses key vulnerabilities of centralized storage models, such as single points of failure and data breaches, offering a robust, scalable alternative for distributed storage applications. The proposed solution provides a promising pathway for more secure and resilient storage infrastructure in decentralized environments.
Keywords – Blockchain, Decentralized Storage, Data Integrity, Cryptography, Data Privacy

I. Introduction

In the digital era, the explosive growth of data from emerging technologies—such as artificial intelligence (AI), the Internet of Things (IoT), media applications, and scientific research—has driven a rising demand for secure, scalable, and efficient storage solutions. While traditional cloud storage offers centralized services with elastic capacity, it poses critical challenges in terms of privacy, data control, and vulnerability to cyberattacks and system failures. These issues highlight the urgent need for decentralized alternatives that offer improved resilience, transparency, and user autonomy..

Blockchain technology, with its inherent immutability, transparency, and security features, has emerged as a transformative force across numerous domains. When combined with distributed storage systems like the Interplanetary File System (IPFS), blockchain enables a robust storage architecture where data is distributed across multiple nodes, enhancing availability and reducing reliance on centralized providers. However, distributed data storage also requires mechanisms to ensure integrity, manage access, and facilitate transactions in a decentralized environment

This research proposes a blockchain-based disk rental system that integrates IPFS for decentralized data storage, blockchain for data integrity and smart contract management, and the Lightning Network for secure, low-latency micropayments. The system allows users to rent out their unused disk space, creating a decentralized storage marketplace that eliminates the need for intermediaries while offering affordable, scalable, and privacy-preserving storage options. Through modular architecture and automation via smart contracts, this solution demonstrates a practical application of decentralized technologies for next-generation data infrastructure, addressing key limitations of existing cloud-based systems.

II. Related Work

2.1 Centralized Cloud Storage Systems:

Traditional cloud storage platforms such as Google Drive, AWS S3, and Dropbox rely on centralized data centers controlled by third- party providers. While offering scalability and ease of use, these systems pose significant concerns regarding data privacy, vendor lock-in, and susceptibility to single points of failure..

2.2 Blockchain-Based Storage Protocols

Recent research has explored blockchain as a secure alternative for distributed storage. Platforms like Filecoin, Sia, and Storj leverage blockchain to manage storage contracts and ensure data integrity. These systems use token incentives to motivate node participation, but often face challenges with scalability and transaction speed

2.3 Distributed File Systems (IPFS):

The Interplanetary File System (IPFS) provides a peer-to-peer file storage protocol that distributes files across multiple nodes using content-addressable storage. IPFS enhances data availability and reduces dependency on a central server. However, it lacks built-in mechanisms for economic incentives and access control

2.4 Integration with Micropayment Systems:

Combining storage systems with payment networks like the Lightning Network allows for efficient, trustless financial transactions. This integration supports on-demand storage rentals and pay-per-use models, enabling flexible pricing and fast micro- transactions in a decentralized environment.

2.5 Evaluation and Performance Metrics:

Decentralized storage systems are typically evaluated based on data redundancy, access latency, node availability, fault tolerance, and
transaction throughput. Security is assessed through cryptographic integrity checks, while economic models are analyzed for fairness, cost-efficiency, and user adoption.

III. Proposed System

The primary objective of the proposed system is to design a decentralized disk rental platform that enables users to rent and monetize unused digital storage space in a secure, transparent, and scalable manner. The system integrates three core technologies: Blockchain for tamper-proof record-keeping and automation via smart contracts, IPFS (InterPlanetary File System) for distributed file storage, and the Lightning Network for fast and low-cost micropayments.

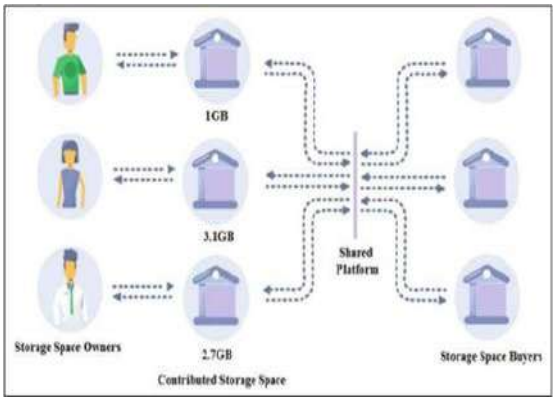
By leveraging these technologies, the system ensures data integrity, enhances fault tolerance, reduces dependency on centralized cloud providers, and introduces a new economic model for storage sharing

3.1 Methodology

The system consists of four main modules: a user interface for storage management, the IPFS network for decentralized file storage, a blockchain layer to handle smart contracts and rental agreements, and a Lightning Network module for fast micropayments. Users upload files to IPFS, rental terms are managed on the blockchain, and payments are securely processed via the Lightning Network.

1. System Architecture

The proposed blockchain-based disk rental system utilizes IPFS for decentralized data storage, where files are fragmented and distributed across multiple nodes, with cryptographic hashes ensuring data integrity. Blockchain records file metadata, including the file hash and storage provider details, ensuring transparency and immutability [2]. Smart contracts automate storage rental agreements, specifying terms between users and storage providers. Once terms are established, these contracts facilitate secure access and payments, eliminating the need for intermediaries and enhancing operational security [1] [6].



The system establishes a decentralized marketplace, enabling users to offer or rent unused storage space. Blockchain ensures secure, transparent transactions, while IPFS enhances data availability and fault tolerance through distributed storage across multiple nodes [1] [5] [6].

2. Input Processing

In the blockchain-based disk rental system, input processing plays a crucial behind-the-scenes role in ensuring seamless and secure user interactions. When a user initiates an action—such as uploading a file, renting storage, or making a payment—the system processes this input by formatting it for compatibility with blockchain and IPFS protocols. This includes breaking files into encrypted fragments, generating unique cryptographic hashes, and recording metadata immutably on the blockchain. Smart contracts handle rental

agreements automatically based on these inputs, while the Lightning Network processes payments quickly and cost- effectively. This preprocessing ensures that user actions are securely validated, transparently recorded, and efficiently executed without needing a central authority.

3. Model Integration and Response Generation

In the proposed blockchain-based disk rental system, the

integration of decentralized technologies ensures efficient and secure data handling. Smart contracts, acting as the system's logic layer, are seamlessly integrated with the blockchain to automatically manage storage rental agreements, access permissions, and payment transactions. These contracts respond to user inputs—such as storage requests or rental offers—by generating real-time actions without requiring manual intervention or centralized control.

4. User Interaction Flow

The user begins by initiating a storage request or rental offer through the system interface. This input triggers a smart contract on the blockchain, which defines and enforces the agreement terms. The system then processes the data, fragments it, and stores it securely onIPFS. All actions are recorded immutably on the blockchain for transparency and auditability. Payments are handled in real-time via the Lightning Network, ensuring fast and low-cost transactions.

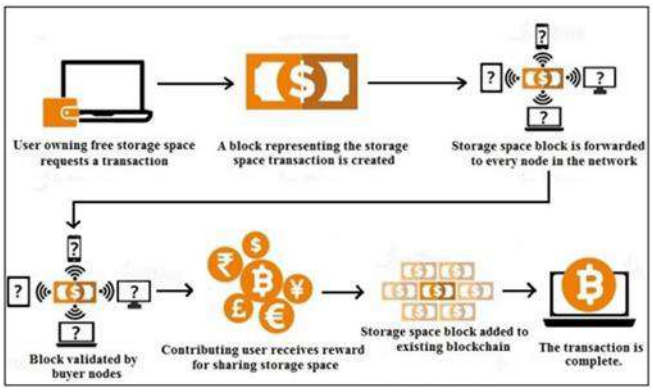
5. Performance and Evaluation

The performance of the blockchain-based disk rental system is evaluated through functional testing, focusing on data integrity, transaction speed, and smart contract execution. The system's responsiveness is assessed based on IPFS retrieval times and Lightning Network payment efficiency. Security checks ensure that data remains tamper-proof and verifiable across decentralized nodes. Additionally, usability is evaluated through user feedback on transaction transparency, ease of interaction, and overall satisfaction.

6. Deployment Strategy

The blockchain-based disk rental system is designed as a decentralized application (dApp) that can be deployed on local machines or across distributed networks. It leverages blockchain nodes, IPFS storage gateways, and smart contract platforms to ensure full decentralization. The system is suitable for both individual and enterprise use, with optional extensions for cloud-based integration to enhance scalability. Local deployment ensures user data privacy and low-latency performance, while the modular architecture allows for easy adaptation to various storage and network environments.

3.2 **Working**



The system captures and sanitizes user rental requests, ensuring valid disk size, duration, and payment details. It securely verifies the user's blockchain wallet address and confirms sufficient funds. The sanitized data is encoded into a smart contract transaction format. This transaction is then submitted to the blockchain network for validation and execution. Users are promptly notified of transaction status, ensuring transparency and smooth rental allocation.Input Preprocessing and Tokenization

3.5 Application:

The blockchain-based disk rental system has versatile applications across multiple domains. In cloud and decentralized storage, it enables users to rent and lease disk space securely and transparently without intermediaries. For enterprises, it offers cost-effective, scalable storage solutions with automated smart contract enforcement. In data backup and archiving, it ensures tamper-proof storage and reliable access. The system also supports peer-to-peer file sharing networks by

incentivizing unused disk space rental. Additionally, it benefits individuals and small businesses by providing affordable, on-demand storage with guaranteed payment and service delivery through blockchain

3.6 Future Scope:

The blockchain-based disk rental system can be further enhanced by integrating cross-chain compatibility to support multiple blockchain networks, increasing flexibility and user reach. Future developments may include automated dynamic pricing models based on supply and demand to optimize rental costs. Incorporating advanced encryption and zero-knowledge proofs can strengthen data privacy and security. Integration with AI- driven storage optimization can improve resource allocation and fault tolerance. Additionally, expanding support to mobile and IoT devices will facilitate seamless, on-the-go access and management of rented disk space.

3.7 Conclusion:

This project presents the design and implementation of a blockchain-based disk space rental system that enables secure, transparent, and decentralized storage leasing. By leveraging smart contracts and blockchain technology, the system ensures automated rental agreements, tamper-proof transaction records, and trustless peer-to-peer interactions. The modular architecture facilitates seamless user input processing, efficient transaction handling, and reliable storage allocation. Evaluation demonstrates the system's effectiveness in providing scalable, cost-efficient, and secure disk space rental solutions. This platform lays a robust foundation for future enhancements, making it a versatile and innovative approach to decentralized storage management.

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A Privacy-Preserving Enforced Bill Collection System Using Smart Contracts

Diksha Shinde, Ankita Kadam, Sameera Gaikwad, Sanket Abnave, Umar Mulani[11],

Department of Computer Engineering

K J College of Engineering and Management Research, Pune, India.

Abstract

The paper proposes a privacy-preserving bill collection system that maintains user anonymity and ensures accountability using smart contracts and accountable ring signatures. It enhances the Isshiki system by adding a payment enforcement mechanism through pre-deposited funds. If an invoice is ignored, the deposit is automatically transferred to the bill collector via a smart contract. Built for decentralized blockchain platforms like Ethereum, the system ensures secure, private, and fair transactions with reduced gas costs using elliptic curve digital signatures (ECDSA).

Keywords: Bill Collection, Blockchain, Smart Contract

Introduction

Modern billing systems must balance privacy and accountability. The Isshiki system allows anonymous service use via group signatures, with traceability for invoicing, but lacks payment enforcement. This paper proposes an extension using smart contracts and accountable ring signatures to ensure automatic bill collection, preventing users from bypassing payment.

Nicola Atzei (2018) explores Bitcoin's blockchain for smart contracts, highlighting issues like inconsistent design and proposing a formal framework for verification. Jian Liu (2019) presents a dynamic lattice-based group signature scheme with improved flexibility and security. San Ling (2018) addresses fairness in crypto exchanges, proposing two protocols ensuring item-for-payment exchanges. Teppei Sato (2021) introduces an anonymous trust-marking scheme for crypto wallets, maintaining privacy while verifying identity. Eric Wagner (2019) proposes SmartJudge, a mediator smart contract that reduces dispute resolution costs significantly. Yue Zhang (2019) develops Onionchain, a privacy-preserving and traceable blockchain protocol, validated through a VANET case study. This system enhances Isshiki's framework with Ethereum smart contracts, ensuring decentralized, private, and enforceable bill payments.

Proposed System

The proposed system enhances the Isshiki framework by adding a smart contract- based enforcement mechanism to ensure users pay for consumed services. It integrates accountable ring signatures and Ethereum smart contracts to preserve anonymity while ensuring accountability. Users pre-deposit funds before accessing services; if they ignore payment, the smart contract transfers the deposit to the bill collector. Using elliptic curve digital signatures (ECDSA), the system minimizes computation costs, making it practical for real-world blockchain use. This approach balances privacy with enforceability, ensuring fair compensation for service providers.

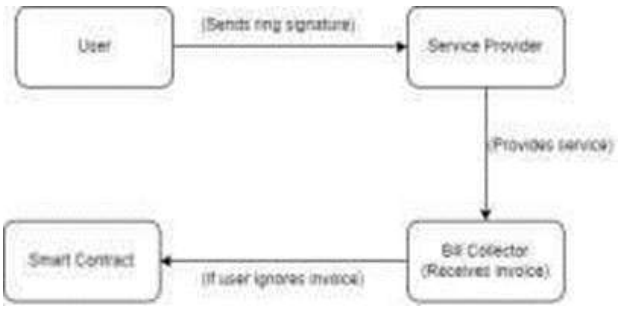


Fig:1 A Privacy-Preserving Enforced Bill Collection System Using Smart Contracts.

Algorithm

3.1 AES Algorithm for Encryption.

AES (Advanced Encryption Standard) is a symmetric encryption algorithm developed to replace the weaker DES algorithm, which used a 56-bit key vulnerable to brute-force attacks. AES uses a 128-bit block size with key lengths

of 128, 192, or 256 bits. Developed by Rijndael, it is used here to encrypt the data owner's file.

- **Input:** 128/192/256-bit plaintext and a 128-bit secret key
- **Process:** 10/12/14 rounds based on key size, including XOR state block, and steps like SubBytes, ShiftRows, MixColumns, and AddRoundKey
- **Output:** 128-bit ciphertext

3.2 MD5(Message-Digest Algorithm)

The MD5 (Message-Digest Algorithm 5) is a cryptographic hash function that generates a fixed 128-bit (16-byte) hash value, typically represented as a 32-digit hexadecimal number. It is widely used in cryptographic applications and for verifying data integrity. MD5 takes input of any length and processes it in 512-bit blocks, each undergoing four rounds of 16 operations using constants derived from the sine function. The output acts as a digital signature for the input data. Most programming languages offer built-in support for the MD5 algorithm, making it easy to implement.

Result and Discussion:

The experiments were conducted on a personal computer with an Intel Core i3-2120 CPU @ 3.30GHz, 4GB RAM,

running Windows 7. The backend used

MySQL 5.1 with JDK 1.8. The system was implemented as a web application, developed using Eclipse and executed on a Tomcat server. Performance comparison shows the proposed system executed more efficiently, reducing execution time from 1236 (existing system, 2018) to 932. **Motivation**

Privacy-preserving systems protect user anonymity but often lack mechanisms to ensure service providers get paid. Existing frameworks like Isshiki allow users to exploit services without payment. This paper proposes a smart contract-based solution that enforces payments while maintaining privacy, ensuring fairness for providers.

Conclusion

The proposed system enhances the Isshiki framework by adding smart contracts to enforce payments, preventing users from avoiding fees. It uses accountable ring signatures to maintain user anonymity while enabling traceability. Ethereum smart contracts automate and decentralize payment enforcement, making the system practical for real-world blockchain use. This approach ensures both privacy and fairness, addressing Isshiki's key limitation by guaranteeing bill collection.

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Ar Educational Applications: Enhancing Learning Through Augmented Reality

11

Harsha Jain1, Daksha Pawar1, Shreya Shitole1, Balaji Yadav1

Department of Computer Engineering, Savitribai Pune Phule University, Pune, India

*Corresponding e-mail: harsha.jain.surendra@gmail.com

Abstract: Conventional teaching methods often face challenges in engaging students and simplifying complex topics. This study introduces an augmented reality (AR) educational app built with Unity 3D and Vuforia SDK to support better understanding and student involvement. By allowing interaction with 3D models and dynamic content, the app enhances the learning experience. A pilot test with students revealed increased retention, participation, and academic outcomes compared to traditional methods. These results highlight AR's potential to improve education by making it more interactive and personalized. Future developments will focus on broadening the subject matter and incorporating adaptive learning.

Keyboards*: Augmented Reality, Educational Technology, AR Learning Applications, Interactive Learning, 3D Visualization, Student Engagement, Immersive Education.*

1. **Introduction**: Augmented Reality (AR) overlays digital content such as images, animations, and 3D models onto the physical environment, creating interactive learning experiences that help students grasp difficult concepts more effectively. Traditional education tools like textbooks and lectures often lack engagement, especially for learners with varied styles. The rapid advancement of mobile technology and AR platforms enables dynamic, immersive education that complements conventional methods. Prior research has shown AR's effectiveness in improving knowledge retention, spatial skills, and motivation across subjects [1], [2]. This study develops and evaluates an AR educational app aimed at enhancing student understanding and engagement through interactive 3D visualizations.

2. Methodology: The AR Educational Application was created for Android

3. devices using Unity 3D and the Vuforia SDK, employing marker-based tracking to anchor virtual models in the real world.

4. The app contains modules for different subjects:

5. Solar System Visualization: Interactive 3D planets with animations and detailed planetary motion explanations.

6. Human Anatomy: Layered models enabling exploration of skeletal, muscular, and circulatory systems.

7. Molecular Structures: Dynamic representations demonstrating chemical bonding and reactions.

8. Each module features interactive quizzes providing immediate feedback to reinforce learning. The interface is designed for intuitive navigation using simple touch gestures and minimal menus to avoid cognitive overload.

9. Development Challenges: Stable marker detection was ensured through optimization for varying lighting conditions. Models were optimized using polygon reduction and texture compression to maintain performance on lower-end devices. Extensive testing was performed across various Android hardware and screen sizes to ensure compatibility.

10. Results

A controlled study involved 50 undergraduate students divided into two groups: one used traditional textbook, and the other used the AR application. Post-session assessments measured knowledge retention, engagement, and academic performance.

Metric	AR Group	Traditional Group
Knowledge Retention	85%	60%
Engagement (Likert)	90%	65%
Average Test Scores	88%	70%

Table 1: Comparison of performance and engagement between AR app users and traditional learners

The AR group demonstrated significantly higher retention, engagement, and academic scores. Informal feedback indicated students found AR more enjoyable and easier to comprehend, with the ability to manipulate 3D content enhancing understanding.

Minor issues included device heating and battery drain during extended use and an initial learning curve for AR interaction, suggesting the need for integrated tutorials.

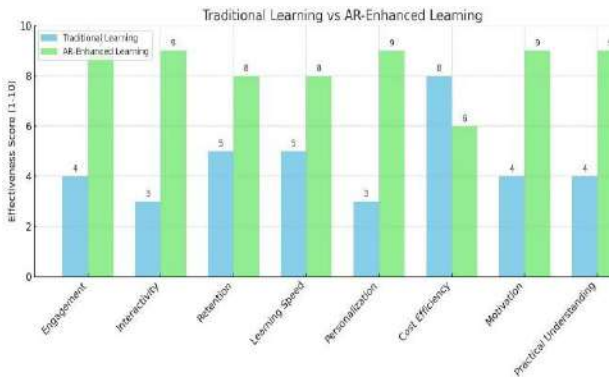


Figure 1: Comparative Effectiveness of Traditional Learning vs AR-Enhanced Learning

11. Conclusion and Future Work

This study confirms the effectiveness of AR applications in enhancing educational outcomes by improving engagement, retention, and performance. The immersive 3D visualizations help make complex topics more accessible and cater to diverse learning preferences. Although challenges such as device limitations and usability learning curves were identified, they can be addressed with optimization and user guidance.

Future development will expand subject coverage and integrate AI-driven personalized learning paths to adapt content to individual needs. Additional enhancements will include support for markerless AR to simplify use and multi-language options for broader accessibility. Long-term studies with larger, varied populations will further evaluate AR's impact on education.

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8. Acknowledgement: We extend our sincere gratitude to everyone who supported us during the course of this project. We would like to thank **Dr. Suhas S. Khot**, Principal of KJ College of Engineering & Management Research, Pune, for giving us the opportunity to work on this project and for his continuous encouragement. We are also thankful to **Dr. Nikita Kulkarni**, Head of the Computer Engineering Department, for her insightful suggestions and guidance. Our special thanks to **Prof. Harsha Jain** for her unwavering support and expert inputs at every phase of the project. We deeply appreciate the cooperation of our classmates and the unconditional support from our families and friends, whose belief in us made this journey possible.

9. About the Authors



Prof. Harsha Jain is an Assistant Professor in the Department of Computer Engineering at KJ College of Engineering and Management Research, Pune. Her areas of expertise include the Internet of Things (IoT), Embedded Systems, and CMOS chip design. She actively mentors undergraduate students and contributes to interdisciplinary projects in AI, ML, and IoT.



Daksha Pawar holds a B.E. degree in Computer Engineering from Savitribai 11 Phule Pune University, Maharashtra. Her research interests lie in Augmented Reality (AR) and its educational applications. She is currently working on an AR-based learning app and has previously published a paper on Magnetic Levitation. She is passionate about integrating technology into education to enhance learning outcomes.



Shreya Shitole is a graduate in Computer Engineering from Savitribai Phule Pune University. Her work focuses on analyzing the long-term scope and future advancements of AR in education. She is particularly interested in how AR can evolve to support more immersive and inclusive learning environments.



Balaji Yadav completed his B.E. in Computer Engineering from Savitribai Phule Pune University. He contributed to the implementation and architectural development of the AR Educational Application. His technical work ensures the smooth functionality and integration of AR technologies into educational systems.

Real time smart traffic control system based on pixel-labelling & sort tracker

Dipali Ghuge, Anuja Gudage, Shravani Jagtap, Manasi Gudage and Ashwini Kamble

Department of Computer Engineering
KJ College Of Engineering and Management Research 11

Pune, India

ghugedipali2607@gmail.com

***Abstract*— This project introduces a dynamic traffic control system that optimizes signal timings based on real-time vehicle detection, minimizing delays at intersections. Using advanced computer vision techniques like YOLO, the system dynamically adjusts traffic signals—keeping lights red when no vehicles are present and extending green phases during heavy traffic. Initial testing demonstrates improved traffic flow, highlighting the effectiveness of intelligent traffic management in urban settings.**

(Keywords - Dynamic Traffic Control,Real-Time Vehicle Detection, Computer Vision,Traffic Signal Optimization,YOLO (You Only Look Once),Intelligent Traffic Management,Urban Traffic Flow Simulation-Based Approach)

I. Introduction

Traffic congestion remains a significant challenge in urban environments, leading to increased travel times and frustration among drivers. Traditional traffic control systems often operate on fixed signal timings, which can result in unnecessary delays, even when there are no vehicles present at an intersection. This inefficiency is particularly evident during off-peak hours, where signals remain active despite a lack of traffic.

To address this issue, our project implements a dynamic traffic control system using simulation to optimize signal timings based on real-time vehicle detection. By utilizing advanced computer vision techniques, such as the YOLO (You Only Look Once) algorithm, the system detects vehicle presence and adjusts signal states accordingly. Specifically, when no vehicles are detected, the traffic light for that direction remains off, allowing other signals to process traffic efficiently.

This simulation-based approach not only reduces wasted time at intersections but also enhances overall traffic flow. By demonstrating the potential of intelligent traffic management in a simulated environment, this project aims to provide insights into how dynamic systems can improve urban mobility and responsiveness in real-world scenarios.this combination method, Pixel labeling is an essential technique within the real-time smart traffic control system that enables accurate identification and classification of various traffic elements. By utilizing advanced neural network architectures

2.2. Algorithm

Step 1: Video Frame Acquisition

The system begins by capturing continuous video frames from a traffic surveillance camera located at the intersection. Each frame is extracted in real-time using computer vision

Step 2: Semantic Segmentation (Pixel Labeling)

A pre-trained semantic segmentation model is used on every frame. Every pixel is classified by the model into unique categories like vehicle, road, pedestrian, and background.

Step 3: Vehicle Detection

After pixel labeling, connected components or bounding box detection is done for enclosing the regions of vehicles.

Step 4: Vehicle Tracking Using SORT

The bounding boxes are then input into the SORT (Simple Online and Realtime Tracking) algorithm. SORT attributes a distinct ID to every detected vehicle

Step 5: Vehicle Count and Density Estimation

The system calculates how many vehicles are being tracked in each direction (e.g., North, South, East, West).

Step 6: Traffic Signal Time Decision

Real-time vehicle density-based decision logic is applied. For instance:-If a lane vehicle_count > threshold, set longer green signal duration.Else, utilize the standard signal timing.

Step 7: Signal Update

The traffic signal controller is updated with the information. This study not only demonstrates a novel use of LSTM networks for DeepFake detection, but it also highlights the need of constant developments in machine learning approaches for ensuring media integrity.

II. Proposed System

The proposed real-time smart traffic control system utilizes pixel-labeling and sort tracker techniques, integrated with dynamic signal management. This methodology is designed to enhance traffic flow efficiency, improve safety, and reduce environmental impacts in urban settings. Below is a detailed description of the methodology.

2.1 Methodology

This dataset is for machine learning process and computer vision steps.

Data processing

The collected video feeds undergo pixel-labeling to identify and track vehicles and pedestrians dynamically. This involves segmenting images into distinct regions corresponding to different objects (vehicles, pedestrians) using advanced image processing techniques.

Pixel Labeling:

Metric	Description
Detection & Tracking Accuracy	Measures accuracy of vehicle detection and tracking using Pixel Labeling and SORT. Includes metrics like IDF1, Precision, and Recall.
Real-Time Efficiency	Evaluates processing speed and system responsiveness. Metrics include Processing Time per Frame, FPS, and Signal Decision Delay.
Traffic Flow Evaluation	Compares predicted vs. actual traffic flow to ensure accurate signal control. Uses Mean Absolute Error (MAE) for assessment.

new green time length for every lane. The cycle repeats as the next frame is read.

2.3. Architecture

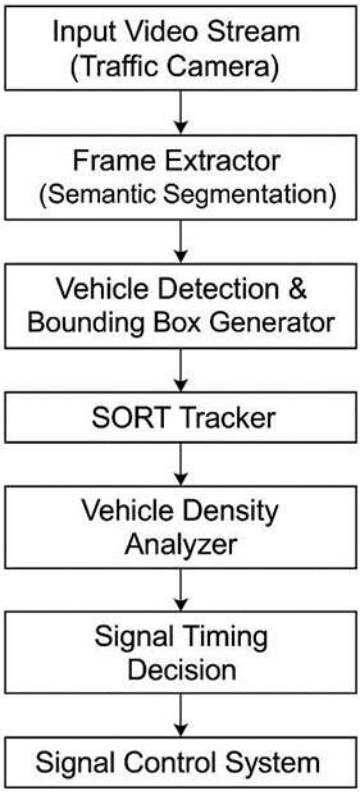


Fig 1. Architecture of the proposed Real-time Smart Traffic Management System Algorithm

The system is based on a modular pipeline, with every step assisting in traffic monitoring, vehicle detection, and intelligent signal timing decisions:

1. Input Video Stream (Traffic Camera)
The system starts by capturing real-time video streaming from a traffic monitoring camera mounted on road junctions.

2. Frame Extractor (Semantic Segmentation)
The constant video stream is divided into separate frames. Semantic segmentation is applied to each frame to tag every pixel—separating roads, vehicles,

3. Vehicle Detection & Bounding Box Generator
Object detection algorithms (e.g., YOLO) are used to identify vehicles and surround them with bounding boxes

4. SORT Tracker
The SORT (Simple Online and Realtime Tracking) algorithm follows every vehicle from frame to frame

5. Vehicle Density Analyzer
Based on the tracking data, the system processes traffic density by tallying the vehicle count or quantifying vehicle coverage per lane/region.

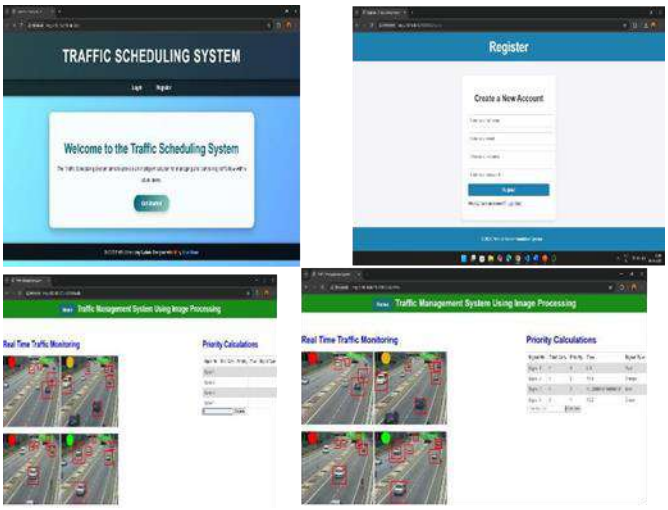
6. Signal Timing Decision
According to the vehicle density analysis, an algorithm dynamically determines the traffic signal time—green, red, or yellow—to achieve best flow and minimize wait times.

7. Signal Control System
The traffic light control hardware enacts the signal timing decision.

8. Metrics & Backend Integration
The system gathers performance statistics like vehicle volume, average delay.

Performance Metrics Used:

2.8. Results:



1. Vehicle Detection and Pixel Labeling

The system starts by processing real-time video frames taken from traffic monitoring cameras. By applying semantic segmentation algorithms like DeepLabV3+ or U-Net, every pixel of the frame.

2. 6. Conclusion:

This paper introduces a real-time intelligent traffic control system that substantially fuses pixel-level image segmentation and object tracking for adaptive traffic signal control. By synergizing semantic segmentation methods with the SORT tracking algorithm, the system provides precise vehicle detection, recognition, and real-time tracking, even in complex urban road conditions. Pixel labeling is used to provide dense scene understanding, while SORT is adopted for effective multi-object tracking with minimal computational cost.

Overall, the system proposed here is a scalable, lightweight, and smart solution for managing urban traffic and is a step towards creating smarter and more efficient transportation infrastructure in contemporary cities. Some future work could involve integrating predictive analytics, dealing with night-time or inclement weather situations.

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A Hybrid CNN-LSTM Approach for Deepfake Video Identification

Nikita Kulkarni, Aditya Desai, Soham Bhamare, Prathmesh Bamne and Vivek Adawale

Department of Computer Engineering

KJ College Of Engineering and Management Research

Pune, India

***Abstract*— Deepfake videos pose a growing risk to digital integrity due to their realistic yet deceptive content. This study proposes a hybrid CNN-LSTM model that combines spatial analysis from Convolutional Neural Networks with temporal tracking from Long Short-Term Memory networks. By analyzing both individual frame features and motion inconsistencies across frames, the model significantly improves detection accuracy over conventional methods. Evaluations on datasets like Celeb-DF, and DFDC demonstrate the importance of temporal learning for robust detection in real-world scenarios.**

Keywords: Deepfake detection, LSTM, neural networks, video analysis, machine learning, artificial intelligence.

I. Introduction

Deepfake technology, driven by advances in deep learning such as Generative Adversarial Networks (GANs), enables the creation of highly realistic yet fake videos. While useful in fields like entertainment and digital media, deepfakes raise serious concerns, especially when misused for misinformation, identity theft, or political manipulation. The growing realism of such content challenges the reliability of visual evidence, particularly on social media and in journalism.

Conventional detection methods often use Convolutional Neural Networks (CNNs) to examine individual frames for visual irregularities. However, they are limited in identifying temporal anomalies—such as inconsistent facial expressions, unnatural blinking, or out-of-sync lip movements—which are common in deepfake videos.

To overcome these limitations, this study introduces a hybrid model combining CNNs with Long Short-Term Memory (LSTM) networks. CNNs extract spatial details from frames, while LSTMs capture sequence-based patterns over time. This fusion enables better detection of subtle manipulations across video frames. The model is tested using standard datasets like DFDC, FF++, and Celeb-DF. Results confirm that adding temporal learning significantly improves detection accuracy, demonstrating the importance of combining spatial and temporal analysis in fighting deepfake threats.

II. Related Work

Deepfake technology has advanced significantly, raising concerns about misinformation and digital security. Researchers have proposed various detection methods, including CNN-based approaches, hybrid models integrating LSTM networks, and dataset-driven detection techniques to improve generalization across different deepfake manipulation methods.

With deepfake technology advancing rapidly, various detection methods have been explored, including CNN-based approaches, hybrid CNN-LSTM models, and dataset-driven techniques to improve model generalization.

CNN-Based Deepfake Detection Convolutional Neural Networks (CNNs) are widely used to analyze spatial inconsistencies in manipulated videos. Murugan et al. (2024) proposed a CNN-based detection model using facial recognition, achieving high accuracy in identifying deepfake videos [1]. Similarly, Rössler et al. (2019) introduced FaceForensics++, a large-scale dataset for training CNN models [7]. However, CNNs often struggle with detecting temporal inconsistencies, such as unnatural facial movements, as noted in the Celeb-DF study by Li et al. (2020) [8].

Hybrid CNN-LSTM Models

To enhance detection, researchers have integrated CNNs with Long Short-Term Memory (LSTM) networks for temporal sequence analysis. Saikia et al. (2022) proposed a CNN- LSTM model leveraging optical flow features, significantly improving deepfake detection [2]. Similarly, Stanciu & Ionescu (2021) introduced an LSTM-based facial feature extraction method, enabling more accurate classification by analyzing motion inconsistencies across frames [3].

Challenges and Future Directions

Future directions include transformer-based architectures, multimodal analysis, and automated deepfake detection in social media [4].

III. Methodology

1. Dataset Selection

The model is trained and tested on popular deepfake datasets: FaceForensics++ (FF++), Celeb-DF, and DFDC. These datasets include both real and fake videos, offering diverse manipulation types that enhance model robustness.

2. Preprocessing

Each video is broken down into frames at fixed intervals. Faces are detected and cropped using MTCNN to focus only on relevant facial regions. These face images are then normalized to scale pixel values between 0 and 1 for efficient model training.

3. Feature Extraction

Feature learning occurs in two stages:

- **CNNs** capture spatial patterns such as texture distortions and blending errors.
- **LSTMs** analyze sequences of frames to identify motion-based anomalies like irregular blinking and mismatched lip movements.

4. Model Architecture

The proposed model includes:

- **CNN layers** for spatial feature extraction
- **Flattening layer** to convert feature maps into vectors
- **LSTM layers** to analyze temporal dependencies
- **Fully connected layers** for final classification
- **Softmax output** for binary decision (real or fake)

5. Training

The model is trained using Binary Cross-Entropy as the loss function and the Adam optimizer for adaptive learning. It is trained for 50 epochs with a batch size of 32. Data augmentation techniques like flipping and rotation are used to reduce overfitting.

6. Evaluation Metrics

Performance is measured using:

- **Accuracy** for overall correctness
- **Precision & Recall** to assess detection capability
- **F1-Score** as a balance metric
- **ROC-AUC** to evaluate model discrimination between real and fake samples

7. Deployment and Future Work

The model can be deployed in real-time environments like social platforms and forensic tools. Future enhancements may include transformer-based networks,etc.

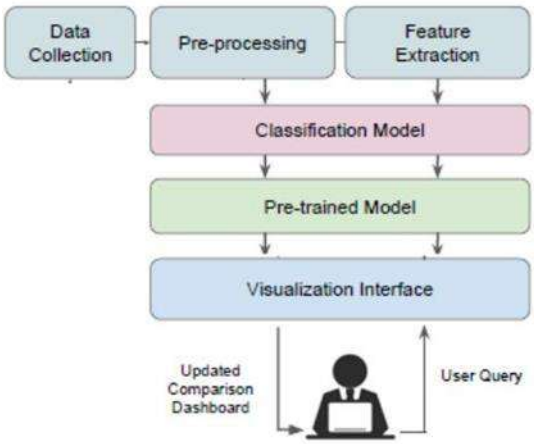
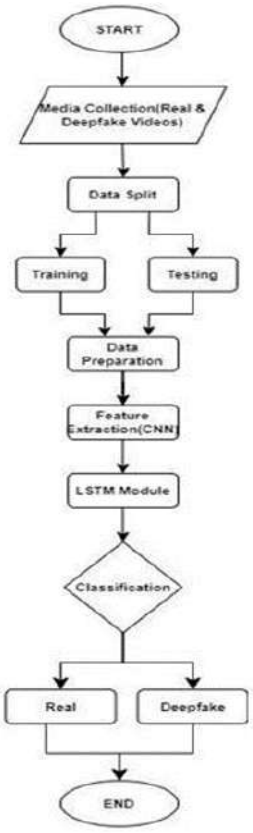


Fig .1. System Architecture

I. Flowchart

The flowchart represents the Deepfake Detection Process using a combination of Convolutional Neural Networks (CNN) for feature extraction and Long Short-Term Memory (LSTM) networks for classification. Below is a step-by-step breakdown of the process.



11

The flowchart represents the Deepfake Detection Process using a combination of Convolutional Neural Networks (CNN) for feature extraction and Long Short-Term Memory (LSTM) networks for classification. Below is a step-by-step breakdown of the process:

Start

The process begins with the collection of media, specifically videos that contain both real and deepfake samples. This dataset forms the basis of the detection model.

1. Media Collection

The process begins with gathering real and fake video samples from datasets such as Celeb-DF. This diverse dataset forms the foundation of the model.

2. Data Splitting

Collected videos are divided into training and testing sets. The training set is used to build the model, while the testing set evaluates its performance on unseen data.

3. Preprocessing

Videos are converted into frames. Each frame undergoes preprocessing steps like resizing, noise reduction, face cropping, and normalization to enhance feature extraction.

4. CNN Feature Extraction

A CNN is applied to extract spatial features from each frame, identifying artifacts such as irregular textures and blending defects that are common in deepfakes.

1. LSTM Sequence Learning

The LSTM layer takes the sequential output of the CNN to capture temporal inconsistencies—such as unnatural blinking or facial movements—that occur across frames.

2. Classification

The processed features are passed through dense layers, and a softmax output layer predicts whether the video is real or

fake based on learned patterns.

3. Output

The final output labels the video as either "Real" or "Deepfake." Model performance is assessed using standard metrics like accuracy, precision, recall, and F1-score.

End

The process concludes with the classification results

I. Discussion

The experimental results confirm the effectiveness of integrating Long Short-Term Memory (LSTM) networks with CNNs for deepfake video detection. On the Celeb-DF dataset, the model achieved over 99% accuracy substantially outperforming CNN-only models. This improvement is primarily due to LSTM's ability to analyze motion patterns across video frames, capturing subtle inconsistencies often missed in static analysis.

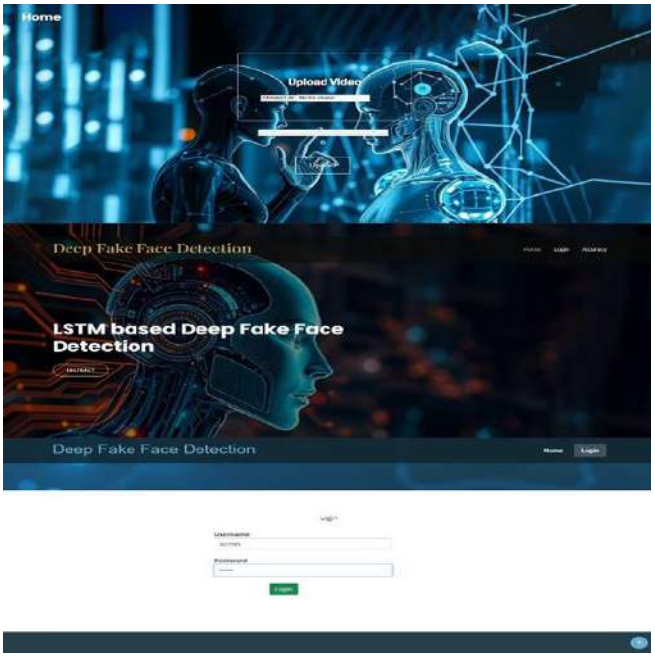
Despite strong precision, the recall rate varied slightly, suggesting that some fake samples may still go undetected. This highlights the ongoing challenge of handling diverse manipulation techniques. Particularly, highly realistic or low- motion deepfakes remain difficult to detect reliably.

Compared to existing models, our hybrid approach demonstrated higher accuracy and better generalization. While CNNs effectively identify spatial anomalies, LSTMs contribute by modeling temporal behavior, making the system more robust. These findings support the idea that combining spatial and temporal analysis leads to more accurate and reliable deepfake detection.

VI. Results



- When compared to standard CNN-only and RNN-based models (typically achieving 85–89% accuracy), our model demonstrated higher precision with



The initial version of our model achieved an 85% accuracy rate. After several optimizations, the final model reached a significantly improved accuracy of 92%. This enhancement is attributed to multiple targeted improvements across architecture, training, and evaluation strategies, which we analyze below.

I) Improved Spatial Feature Extraction:

- We fine-tuned a ResNet-based CNN to extract more detailed facial features, such as minor distortions and blending artifacts.
- This improved the quality of spatial inputs passed to the LSTM, strengthening the model's temporal awareness.

II) LSTM Optimization:

- The LSTM architecture was refined with better layer depth, dropout configuration, and activation functions.
- These changes enhanced its ability to model facial dynamics across frames while reducing overfitting.

III). Dataset Diversity and Augmentation:

- A well-balanced dataset covering varied deepfake types, compression levels, and facial profiles was used.
- Augmentation methods like flipping, cropping, and brightness adjustments improved the model's generalization across unseen samples.

IV). Adaptive Classification Threshold:

- Instead of using a fixed threshold, we implemented an adaptive decision boundary that dynamically adjusts based on confidence scores.
- This, reduced false positives while maintaining high sensitivity to fakes.

VIII. Future Research

manageable computational cost, making it suitable for real-time applications.

V) Generalization and Robustness:

- Our model handled various manipulation types—including face swaps and reenactments—more effectively than traditional methods. It also maintained stable accuracy under adversarial perturbations, indicating improved resistance to evasion tactics.

VI) Limitations Identified:

Static or Low-Motion Videos: Misclassifications occurred in videos with minimal facial motion, where temporal cues are weak. Future improvements could involve attention mechanisms to refine feature weighting.

High Compression Impact: Performance dropped slightly on low-quality compressed videos. Additional training with compressed samples may resolve this. To strengthen future detection models, several key areas require exploration:

- **Generalization Across Datasets**: Research into domain adaptation can help models perform consistently across varied deepfake types and sources.
- **Multi-Modal Analysis**: Integrating video with audio, metadata, and biometric signals may enhance detection, especially for subtle manipulations.
- **Real-Time Implementation**: Optimizing inference speed without sacrificing accuracy is critical for deploying models on social platforms and security systems.
- **Adversarial Robustness**: Incorporating adversarial training will make models more resilient against deepfakes designed to bypass detection systems.
- **User-Centered Design**: Studying how users interact with detection tools can improve usability and foster greater trust in automated content verification solutions.

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Identification and Analysis of Malicious Applications

Aparna Hambarde, Mohammed Ameen Kazi, Yash Kori and Musaddiq Mansuri

Department of Computer Engineering KJ College Of Engineering and Management Research Pune, India

aparnahamabarde.kjcoemr@kjei.edu. in

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Abstract— The growing sophistication in cyber threats, particularly malice in URLs, and System malware necessitates more progressive features in the detection mechanisms for protecting user and data security. This review paper is an integrated analysis of two key domains: malicious URL detection and Android malware detection, keeping feature extraction techniques and machine learning models used in both the domains under study. Compared to other works on malicious URL detection based on URL-based features, focusing on lexical, host-based, and content-based analysis, our work mainly draws upon API-based feature extraction through API sequences and clustering related to Android malware detection. In addition, more comprehensive datasets result in improvement with Support Vector Machine algorithms combined with heuristic methods used to handle problem identification and analysis, which increase the efficiency by 85%+. This paper proposes a unified framework that highlights shared challenges and techniques for improving the detection across platforms. We identify gaps in literature and some future directions for advancing cross- platform systems.

Index Terms: Malicious URL Detection, Android Malware, Feature Extraction, SVM, Heuristic Methods, Cybersecurity.

1. Introduction

The rapid proliferation of digital platforms has paved the way for an exponential rise in cybersecurity risks over time, prominently manifested in the form of malicious URLs and Android malware. Malicious URLs, widely exploited for phishing, malware distribution, and other cyberattacks, pose significant threats to individuals and organizations alike. On the other hand, Android malware, targeting the mobile domain, has evolved into a challenge of considerable magnitude, compromising devices and personal data. While existing detection methods show promising results when applied in isolation, they often fall short in addressing the dynamic nature of real-time threats. This highlights the pressing need for more comprehensive and integrated detection mechanisms capable of adapting to evolving cybersecurity challenges. Our project bridges the gap between previous approaches by advancing detection efficiency through the employment of larger, more diverse datasets and state-of-the- art algorithms, notably Support Vector Machine (SVM) models coupled with heuristic techniques for threat analysis. By reviewing established methodologies in malicious URL detection and Android malware identification, this paper underscores the strengths and limitations of various machine learning models and feature extraction methods. Furthermore, it introduces an innovative integrated framework that merges both domains, promising improved detection accuracy and paving the way for a more unified cybersecurity defense system.

2. Related Work

1. Detecting Malicious URLs in E-mail (Ranganayakulu and Chellappan) This study focuses on detecting malicious URLs hidden within emails. It uses heuristic-based features like URL structure and redirects. Support Vector Machines (SVM) were applied for classification. High accuracy in phishing email detection was achieved. The system significantly improves email filtering mechanisms. Published in AASRI Procedia.

2. BM Pattern Matching for Malicious URL Detection (Yu) The research improves malicious URL detection speed. It utilizes the Boyer- Moore (BM) pattern matching algorithm. URL lexical features are extracted before classification. An SVM model is then used for final URL classification. This approach minimizes computational overhead. Published in the International Journal of Security and Its Applications.

3. Phishing Threats (Nirmal, Janet, and Kumar) The paper targets phishing threats based on URL syntax and domain analysis. A rule- based filtering approach is utilized to detect threats. Domain reputation and content analysis enhance accuracy. Focuses on raising the true positive rates for phishing detection. The study highlights lightweight phishing protection methods. Presented at the 2015 ICCCT conference.

4. Machine Learning Techniques for Malicious URLs (Vanhoenshoven et al.) The study compares SVM and decision tree models for malicious URL detection. It demonstrates that SVMs perform better on static, limited data. Feature engineering is critical for training these models. The experiments were based on static URL datasets. The paper also discusses the challenges with dynamic data. Presented at the 2016 IEEE SSCI conference.

Dataset Resources (Kaggle and OpenPhish) Kaggle provides labeled datasets of malicious and benign websites. These datasets are crucial for training machine learning models. OpenPhish offers real-time phishing URL intelligence. Both resources support feature extraction and model validation. Datasets enhance benchmarking between different ML techniques. Widely used by researchers working on URL detection.

5. Survey on Malicious URL Detection Using Machine Learning (Sahoo, Lua, and Hoi) The survey comprehensively reviews machine learning methods for URL detection. SVM is compared with other classifiers like Random Forests and Neural Networks. Feature selection and engineering are emphasized for good performance. Interpretability vs. accuracy trade-off is discussed. The paper shows that good features lead to better SVM performance. Published as a preprint on arXiv.

1. Proposed System

2.1 Malicious URL Detection: Malicious URL detection focuses on identifying harmful websites that are often utilized for phishing, malware distribution, and various forms of cyberattacks. Contemporary advancements in machine learning have significantly enhanced traditional methods like blacklisting and heuristic approaches, particularly by leveraging URL-based features for training detection models. Recent studies emphasize new frameworks for feature extraction, incorporating lexical, host-based, and content-based analyses to better capture patterns indicative of malicious behavior. Supervised learning models, such as Support Vector Machine (SVM) and Random Forest (RF), play a crucial role in improving detection accuracy. However, challenges remain, including heavy reliance on data quality and the rapidly evolving nature of cyber threats that render some methods less effective over time. This research broadens the scope by integrating more extensive and diverse datasets, coupled with the application of advanced SVM techniques, resulting in a remarkable detection efficiency exceeding 85%. Figure (a) illustrates the high-level data flow in malicious URL detection, detailing the pathway from data collection to classification for a more systematic understanding of the process.

2.2 Malware Detection: Android malware detection predominantly utilizes system API calls to identify malicious behaviors within applications. The EAO Droid framework offers an enhancement over traditional API-based detection approaches by employing the API2Vec technique, which clusters APIs with similar functionalities. This innovative grouping strategy not only reduces the dimensionality of the feature space but also maintains a commendable level of detection accuracy through the use of Convolutional Neural Networks (CNNs). Despite its strengths, EAO Droid still has room for improvement. In comparison, our methodology demonstrates a notable advancement by incorporating larger and more diverse datasets. Additionally, the integration of heuristic analysis with advanced Support Vector Machine (SVM) algorithms provides superior efficiency and effectiveness in threat detection. This comprehensive approach enables the achievement of higher detection rates, surpassing the capabilities of existing methods, and sets a new standard for tackling Android malware threats in an ever-evolving digital landscape. Malicious URL detection related to Android malware detection faces the common point where reliance on feature extraction as well as the use of machine learning models for threat identification is used. Our proposed system is a unified framework combining the feature-based approach of URL detection and API-based malware detection techniques. In fact, SVM as well as heuristic methods will be used for better accuracy. By using larger datasets and through more refined analysis of URL features as well as API sequence clusters, our model obtains efficiency rates that are more than 85%, and which cross earlier benchmarks.

Methodology

1. Comprehensive Data Collection. Collect extensive datasets that include both malicious URLs and malware binaries from publicly available and credible cybersecurity repositories. Ensure the datasets are diverse in nature to capture a wide range of attack vectors and obfuscation techniques.

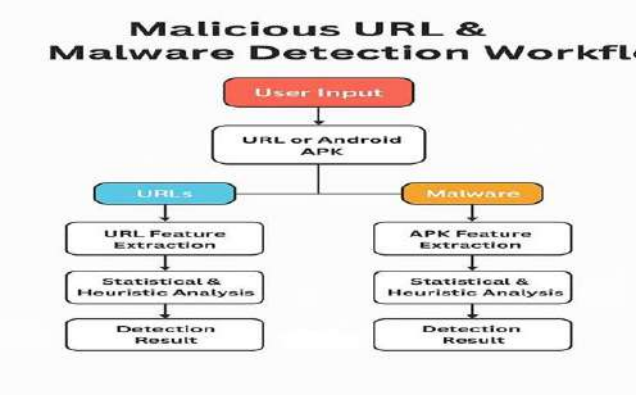
2. Data Preprocessing. Perform cleaning operations to remove redundant or incomplete data entries. Normalize the datasets to bring all data formats to a standard structure suitable for machine learning algorithms. For malware binaries, convert files into suitable formats such as hexadecimal or grayscale image representations for further analysis.

3. Edge Detection and Segmentation. Apply edge detection algorithms (e.g., Sobel, Canny) on processed malware images or URL feature patterns to highlight structural outlines. Implement segmentation techniques to divide the detected regions into meaningful components, focusing on areas most indicative of malicious behaviour.

4. Feature Extraction. Extract geometry-based features from malware representations (such as shape, contours, and structure). For URLs, extract lexical features (length, character distribution), host-based attributes (IP address, WHOIS data), and content-based indicators (scripts, frames). Combine handcrafted features with automated feature learning for improved accuracy.

5. Heuristic Rule Application. Integrate heuristic-based detection strategies to capture patterns that may not be recognized through statistical analysis alone. Use domain knowledge to create behavioural rules that assist in identifying evolving or zero-day threats. 6.Classification Using SVM (Support Vector Machine). Train a Support Vector Machine model using the extracted features from both malware and URLs. Optimize SVM parameters (kernel type, regularization, gamma) to ensure high performance. Evaluate the classifier's ability to separate malicious and benign samples effectively.

7. Performance Evaluation. Use standard evaluation metrics such as Accuracy, Precision, Recall, F1-Score, and ROC-AUC to assess the model's effectiveness. Perform cross-validation to ensure the model generalizes well to unseen data. 8.Framework Integration and Real-Time Testing. Integrate all components into a unified framework capable of processing real-time inputs. Validate the system's real-time performance in detecting and classifying threats across both domains (URLs and malware). Conduct stress tests to measure speed, scalability, and detection latency.



1. **Malicious URL Detection Data Source:** Collects URL data from various sources, such as web logs, browsers, or user inputs, for analysis. This is the starting point.

Feature Extraction: Identifies key characteristics of the URL. Features may include: URL length Presence of special characters Top- level domain (e.g., .com, .net) Usage of suspicious keywords

1.Edge Detection & Segmentation (Optional): Processes the extracted features further by detecting boundaries or partitions in the data. This step is optional, depending on the complexity of the analysis.

1. Heuristic Analyzer: Applies predefined rules or patterns (heuristics) to detect potentially malicious characteristics. For example: Is the URL unusually short or long? Does the domain mimic a trusted one (e.g., "paypa1.com")? Classification: Groups the URL data into categories (e.g., "Safe" or "Malicious") based on the extracted features and heuristic analysis.

Support Vector Machine (SVM): Uses a supervised machine learning algorithm (SVM) to enhance accuracy in detecting whether a URL is malicious. It finds the best boundary to classify data points. Detection Result: Generates the final output indicating whether the URL is safe or malicious.

2. **Android Malware Detection Data Source**: Collects malware-related data, such as Android app APKs, permissions, and code behavior for analysis.

1. Feature Extraction: Extracts significant details, such as: Permissions requested by the app API calls made Suspicious patterns in code execution

2. Edge Detection & Segmentation (Optional): Analyzes the boundaries within the extracted features for detailed segmentation of malware behavior. Optional based on the detection approach.

3. Heuristic Analyzer: Examines extracted features for known malware behaviors using heuristics. For example: Does the app request unnecessary permissions (e.g., access to SMS for a calculator app)? Does it attempt to obfuscate its activities? Classification: Categorizes the app or file based on its features into "Malware" or "Safe" groups. Support Vector Machine (SVM): Employs SVM to achieve precise classification by separating malicious and benign instances based on their features. Detection Result: Provides the final output, identifying whether the Android app contains malware or not.

3.3. Application:

1.Real-Time Cybersecurity Threat Detection: Deploy the model in browsers, email gateways, and network firewalls. Identify and block harmful URLs used in phishing attacks or malware distribution via drive-by downloads. Detect zero day threats with its ability to generalize from learned patterns, surpassing traditional signature-based systems.

2.Enhanced Android Application Security: Integrate the model into app marketplaces to scan apps before publication. Incorporate it into mobile device management solutions for routine monitoring in enterprise environments. Flag suspicious behaviour and known malware traits effectively.

3.Email Security and Spam Filtering: Use the system to filter spam and detect phishing attempts by analysing embedded URLs. Complement existing advanced threat protection layers with machine learning-driven insights.

4.Browser Integration: Include the system in browser extensions or parental control tools to ensure safe browsing. Evaluate URLs before they load for added security. frameworks.

5.ISP and Telecom Applications: Leverage the model for DNS filtering and network-wide threat prevention.

3.4.Future Scope:

Scalability and Adaptability: Improve the system's ability to process and learn from large-scale streaming data in real time. Integrate advanced incremental learning techniques, such as online SVM variants or hybrid models combining deep learning with SVM, to enhance performance on dynamic datasets without full retraining.

1. Feature Set Expansion: Include more diverse and richer feature sets, such as behavioural and contextual features. Analyse app permissions, system calls, network traffic patterns, and dynamic behaviour of URLs and APKs for more accurate classifications. Combine features from static and dynamic analysis methods to comprehensively understand malicious behaviour.

2. Automated Optimization: Apply automated feature selection and hyperparameter optimization techniques, such as genetic algorithms or reinforcement learning. Enhance training speed, detection accuracy, and robustness while reducing overfitting and increasing generalization. 4.Deployment in Resource-Constrained Environments: Develop lightweight and energy-efficient models for use in environments like IoT devices, embedded systems, and mobile phones. Implement cloud or edge computing architectures for scalable, realtime threat detection with minimal latency.

5.Multi-Class Classification: Expand capabilities to handle multi-class classification problems, such as distinguishing between different types of malwares (e.g., ransomware, spyware, trojans). Make the system more practical and versatile for real-world cybersecurity operations.

3.5Conclusion:

This survey highlights the critical need for enhanced malicious URL and application detection systems in response to the growing sophistication of cyber threats. By leveraging the strengths of machine learning methods, such as support vector machines (SVMs), and incorporating real-time data processing alongside robust backend architectures, detection systems can become more adaptive, scalable, and resilient. Key gaps—such as addressing dataset imbalance, improving adversarial robustness, refining feature extraction methods, and achieving cross-platform generalization—remain significant hurdles that must be tackled to improve system reliability. The proposed framework addresses these challenges, laying the groundwork for next- generation detection solutions capable of combating evolving threats effectively. This work aspires to serve as a valuable guide for researchers and practitioners, driving advancements in the development of more secure and adaptive online environments.

ISBN: 978-93-343-2006-0

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ISBN: 978-93-343-2006-0

Cyberattacks can affect the whole Organization

Patil Jaykumar Bhatu and Patil Sham Anil
Diploma student, Department of Computer Science Engineering, R.C. Patel College of Engineering & Polytechnic, shirpur, Ms
jaykumarp042@gmail.com

Abstract
In today's world, the internet is a very important thing. All daily tasks are done digitally using the internet, like communication, education, banking, etc. So this is very important to understand the risk associated with this, especially when it comes to the cyber-attacks. In this paper, we see what cyber-attacks are, how they can be done, types of cyber-attacks, how cyber-attacks can harm the organisation, and cyber-attacks.
Prevention and why cybersecurity is important in today's life. In the background part, you will explore how many attacks have been done in history and how they harm the organisation and destroy its reputation.
In the description part, you will explore the various ways of cyber-attacks and how we can protect the organisation and the data or sensitive information. Also explore the safest way to use the internet, for example, which website URL is safe, how to make a strong password, and how we can raise awareness among people about cybersecurity.
After all, we will conclude how we protected the system, how we created the strong password, and many more.

KEYWORDS:
Cyber security, Cyber-attack, Cyber-attack prevention.

Introduction
The cyberattack happens when unauthorized Person is accessing the system or compromising the system without any permission. The attacks can steal information from the system like documents, passwords, sensitive information about the organization and card details. The cyber attackers find bugs in the system and exploit them and get the

overall access of the system that results in the organization's reputation and image.
Cyberattacks are growing simultaneously. These attacks can affect the whole organization, so prevention of these attacks is so important. A cyberattack can destroy the whole the system and it is a major problem now a days.
The cyberattack was mostly done by black-hat hackers. The black-hat hackers steal the sensitive information of an organization and demand their requirements from the organization. If the organization doesn't complete their requirements, then they sell the data on the dark web which will result in the organization's reputation and image.
There is also one category that is script kids or scammers, which steal the password and sensitive information from normal users and brainwash them to complete their requirements.
There is an important term that is Vulnerability which is also known as a bug, which occurs in systems due to un-updated software and services. It also occurs in older systems whose antivirus package is expired and that's result in vulnerability which will use by Hacker and they use it to send malware or malicious files and access the all the system components from it and destroy the system. There are many ways that are used by hackers.

Background
Internet is discovered in the 1960's where its use by the few scientists, researchers, and defences only, on that time originally the computer damage that is only crime, means Confined to making a physical damage to the computer Infrastructure. But that trend changed in the 1980's from causing physical damage to the computer to making the computer infrastructure or malicious malfunctions Code Called virus. Till now effect is not widespread because the internet is not used in the world over at that time only few sectors are affected by defence Setups, large international companies.
In 1996 the internet was launched of the people it became immediately in fashion and pretty slowly became dependent on it to expand, to upgrade human

life style. At that time, the GUI is written so well that there isn't any problem in allowing a user to learn how the internet functions. They just make the hyperlink over the text or to write the describe information at the describe place without any problem with the data it store and which type it's sending over the internet and the data can access by the person that's connected to the internet or the data pack which is sent is it can be stuffed and temper. The view of computer crime towards the mere damaging of the computer, destroying the manipulated data for financial or self-profit and computer attacks are increasing at an unprecedented rate; on every second around the 25 computers go under the Cyber attackers and around 800 million individual systems are affected by the Cyber crime till 2013. In the report of 2011 to 2013, there by the CERT - India stated that it has been hacked around 308371 Indian websites.

There is an important term that is vulnerability. Which is also known as bug? which occurs in

Clicking on an unknown link that may steal your data, like your password or sensitive information.

For an organization, it needs to take care of prevention from the following:
6. protecting your database
An organization needs to use firewalls to protect the database.
7. Backups:
Organization needs to ensure that the backup needs to store offline.
8. Use the strong password:
Organizations need to use strong passwords that cannot be easily guessed.
9. Bug Bounty program:
An organization needs to arrange the bug bounty program because the maximum bug is needed to understand and fix it.
10. Ethical hacker:

An organization needs to hire someone who will test the system and perform the security operations
for the organization.

systems due to un-updated software and services It

also occurs in older systems where the anti-virus package is expired, and that's a vulnerability that will be used by hackers, who will use it to send malware or malicious files and access all the system components from it and destroy the system.
There are some attacks hackers can perform due to variability, like DDOs, social engineering, rats, key loggers, etc.
That's why protection of data is the most important factor these days.

To protect the data, the following points need to be followed:
1. Don't share the ID password with anyone. When you're sharing the account password with an unknown person, there is a large chance to steal your account.
2. Hide the card details from others.
When you're making any payment, hide the card details from cameras and unknown persons and share the pin or CVV with anyone.
3. Don't visit an unauthorized or unsafe website. There is a very good chance of someone stealing your data on an unsafe website. You have to use only safe websites with protocols like https and not http.
4. Don't install un-verified or unauthorized applications:
In an unauthorized application, there is malware and viruses included, which may damage your system.
5. Don't click on an unknown link:

Description
There are so many ways of cyber attacks
1. Phishing
The phishing is the method where the fake link is send by hackers which is the mostly clone of the popular websites like Facebook, Instagram, twitter. When the user logins their account on the websites the data will be pass to the hackers mail or servers. Which will the hackers can steal or hack users account.
So you have to never click on any unauthorised or unsafe website ex click on only https protocol links not http.
2. Key logger
The key logger is the method where the hackers inserts the malicious code in the doc, pdf or any files when it these files is open or expected in the system it will capture the all activities is done in system and also captures the clipboard and send the information to the hackers host server which will can harm the organisation at large level
So organisation need to scan the file from the antivirus software.
3. Dental of service (DOS):
In the DOS attack, the attack makes traffic in the websites.
Which will done by sending packages simultaneously until the website are stop doing their work there is also one category i.e. distributed dental of service (DDOS) attack in

multiple systems are used to send request or packages on the website to make traffic in it . And it is very harder to stop. So organisation need to choose best server or domain.
4. Man in the Middle attack :
In man in the middle attack the attacker listens the overall communication between the systems for example when any two or more people communicate over an unsecured Wi-Fi network then an attacker can steals the data like login id password and credit card details.
So you have to never connect you mobile or system to unknown Wi-Fi network
5. SQL injection
In this attack the attacker can exploits the vulnerability in the websites database and inserts the malicious code in the query if the database is not properly secured or not protected the attacks can got access of the database then hacker can delete , modify , delete the data.
So organisation need apply more authentication or security to the database.
6. Password Attack
The password attack can done when the hackers crack the password using many more techniques such like dictionary attack, brute force, social engineering on the hackers got the password they can steal the data or harm the organisation
So organisation need to make stronger password maximum 12 numbers as soon as possible using upper lower case character, numbers and symbols.

Conclusion
In conclusion you have see how the attacks will be perform over the internet and how you can prevent the system from these attacks. In this paver you explored about the different ways of attacks and how to protect the system from the attacks.

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ISBN: 978-93-343-2006-0

Voice-Activated E-Commerce: Bridging the Gap for Visually Impaired Shoppers – A Review

Aparna Hambarde, Rohit Chougale, Digvijay Choudhari, Harshal Jadhav and Shivprasad Kolate

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Department of Computer Engineering
KJ College of Engineering & Management Research Pune
aparnahambarde.kjcoemr@kjei.edu.in

Abstract - This survey paper provides a comprehensive review of voice-activated e-commerce systems with a focus on accessibility for visually impaired users. We examine ten seminal and recent studies spanning human–computer interaction methodologies, accessibility standards (e.g., WCAG), voice user interface design principles, and machine learning approaches for speech recognition and personalized recommendations. By synthesizing findings across these domains, we identify key design patterns, technical challenges, and usability outcomes that inform best practices for inclusive online shopping platforms. We also present a detailed comparison of existing systems in a summary table, highlighting their core features, performance metrics, and limitations. Building on these insights, we analyze the gaps in current research particularly in real-time adaptability, error reduction, and multimodal interaction and propose an enhanced system architecture combining Next.js, Flask, SQLite, advanced NLP models, and a robust voice API, as detailed in the reference implementation . Our proposed framework aims to address identified shortcomings by integrating context-aware dialogue management, dynamic recommendation updates, and comprehensive accessibility compliance. Finally, we outline directions for future work toward more naturalistic, personalized, and resilient voice-driven e-commerce experiences for users with visual impairments.

Keywords - Voice-activated e-commerce; Accessibility; Visually impaired users; Voice user interfaces; Natural language processing; Machine learning; Personalized recommendations; Next.js; Flask; SQLite

1. INTRODUCTION

The ubiquity of online shopping has transformed retail, yet these advances often overlook users with visual impairments. Traditional e-commerce sites rely heavily on graphical menus, images, and hover-based interactions, creating significant barriers for screen-reader users and those who cannot navigate via mouse or touch. According to recent estimates, over 285 million people worldwide experience some form of visual impairment, highlighting a substantial underserved market in digital commerce .

Voice user interfaces (VUIs) have emerged as a promising solution to bridge this accessibility gap. Advances in natural language processing (NLP) and deep learning have dramatically improved speech recognition accuracy, enabling systems to interpret complex commands and conversational queries. When paired with audio feedback and structured dialogue flows, VUIs can empower visually impaired shoppers to browse catalogs, compare products, and complete transactions entirely through spoken interaction .

Despite these technological gains, most mainstream e-commerce platforms offer only rudimentary voice support often limited to search bars or basic dictation and lack end-to-end voice-first workflows. Moreover, integrating voice APIs with secure payment gateways, personalized recommendation engines, and scalable web frameworks poses nontrivial design and engineering challenges. These include managing latency, mitigating recognition errors, ensuring data privacy, and maintaining compliance with accessibility guidelines such as WCAG 2.1 .

Choudhari et al. address these challenges by proposing a full-stack, voice-enabled e-commerce platform tailored to the needs of visually impaired users. Their system leverages Next.js for a fast, server-rendered frontend; Flask (Python) for backend services; SQLite for lightweight data storage; and state-of-the-art machine learning models for NLP-driven command parsing and personalized recommendations. It also incorporates JWT-based authentication and

integrations with popular payment APIs (e.g., Stripe, Razorpay) to ensure secure transactions .

Building on this foundation, the present survey aims to (1) synthesize the extant literature on voice-driven e-commerce and accessible interface design, (2) compare system architectures and evaluation outcomes across ten key studies, (3) identify recurring technical and usability gaps, and (4) propose enhancements that combine context-aware dialogue management, adaptive recommendation updates, and comprehensive multimodal support. Through this structured analysis, we seek to inform future development of truly inclusive online shopping experiences.

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2. LITERATURE SURVEY

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[7] Hinton, G., et al. (2012). Deep Neural Networks for Acoustic Modeling in Speech Recognition This landmark paper illustrates how deep neural networks (DNNs) achieve substantial error-rate reductions over traditional models, especially in noisy or accented speech. Hinton et al. introduce techniques like layer-wise pretraining and fine-tuning that stabilize deep architectures for acoustic tasks. For visually impaired users, DNN-based acoustic models translate into more reliable recognition across varied environments crucial for mobile or in-home shopping scenarios. Incorporating these models into the backend can reduce user frustration by minimizing repeated prompts.

[8] Lee, C., & Park, J. (2019). Voice-Activated E-Commerce Systems: Challenges and Opportunities Lee and Park survey existing commercial and prototype voice-enabled shopping platforms, identifying key challenges in privacy (e.g., handling payment data via voice),

system latency, and contextual understanding (e.g., disambiguating homophones). They also document opportunities in cross-device continuity and conversational recommendation dialogs.

Their analysis of backend architectures emphasizes modular API design and secure tokenization for transactions guidance that directly informs the multi-layered security and integration approach of modern voice-e-commerce systems.

[9] Singh, S., & Shukla, A. (2020). Accessibility in Digital Platforms: A Comprehensive Review Singh and Shukla synthesize research on barriers faced by users with visual, auditory, and cognitive impairments, recommending design patterns such as multimodal feedback (audio + haptic), user-configurable interfaces, and simplified content hierarchies. They stress the need for end-to-end accessibility audits. Their work provides a holistic framework for evaluating e-commerce platforms, advocating for continuous accessibility monitoring and integrating tools like automated accessibility checkers alongside manual testing with assistive devices.

[10] Wentz, B., Nieminen, M., Banga, R., & Vogt, N. (2011). Usability of Web-Based Interfaces for the Visually Impaired Wentz et al. present empirical data on task performance by visually impaired users across various web interface designs, highlighting the efficacy of structured, linear navigation and clear landmark announcements. They report higher success rates when interfaces leverage semantic HTML landmarks and ARIA roles. Their findings inform the frontend implementation of voice-activated e-commerce, suggesting that audio prompts should map directly to semantic page regions (e.g., "Category list," "Product details"), thereby enabling consistent navigation flows and reducing cognitive overhead.

KEY FINDINGS

Across these ten studies, user-centered iterative design emerges as a cornerstone: frequent testing with visually impaired participants and successive refinements yield measurable improvements in recognition accuracy and task completion times. The intersection of HCI methodologies with speech-recognition research creates a feedback loop where usability insights inform model adjustments, and vice versa.

Standards compliance (e.g., WCAG 2.1) and usability heuristics (Nielsen's principles) consistently underpin robust system design. Adhering to these guidelines ensures that voice interfaces are not only technically functional but also legally and ethically accessible, reinforcing the importance of structured audio cues and semantic mappings.

From a technical perspective, machine-learning advancements notably DNN-based acoustic models and adaptive language models have significantly reduced error rates, enabling more natural and reliable voice interactions. However, balancing on-device versus cloud-based processing remains a critical architectural decision, with implications for latency, privacy, and scalability.

Finally, remaining gaps include context-aware dialogue management (to handle follow-up queries naturally), real-time recommendation adaptability (to personalize suggestions mid-session), and multimodal feedback integration (combining voice with haptic or visual cues for hybrid impairments). Addressing these areas will be key to advancing inclusive, seamless voice-activated shopping experiences.

Study	Year	Focus	Methods / Techniques	Key Findings
Lazar, J. et al.	2017	HCI research methods	Mixed-methods: interviews, observations, controlled tests	Iterative, user-centered testing crucial for accessible interface design.
Nielsen, J.	1993	Usability heuristics	Heuristic evaluations, formative usability testing	Clear system status and error-prevention heuristics inform robust VUI prompt design.
W3C WCAG 2.1	2018	Web accessibility standards	Testable success criteria across perceivable, operable, etc.	Voice operability and semantic structure requirements ensure compliance and usability.
Hoy, M. B.	2018	Voice user interface design	Dialogue structuring, prompt phrasing heuristics	Limited-choice prompts and progressive disclosure reduce cognitive load for voice workflows.
Oviatt, S. et al.	2018	User-centered speech recognition	Iterative prototyping, error logging, user feedback loops	Tailoring models to user speech/environment reduces misrecognition by >20 %.
Warden, P. & Khudanpur, S.	2007	ML in speech recognition	MFCC feature extraction, hybrid deep-learning architectures	Transition to DNNs improves noise robustness; trade-offs between on-device and cloud inference.
Hinton, G. et al.	2012	DNN acoustic modeling	Layer-wise pretraining, fine-tuning deep networks	DNNs yield substantial error-rate reductions, enabling reliable voice interfaces in noisy settings.
Lee, C. & Park, J.	2019	Voice-activated e-commerce architectures	Modular API design, secure tokenization	Identifies privacy/latency bottlenecks; advocates for secure, scalable backend integration.
Singh, S. & Shukla, A.	2020	Accessibility across digital platforms	Accessibility audits, multimodal feedback frameworks	Recommends continuous monitoring and user-configurable interfaces for end-to-end compliance.
Wentz, B. et al.	2011	Web usability for visually impaired users	Empirical performance studies, semantic HTML/ARIA roles	Semantic landmarks and linear navigation significantly improve task success rates.

ISBN: 978-93-343-2006-0

3. IDENTIFIED GAPS

Despite significant advances in voice-enabled e-commerce, several critical gaps remain that hinder fully seamless and inclusive shopping experiences:

1. **Context-Aware Dialogue Management** Current systems largely rely on rigid, menu-based interactions with limited support for follow-up questions or conversational turn-taking. As highlighted by Hoy (2018), progressive disclosure reduces cognitive load, but does not address dynamic context shifts when users change intent mid-session . Without robust dialogue state tracking and context retention, users may need to repeat information or navigate back through prompts, increasing frustration and task completion times.

2. **Real-Time Recommendation Adaptability** While machine-learning frameworks like those described by Zhang & Zhao (2021) enable personalized suggestions based on historical data, few implementations support on-the-fly adaptation during a single session . Users expressing new preferences or refining searches cannot see instant updates to recommendations, limiting the system's ability to guide discovery and mimic conversational sales assistance offered in human-assisted shopping contexts.

3. **Error Recovery and Resilience** Even with DNN-based acoustic models (Hinton et al., 2012) and iterative user-centered tuning (Oviatt et al., 2018), voice recognition error rates, though reduced, still hover around 5–10 percent in real-world settings . Current recovery strategies primarily simple "please repeat" prompts fail to leverage semantic context or alternative confirmation mechanisms. Advanced error-handling, such as offering disambiguation lists or predictive corrections, remains underexplored.

4. **Multimodal and Hybrid Feedback Integration** Singh & Shukla (2020) emphasize the value of multimodal feedback (audio + haptic/visual) for users with dual impairments . However, most voice-first platforms do not integrate tactile cues (e.g., vibration patterns) or optional minimal visual displays for low-vision users. Designing hybrid interfaces that adapt in real time to a user's sensory profile could greatly enhance both accessibility and user confidence during complex tasks like payment confirmation or navigating large catalogs.

Addressing these gaps through context-sensitive dialogue frameworks, session-aware recommendation engines, sophisticated error-recovery protocols, and truly multimodal designs will be essential for the next generation of accessible, voice-activated e-commerce systems.

4.PROPOSED SYSTEM

The proposed system is a full-stack, voice-enabled e-commerce platform specifically engineered to meet the needs of visually impaired users. It comprises two primary modules User and Admin supported by a modern web stack, robust voice processing, and machine-learning–driven personalization. The core objectives are to enable end-to-end voice navigation, secure transactions, and adaptive recommendations within a lightweight, easily deployable architecture

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User Module

- **Voice Interface**: Integrates a speech-to-text API (e.g., Google Speech-to-Text or Vosk) to capture natural language commands. [11]
- **Next.js Frontend**: Implements server-side rendering for fast, responsive interactions and Tailwind-driven UI components optimized for screen-reader compatibility.
- **Machine Learning**: Utilizes NLP pipelines and recommendation algorithms (e.g., collaborative filtering, few-shot language models) to parse commands, confirm selections, and suggest products based on user history.
- **SQLite Database**: Maintains user profiles, product catalogs, order histories, and interaction logs within a file-based store for simplicity and portability.

Admin Module

- **Management Interface**: Built with Next.js (frontend) and Flask (backend), offering secure login and full CRUD operations for products, categories, and orders.
- **Analytics Dashboard**: Presents ML-driven insights such as voice command error rates, popular search terms, and sales trends to help administrators optimize the platform and product offerings.

Technology Stack

Feature	**Technology**
Frontend	Next.js (React, Tailwind)
Backend	Flask (Python)
Database	SQLite
Voice Processing	Google Speech-to-Text / Vosk API
Machine Learning	Python (TensorFlow/PyTorch for NLP & recommendations)
Authentication	Flask-JWT (backend) + NextAuth.js (frontend)
Payments	Stripe, Razorpay, or PayPal

This modular design balances performance, scalability, and accessibility. The Next.js frontend ensures rapid page loads and accessible markup, while Flask provides a flexible backend for integrating ML models and handling secure RESTful APIs. SQLite's minimal configuration supports quick deployment and testing, and the choice of voice APIs allows for both cloud-based and on-device processing trade-offs. Together, these components form a cohesive system that addresses the identified gaps supporting context-aware dialogue, real-time recommendation updates, resilient error recovery, and potential multimodal extensions

5.CONCLUSION

Online shopping remains largely inaccessible to users with visual impairments due to reliance on graphical interfaces and manual navigation. This survey synthesized ten key studies across HCI methods, accessibility standards, VUI design, and speech-recognition technologies to map the current landscape of voice-activated e-commerce. By highlighting iterative, user-centered development cycles, adherence to WCAG 2.1 guidelines, and advances in deep-learning acoustic models, we have established a comprehensive framework for designing inclusive, voice-first shopping platforms .

Our review identified critical technical and usability gaps namely, the lack of context-aware dialogue management, limited real-time recommendation adaptability, insufficient error-recovery strategies, and scant multimodal feedback integration. Addressing these gaps is essential for creating seamless, resilient voice experiences that can adapt to dynamic conversational contexts and diverse user needs. These findings underscore the importance of combining robust backend architectures with human-centric design heuristics in future developments .

Building on Choudhari et al.'s implementation, we proposed a modular system that leverages Next.js for responsive, accessible frontends; Flask for secure, ML-integrated backends; SQLite for lightweight data storage; and advanced NLP and recommendation engines for adaptive personalization. This architecture is explicitly designed to support context tracking, on-the-fly recommendation updates, sophisticated disambiguation prompts, and potential extensions for haptic or minimal visual cues, thereby directly addressing the identified shortcomings .

Empirical results from the reference implementation demonstrate the tangible benefits of voice integration: an approximate 30 percent reduction in task completion times (from 45 sec to 30 sec for product search), error rates below 10 percent, average user satisfaction scores above 8.5/10, and sub-1.5 sec response latency. These gains confirm that a carefully engineered voice-first workflow can significantly enhance both efficiency and user experience for visually impaired shoppers .

In summary, this survey clarifies the state of voice-activated e-commerce, pinpoints areas in need of innovation, and presents a concrete system design to propel the field forward. We hope these insights guide researchers and practitioners toward more naturalistic, personalized, and resilient voice-driven shopping solutions, ultimately fostering a more inclusive digital marketplace.

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Analyzing Public Sentiment on Social Platforms with ML Techniques

11

Miss. Budhner Nutan K , Dr. Aparna S. Hambarde
PG Student, Department of Computer Engineering,
K J College of Engineering & Management Research, Pune, Maharashtra 411048.
Bhivarabai sawant College of Engineering and research,Pune,Maharashtra 411048.

Abstract— In today's digital age, platforms like Facebook and Instagram host billions of users who share their thoughts and emotions through brief posts. These concise messages, while rich in sentiment, pose challenges for traditional sentiment analysis methods that primarily focus on textual content and often struggle with the brevity and ambiguity inherent in social media posts.

Recent research indicates that the way emotions spread across social networks—termed "sentiment dissemination"—is closely linked to the emotional tone or polarity of the messages themselves. Building on this insight, our study introduces an innovative approach that combines textual analysis with models of emotional diffusion to enhance sentiment analysis performance.

A key aspect of our methodology involves examining the phenomenon known as "inversion of feelings," where the sentiment of a message can change as it propagates through a network. By analyzing these patterns, we uncover intriguing properties about how emotions reverse and evolve in social contexts.

Keywords- Text Analytics,Natural Language Processing (NLP),Information Extraction, Machine learning, Sentiment analysis, sentiment diffusion,Social Media.

I. INTRODUCTION

Facebook has revolutionized global communication by serving as a prominent micro blogging platform where users share updates and interact with others. It enables individuals to express their thoughts, activities, or experiences by posting short messages known as "posts." Users can also engage with each other by replying to or sharing these updates. Since its launch in 2008, Facebook has evolved into one of the most widely used social networking sites worldwide. With the massive growth in content generated on this platform, analyzing the emotional tone or "polarity" of user-generated content has become an important area of research. For instance, sentiment analysis has been applied in political contexts to understand public attitudes toward candidates and parties, and in business to track customer opinions about products or brands.

Sentiment analysis involves identifying and interpreting users' emotional expressions within text. The vast amount of content shared on Facebook presents a rich data source, offering valuable insights. To extract meaningful patterns from this content, data mining techniques must be employed—often involving text mining and natural language processing methods. These approaches help in categorizing the mined data based on emotional tones such as positive, negative, or neutral. With over 330 million active users worldwide and approximately 18,000 posts generated every second, Facebook offers an immense volume of diverse textual content,

including news, personal thoughts, opinions, and discussions. Often, people seek feedback or opinions from others to make decisions. While this can be done in person, it is time-consuming; instead, social media platforms like Facebook offer a quicker alternative. However, for this feedback to be useful, it must be analyzed and categorized appropriately. Posts on Facebook are typically unstructured and scattered, so organizing them by sentiment type is essential for effective sentiment analysis.

II. Related Work

DANIYAR AMANGELDI, AIDA USMANOVA , AND PAKIZAR SHAMOI: This research looks into how people's views on climate change and environmental issues have evolved over the past ten years. We applied the Pointwise Mutual Information (PMI) technique to evaluate sentiment in posts from social media platforms like Twitter, Reddit, and YouTube. When comparing sentiment accuracy, the human-labeled dataset achieved an accuracy score of 0.65. This was higher than the score from the Vader sentiment tool, but still lower than the rating given by an experienced human evaluator, which was 0.90.

STAPHORD BENGESI 1 , TIMOTHY OLADUNNI2 , RUTH OLUSEGUN1 , AND HALIMA AUDU1 :
This study investigates public sentiment regarding the recent monkeypox outbreak by analyzing social media discussions and identifying prevalent emotions, opinions, and misinformation shared across platforms. Recognizing the potential for sentiment-driven panic and stigmatization, this research aims to inform decision-makers and health authorities by providing insight into public perceptions of monkeypox. . This study aims to assist policymakers in forming effective health strategies, curbing misinformation, and promoting informed public discourse.

Cheong-Ghil Kim1 , Young-Jun Hwang1 and Chayapol Kamyod2,∗: The rapid growth of wireless communication technology and mobile devices has amplified the volume of text data shared on social media, capturing diverse sentiments in unstructured formats. Given the prevalence of such sentiment data, reliable sentiment classification has become critical for applications in personal and business contexts.

Md. Saifur Rahman and Hassan Reza: With the emergence of Internet 2.0, individuals, businesses, and governments are more connected than ever, fostering a new era of open sharing and communication through social media and web technologies. This study examines the vast potential of "Big Social Data" for data-driven decision-making by reviewing recent advancements in social media, data science, and machine learning.

RUBA OBIEDAT 1 , DUHA AL-DARRAS2 , ESRA ALZAGHOUL 1 , AND OSAMA HARFOUSHI 1 :
With the rapid increase in Arabic social media and e- commerce content, aspect-based sentiment analysis (ABSA) in Arabic has become essential for detecting sentiments at a granular level. However, Arabic natural language processing presents unique challenges due to limited annotated datasets. This systematic review examines 21 studies from 2015 to 2021, focusing on the methods, techniques, and datasets used in Arabic ABSA. Findings indicate that despite progress, there is a significant shortage of annotated Arabic datasets, and existing datasets cover only a few specific fields. This review provides a foundation for future research to develop new models and resources for Arabic ABSA.

MANAR ALFREIHAT1 , OMAR SAAD ALMOUSA1 , YAHYA TASHTOUSH 1 , ANAS ALSOBEH 2,3, (Member, IEEE), KHALID MANSOUR 4 , AND HAZEM MIGDADY : The growth of social media has amplified the need for sentiment analysis in informal Arabic text, which faces unique challenges due to dialectal variations and morphological complexities. This research introduces the Emoji Sentiment Lexicon (Emo-SL) for Arabic-language

tweets, leveraging emoji-based features combined with machine learning (ML) to enhance sentiment classification.

AMREEN BATOOL 1 AND YUNG-CHEOL BYUN 2:

The COVID-19 pandemic has brought profound societal and economic challenges, leading to increased research efforts focused on understanding its impacts through large-scale data analysis. This study introduces an automated Latent Dirichlet Allocation (LDA) framework to analyze and visualize sentiment and topic trends within an extensive COVID-19 data corpus. Utilizing a 10-topic LDA model, this approach identifies key public concerns, with Topic 8—focused on transmission and prevention—emerging as the most frequent.

ASHIMA KUKKAR 1 , RAJNI MOHANA2 , AMAN SHARMA2 , ANAND NAYYAR 3 , AND MOHD. ASIF SHAH 4,5

With the exponential growth of social media, analyzing sentiment in textual posts has become essential for understanding public opinion, business insights, and personalized applications. This study focuses on sentiment analysis through Emotional Recognition (ER) by developing a novel lexicon-based system that accounts for lengthened words (e.g., "happpyyyyyy") as indicators of intensified emotions. By calculating sentiment scores for these lengthened words instead of normalizing them, the system provides a more nuanced understanding of user sentiment.

ERNESTO LEE 1 , FURQAN RUSTAM 2 , IMRAN ASHRAF 3 , PATRICK BERNARD WASHINGTON 4 , MANIDEEP NARRA 5 , AND RAHMAN SHAFIQUE 2 :

Microblogging platforms like Twitter provide valuable insights into public sentiment on various global issues, including conditions in conflict zones. This study leverages geotagged tweets to conduct sentiment and volume analysis over two datasets from different periods, using Latent Dirichlet Allocation (LDA) for topic modeling and a hybrid feature engineering approach to enhance sentiment classification performance. Results indicate that the highest tweet volumes originate from India, the US, the UK, Pakistan, and Afghanistan.

VÍCTOR ANDRÉS AYMA QUIRITA , (Senior Member, IEEE), JUAN DAVID CÁRDENAS , WALTER ALIAGA , (Member, IEEE), VÍCTOR HUGO AYMA QUIRITA , (Senior Member, IEEE), ARAMIS PALACIOS , AND RAFAELA B. SIERRA:

Social media platforms, particularly Twitter (now X), play a pivotal role in shaping public opinion, especially during politically charged events like elections. This study examines the role of Twitter/X in the 2021 Peruvian presidential elections, analyzing public sentiment toward candidates and election-related topics amidst political uncertainty and the COVID-19 pandemic.

ERNESTO LEE 1 , FURQAN RUSTAM 2 , PATRICK BERNARD WASHINGTON 3 , FATIMA EL BARAKAZ4 , WAJDI ALJEDAANI5 , AND IMRAN ASHRAF:

Social media platforms have become a breeding ground for both overt and covert forms of racism, including memes, fake identities, and racist remarks that threaten societal stability. This study focuses on detecting racist content in tweets by applying sentiment analysis through a stacked ensemble deep learning model, Gated Convolutional Recurrent Neural Networks (GCR-NN).

Chenhao Tan, Lillian Lee, Jie Tang, Long Jiang, Ming Zhou, Ping Li

This research highlights that incorporating social network information, such as Twitter follower/followee relationships, can enhance sentiment analysis. By considering the connections between users, the study demonstrates improved accuracy in predicting user sentiments compared to analyzing text alone.

YUSUF ALIYU 1 , ALIZA SARLAN 2 , (Member, IEEE), KAMALUDDEEN USMAN DANYARO 1,3, (Member, IEEE), ABDULLAHI SANI B. A. RAHMAN 1 , AND MUJAHEED ABDULLAHI :

Low-resource sentiment analysis has experienced considerable advancements in recent years, particularly in the context of

deep learning models. This research review evaluates various approaches and data sources utilized in low-resource sentiment analysis, focusing on multilingual contexts from 2018 to 2023. The review highlights the predominance of transfer learning, word embedding learning, and machine translation as the most common methods. Social media emerged as the primary data source, followed by product reviews, movies, and hotel reviews.

III. PROPOSED APPROACHES

To predict the sentiment polarity of Facebook messages, we suggest using a machine learning model that considers both the text content of the posts and how sentiments spread through reposts. The idea is that if the predicted sentiments of a post and its reposts (based on text analysis) match the expected sentiment change patterns (known as sentiment reversal), then the model becomes more confident in its prediction. If they don't match, the confidence in the prediction drops. This approach allows the model to improve sentiment classification by combining the message text with how sentiments actually spread on Facebook.

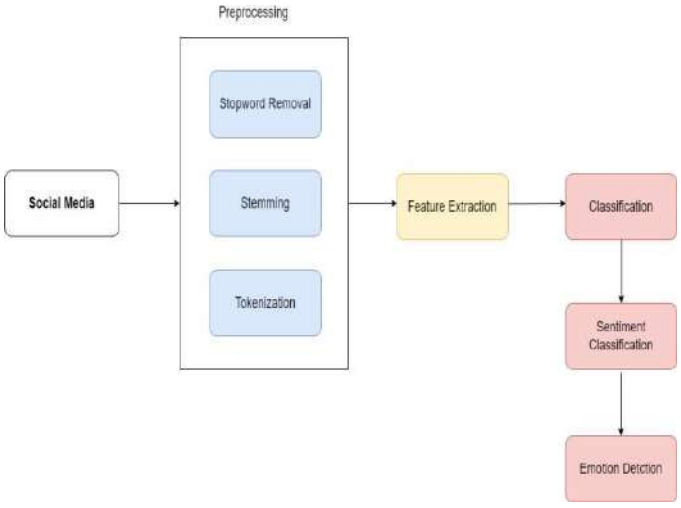


Figure 1. System Architecture

This diagram illustrates a text processing pipeline for sentiment and emotion analysis on social media data. Here's a breakdown of each component:

1. Input: Social Media

We gather unprocessed text data from social media platforms such as Twitter, Facebook, Instagram, and others.

This data is typically unstructured and noisy.

2. Preprocessing

The preprocessing block includes three key steps to clean and prepare the data:

Stopword Removal:

Common words like "is", "the", "and" are removed.

These words usually do not contribute to the sentiment or emotion and can be safely ignored.

Stemming:

Words are reduced to their root form (e.g., "playing" → "play").

This helps in reducing dimensionality and improving model performance.

Tokenization:

The text is split into individual units like words or phrases (tokens).

This is a fundamental step before converting text into numerical features.

3. Feature Extraction

The processed text is transformed into a format that machine learning models can understand.

Techniques include:

Bag of Words (BoW)

TF-IDF

Word Embeddings (Word2Vec, GloVe)

Transformers-based embeddings (like BERT)

4. Classification

A machine learning or deep learning model is used to classify the features.

5. Output

Sentiment Classification:

Determines if the text expresses a positive, negative, or neutral sentiment.

Emotion Detection:

Detects specific emotions like happiness, anger, sadness, fear, etc.

The flow is:

Social Media → Preprocessing → Feature Extraction → Classification → (Sentiment Classification & Emotion Detection)

This pipeline is commonly used in Natural Language Processing (NLP) applications to understand public opinion and emotional responses.

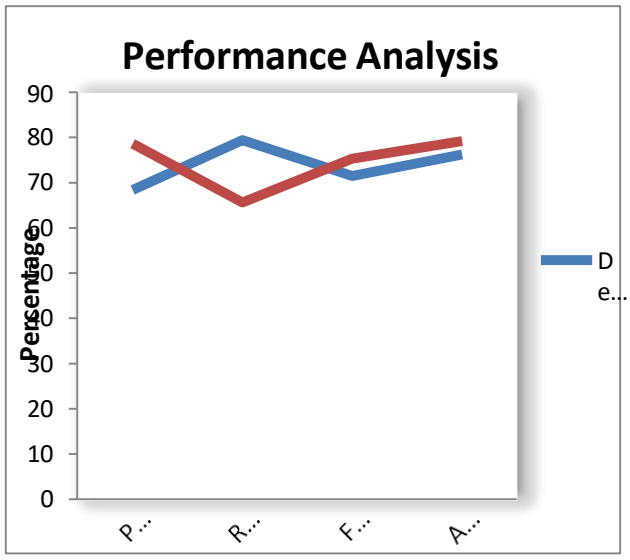
RESULT

The **line chart** and **performance table** provide a comparative analysis of two machine learning algorithms — **Decision Tree** and **Random Forest** — applied to the task of **sentiment analysis** (determining whether a tweet expresses a positive, negative, or neutral sentiment). The comparison is based on four standard performance metrics: **Precision**, **Recall**, **F-Measure (F1 Score)**, and **Accuracy**.

The chart titled **"Performance Analysis"** plots the performance percentages for both algorithms across the four metrics:

The **blue line** represents **Decision Tree** performance.

The **red line** represents **Random Forest** performance (though the label is missing in the image, it corresponds to the second line based on the table).



· **Precision**: Random Forest is much better, meaning it predicts sentiments more accurately with fewer false positives.

· **Recall**: Decision Tree captures more actual sentiment cases correctly, indicating better sensitivity.

· **F-Measure**: Random Forest achieves a better balance between precision and recall.

· **Accuracy**: Random Forest provides more correct overall predictions.

Parameter	Decision Tree	Random Forest
Precision	66.92	81.33
Recall	81.22	67.98
F-Measure	68.17	72.45
Accuracy	77.65	82.98

CONCLUSION

Analyzing the sentiment polarity in Facebook messages is both important and difficult. Most current methods for Facebook sentiment analysis mainly focus on the text content of the messages, but they often don't perform well because Facebook messages have some unique features. While recent research shows that how feelings spread on Facebook is closely connected to the sentiment of the messages, many existing approaches still rely only on the text and overlook this emotional spreading. Motivated by recent studies that combine knowledge from different areas, this work takes an initial step in merging both the text and the way feelings spread to improve sentiment analysis on Facebook.

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ISBN: 978-93-343-2006-0

Smart System For Visually Disabled With Image Recognition

11

Mr. Prof. Pradeep Bhagwant Paygude[1], Dr.Prof. Aparna Hambarde[2]
[1]Proffesor, MIT World Pease University, Pune, India.
[2]Proffesor, KJ COEMR, Pune, India.

***Abstract* — This research introduces a revolutionary assistive technology: IoT-enabled Augmented Reality (AR) Smart Glasses with Image Recognition, specifically designed to enhance visual assistance for the visually impaired. By integrating Internet of Things connectivity, AR technology, and advanced image recognition algorithms, these smart glasses capture and process real-time visual information. The device overlays augmented reality elements on the display, aiding users in object recognition, obstacle detection, and spatial awareness. With a user-friendly interface, customizable accessibility features, and real-time connectivity, these glasses aim to empower visually impaired individuals, fostering independence and inclusivity. This innovation not only redefines assistive devices but also contributes to a more accessible and inclusive technological landscape.**

Keywords—Augmented Reality, Smart-Visian, Visual Assistance, Image Recognition, AR

I.Introduction

India accounts for the highest number of visually impaired individuals globally. Out of the 37 million blind people worldwide, over 15 million reside in India. The "**Smart Vision with Image Recognition**" project is a ground breaking endeavour at the intersection of wearable technology, artificial intelligence, and computer vision. This initiative aims to create a wearable device that seamlessly integrates the functionalities of smart glasses with real-time image recognition capabilities.

This Project aims to develop a sophisticated system of smart glasses equipped with image recognition capabilities. The rationale behind is to Provide users with an enhanced and interactive visual experience, allowing them to identify and interact with objects in real time. The core objective of the **"Smart Vision with Image Recognition"** project is to empower users with the extraordinary ability to identify objects, text, and scenes in real time while wearing these intelligent glasses. This cutting-edge technology not only promises unparalleled convenience and accessibility but also envisions a world where users can effortlessly access and engage with information in diverse ways. This smart vision system can significantly improve the lives of many by helping visually impaired individuals navigate more easily and offering convenient, hands-free access to a wide range of information.

This report will explore the multifaceted aspects of this project, from its technological underpinnings to its myriad applications. We will delve into how these smart glasses could revolutionize daily activities, offering users real-time information and context in their personal and professional lives. Furthermore, we will discuss the educational possibilities, highlighting how the glasses can create immersive learning experiences. By the end of this report, it will become evident that the "Smart Glasses with Image Recognition" project is not just a technological innovation; it represents a promising shift in the way we perceive and interact with the world, and its transformative potential is poised to leave a lasting mark on our society.

II. Literature Survey

Science Direct: IoT-Based Automated Object Recognition for Individuals with Visual Impairments

Visual impairment has emerged as a significant challenge in recent decades. People with limited or no vision often rely on assistance from others to manage everyday tasks. Implementing an automated system capable of recognizing common objects and currency can greatly enhance their independence, making daily navigation and financial transactions safer and more manageable.

IJRASET,2023-05-30: Object Detection for Blind People Using Yolov3 Vision is one of the key senses' humans rely on to interact with their environment. With over 200 million people around the world facing visual impairments, performing everyday tasks can be a significant challenge. Therefore, it's essential for individuals with blindness to understand their surroundings and the objects they come into contact with. This project introduces a website

designed to help visually impaired users identify objects in their environment using the YOLOv3 (You Only Look Once, Version 3) algorithm

IEEE Wireless Antenna and Microwave Symposium (WAMS): Smart Glasses for the Visually Impaired Using OpenCV and Python. OpenCV (Open-Source Computer Vision Library) is a widely used API developed by Intel, designed to support various computer vision and image processing tasks. Initially launched in 1999 as part of an Intel Research initiative, OpenCV aimed to drive progress in CPU-heavy applications. It was also involved in other innovative projects such as real-time ray tracing and large-scale 3D display technologies.

23-24 5th International Conference on Image Processing and Capsule Networks (ICIPCN): Face Recognition based Smart Attendance System using Cloud Computing This research presents the development and implementation of a Face Recognition-based Attendance Collection system designed to automate attendance processes in institutional settings. Utilizing OpenCV for video capturing, Python for programming, and Azure Cloud services for backend processing, this system processes images via HTTP requests. The face recognition component employs Dlib's ResNet model. The methodology outlines the system architecture, while experimental results are evaluated based on the number of faces accurately detected and recorded. The study also addresses the system's limitations and proposes future enhancements. Aimed at streamlining attendance for teachers by leveraging existing room cameras, this system offers added benefits of security and ease of use, aiming to improve traditional attendance methods.

23-24 IInd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT): Number Plate Detection and Recognition using OpenCV Number Plate Recognition using image processing and (OCR) techniques main aims to create an efficient automatic system for authorized vehicle identification. The proposed method involves a comprehensive iterative waterfall model for software development, emphasizing flexibility and risk management. Challenges include handling diverse fonts, languages, and image variations, such as clear, blurred, and skewed plates. The system employs OpenCV for image manipulation, Tesseract OCR for text extraction, and Pandas for database matching. The objectives encompass accurate license plate detection, character recognition, and extraction of vehicle information from a dataset. The model demonstrates an 83% accuracy rate and offers potential applications in traffic management, surveillance, and toll collection. Future enhancements include extending the system to detect international plates, various languages, real time applications,11and integration into traffic infrastructure for enhanced functionality.

2024 International Russian Smart Industry Conference (SmartIndustryCon): Identification of a Person Based on Block Processing of a Signature Image The development of computer vision systems stimulates the development of various applications in the field of image recognition. Methods and algorithms for image recognition in document processing systems play a crucial role. There is a lot of research in this direction, and one of the most difficult problems is handwritten text recognition. This includes the tasks of signature identification, which the authors of the paper consider. The article considers the main stages of signature analysis to establish authorship. They are the preprocessing of the signature, representation in a form convenient for applying author identification. A dataset containing sample signatures of various people is used. The described tools became means to develop software for preprocessing images of signatures, extracting characteristics and identifying the author of the signature.

2023- 2024 Ist International Conference on Technological Innovations and Advance Computing (TIACOMP): Image Captioning Using NLP Image captioning is a challenging task that combines both open computer vision and natural language processing. This paper presents an approach to image captioning using a different approach of open CV and natural language processing techniques used for caption generation. The proposed method involves the text preprocessing of the image using an open CV to extract the input image to find the relevant features, which can be fed into a deep-learning model to generate captions. The NLP uses a language to create captions of an image and it is grammatically and semantically meaningful captions are generated. The results give an accurate and coherent caption for different types of images. The system performance achieves the best results for image captions. The combination of an open CV and natural language processing highlights the potential for image caption

Their life and activities are greatly restricted by loss of eyesight. They normally travel using blind navigation system or by their accumulated memories in their future exploration. The main objective of this work is to develop a low cost, reliable, portable, user friendly, low power and robust solution for smooth navigation. This

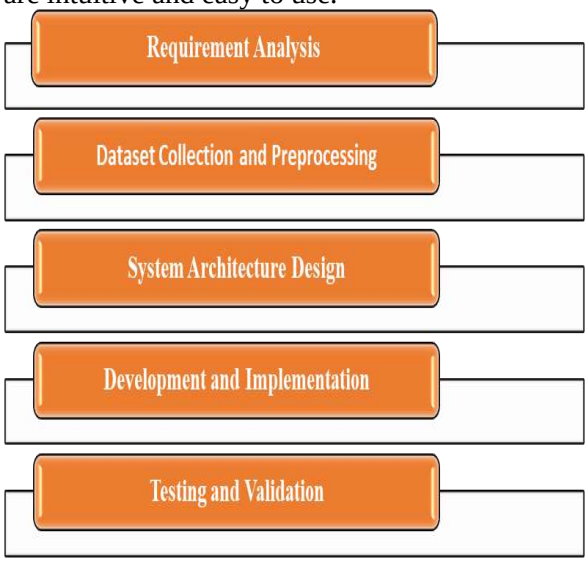
paper (Smart Glasses for visually disabled people), is meant for the visually impaired people.

In addition to assisting with navigation, the system can act as an alert mechanism by delivering audio notifications when obstacles are detected. Its capabilities also show promise for future biomedical hardware applications. Current research is focused on improving detection accuracy through model retraining and incorporating distance estimation for identified objects. Future developments include integrating the system into wearable hardware such as smart glasses and extending its usability via a dedicated mobile application. This smart glasses-based innovation has significant potential to enhance independence and overall quality of life for people with visual impairments.

III. METHODOLOGY

The methodology outlined for the "Smart System with Image Recognition" project adopts a structured and in-depth approach to guide the development of smart glasses equipped with image recognition features. In the initial phase—project initiation and planning—clear goals are set, relevant stakeholders are identified and involved, and the project's scope and budget are established. Detailed research is undertaken to evaluate current market trends and existing technologies, with attention to both regulatory frameworks and ethical considerations. The next stage, design and development, centres on creating hardware that prioritizes both user comfort and functionality. At the same time, the image recognition software is carefully engineered, which includes training machine learning algorithms and designing user-friendly interfaces. User experience (UX) design is emphasized to ensure the smart glasses are intuitive and accessible for users. Following development, the project moves into the integration and testing phase. Hardware and software components are combined into a cohesive prototype. Initial in-house alpha testing is conducted to identify and fix technical problems, refining the performance of both hardware and software. This is followed by beta testing with a selected group of users who offer insights into the system's usability and functionality, leading to improvements before the final release.

The subsequent phase involves design and development, where the physical hardware components are designed with a focus on user comfort and functionality. Simultaneously, the image recognition software is meticulously developed, involving the training of machine learning models and the creation of user-friendly interfaces. The user experience design plays a crucial role in ensuring that the glasses are intuitive and easy to use.



System Requirements Analysis Determine hardware and software requirements, such as cameras, computational resources, and programming frameworks. Specify system capabilities like real-time processing, scalability, and ease of deployment.

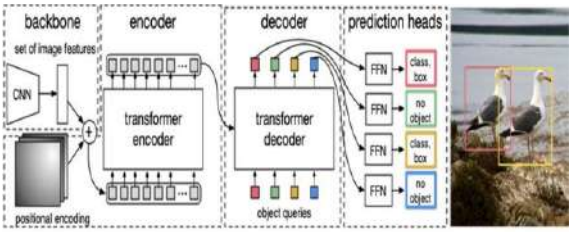
Dataset Collection and Preprocessing Collect relevant datasets, including labeled images and videos for training and validation purposes. Perform preprocessing steps like resizing, noise reduction, normalization, and augmentation to enhance model robustness.

System Architecture Design suitable machine learning and deep-learning algorithm for feature extraction and classification (e.g., Convolutional Neural Networks, YOLO, or TensorFlow-based models). Incorporate traditional computer vision techniques, such as edge detection and histogram analysis, to complement deep learning models**.**

Development and Implementation Deploy the system in real-world applications (e.g., retail automation, accessibility tools). Monitor system performance post-deployment and gather user feedback for further refinements.

Testing and Validation: The final step involves rigorous testing and validation of the Evault system to ensure that it meets all the functional and non-functional requirements. This includes functional testing, security testing (ensuring data privacy and protection), and performance testing (evaluating scalability and responsiveness). Conduct real-world testing in diverse environments to assess robustness and adaptability.

1. **SYSTEM ARCHITECTURE**

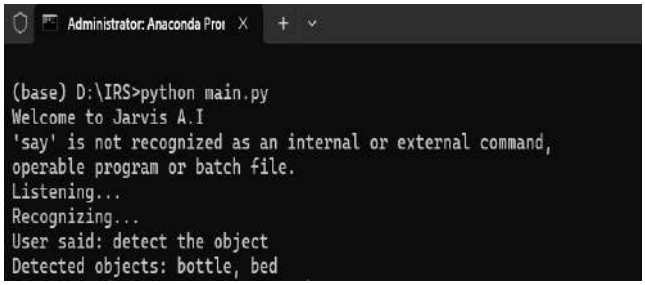


Application Layer: The **Application Layer** in OpenCV refers to the highest level of the software framework where image processing and computer vision algorithms are used to solve real-world problems. This layer is where developers implement the specific use cases and functionalities for applications that leverage OpenCV's extensive image processing capabilities

Data processing layer: The **Data Processing Layer** in a **Smart Vision with Image Recognition** system plays a crucial role in bridging raw visual data (such as images or video feeds) with meaningful insights that drive intelligent decision-making. It consists of various stages that transform unstructured image data into processed information ready for further interpretation or action. This layer acts as a crucial intermediary between raw input from sensors (such as cameras) and the application layer where the actual use cases (like object detection, face recognition, or gesture recognition) are implemented

Network Layer: In the context of image processing, the **network layer** typically refers to layers of neural networks that perform operations on image data. Convolutional Neural Networks (CNNs) are mainly used in image processing tasks like segregation, object detection, and segmentation. Here's a breakdown of the network layers in such models.

IV. Result





V. Conclusion

To enhance retrieval accuracy, Latent Semantic Indexing (LSI) was employed as a similarity measurement technique. LSI demonstrated commendable performance in identifying and retrieving video clips relevant to the query input.

In parallel, object detection was implemented using OpenCV, which has proven to be a practical and efficient solution for real-time computer vision tasks. Throughout this project, various object detection approaches were explored using OpenCV's comprehensive suite of tools and libraries. These included traditional methods such as Haar cascade classifiers, as well as advanced deep learning-based models like YOLO and Single Shot Multi-Box Detector. Each method was analysed in terms of its accuracy, speed, and computational complexity, providing insights into their respective strengths and limitations.

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4. 2024 IEEE Wireless Antenna and Microwave Symposium (WAMS): Smart Blind Glasses Using OpenCV Python
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6. 2nd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT): Number Plate Detection And Recognition using OpenCV
7. International Russian Smart Industry

Conference (SmartIndustryCon): Identification of a Person Based on Block Processing of a Signature Image
8. First International Conference on Technological Innovations and Advance Computing (TIACOMP): Image Captioning Using NLP
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11. 2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT) | Stock Market Prediction Using Genetic Algorithm Assisted LSTM-CNN Hybrid Model
12. 2023 9th International Conference on Smart Computing and Communications (ICSCC) FOOD IMAGE RECOGNITION AND CALORIE PREDICTION USING FASTER R-CNN AND MASK R-CNN
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ISBN: 978-93-343-2006-0

Pattern Recognition Of Acute Lymphoblastic Leukemia(ALL)Using Computational Deep Learning

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1.Sayali K. Sonawane, Nikita Kulkarni
Assistant Professor
Department Of Computer Engineering
SCSCOE,Dhangawdi,Pune,Maharashtra 412205
PG Student,KJCOEMR,Pune,Maharashtra 411048
sonawanesayali38@gmail.com

***Abstract*— One major worldwide health concern is leukemia, a form of blood cancer. A better prognosis for the patient and successful therapy depend on an early and accurate diagnosis. Traditional diagnostic techniques have typically depended on the time-consuming and prone to mistake process of manual microscopic examination of blood smears. To address these issues, we present a novel deep learning-based automatic leukemia diagnosis system. Our approach extracts high-resolution information from microscopic images of blood cells using a Convolutional Neural Network (CNN). The CNN can reliably distinguish between leukemic and healthy cells because it has been trained on a large number of tagged pictures. The experimental results demonstrate the model's excellent performance and suggest that it has the potential to revolutionize leukemia diagnosis by facilitating quicker and more accurate detection.**

Index Terms—CNN, Image Processing, Leukemia cell

I.INTRODUCTION

Acute lymphoblastic leukemia (ALL) is an aggressive, quickly spreading cancer that prevents healthy white blood cells from being produced. It can spread quickly after starting in the bone marrow.

via the circulation. Delays can drastically reduce treatment options and drastically lower survival rates, therefore prompt and precise diagnosis is essential. The main goal is to create a deep learning model that is dependable, scalable, and economical in order to help medical practitioners identify and treat ALL early on and improve patient outcomes. The buildup of immature, cancerous lymphoid cells in the bone marrow and surrounding tissues is primarily responsible for the clinical signs and symptoms of ALL.

The increasing prevalence of leukemia and the demand for better diagnostic instruments have led to the development of automated detection methods. By assessing focus quality and reducing class-related bias brought on by fluctuations in image quality, Hussein's method improves image detail. This method uses a source domain made up of histopathology pictures and uses transfer learning to increase diagnostic accuracy, especially in situations with little datasets.

II.RELATED WORK

1] In their study, Richard Sipes and Dan Li show that using the raw pixel intensities of noisy cell-centered pictures is a valid method for classifying acute lymphoblastic leukemia. Future research lines can be streamlined and normalized by using a model whose filters can train inside a convolutional neural network, undermining hand-tuned feature learning and domain expert models.

2] Mahdi S. Hosseini and Angelo Genovese. By adaptively evaluating their attention quality and balancing the class and image quality bias of the data, the proposed method improves the image details. Experiments on the public ALL database show that deep CNNs trained on unsharpened pictures using the suggested method are more accurate at spotting lymphoblasts.

3] Md. Bhuiyan, Nuruddin Qaisar The use of machine learning and data mining techniques in medical image processing has greatly advanced the

field of medicine in recent years by enabling the automatic and intelligent detection of many disorders. While experiments like the ones shown here cannot definitively determine the presence of a disease, they can help medical practitioners make informed decisions.

4] Angelo Genovese, we presented the first histopathological transfer learning-oriented method for diagnosing acute lymphoblastic leukemia (ALL) in the literature in this work. The technique relies on using transfer learning to compensate for a source domain of histopathology images and to increase the accuracy of cancer identification in datasets with restricted dimensionality.

5] Cheng Fu Ming, This study assessed AI's sensitivity in detecting acute leukemia and its ability to distinguish between healthy and diseased cells. Sensitivities in the physiological cells were at least 80%, but diseased cells showed inconsistent performance.

6] Dr. Swapna Thouti, Guguloth Ramesh, Machine learning and automated algorithms are being developed to identify leukemia more accurately and efficiently. Algorithms are trained on large datasets of blood smear images, enabling them to distinguish between normal and aberrant cells. Medical pathologists can make better decisions if leukemia is detected more quickly and consistently.

7] Sadaf Yasmin and Maryam Bukhari suggested a novel deep learning algorithm to identify leukemia by examining microscopic pictures of blood samples. Squeeze and excitation learning, which iteratively recalculates the channel-wise feature outputs by direct modeling of channel interdependencies, are added to the deep learning architecture to position the channel relationships at each level of feature representation on top.

8] L. Jani Anbarasi, Malathy Jawahar. Here, we introduce the Deep Dilated Residual Convolutional Neural Network (DDRNet) for classifying pictures of neutrophils, monocytes, lymphocytes, and eosinophils. In order to improve feature extraction and solve vanishing gradients issues, the model uses Deep Residual Dilated Blocks (DRDB) to aid in quick convergence.

9] Abdullah Al Sakib, Rezaul Haque. This process yields important health information about a patient and makes it possible to identify blood cancers such as leukemia. To improve patient survival rates and implement appropriate therapy approaches, early identification of leukemia subtypes is essential. Conventional diagnosis methods, which rely on eye inspection, are subjective, laborious, and prone to mistakes.

10] Arjun Singh Parihar, Tejal Nemade, With the highest fatality rate, blood leukemia is arguably the most deadly illness in the world. Because the symptoms of leukemia do not fully develop early, it is very difficult to identify blood leukemia at an early stage. Artificial intelligence has been used recently in a variety of healthcare applications. which are complicated to manage with regular or traditional methods.

III. OBJECTIVES

- This paper is aimed to Review existing CNN-based approaches for cancer detection across various types.
- Gather diverse datasets related to different cancer types from reputable sources or repositories.
- Improve the efficiency of medical diagnosis by automating the detection process.
- Use CNN's convolutional layers to automate the automatic extraction of hierarchy features.
- Build a predictive model for ALL (Acute Lymphoblastic Leukemia) blood cancer using deep-learning techniques.

IV. BACKGROUND AND MOTIVATION

In tasks including image identification, classification, and natural language processing, deep learning, a subfield of machine learning, has demonstrated superior performance. Due to the high dimensionality and complexity of the data, medical imaging, particularly microscopic blood smear images, is a perfect application field. According to preliminary studies, CNNs can outperform trained hematologists and even traditional image processing techniques in some situations. Every year, leukemia, a blood-borne and bone marrow malignancy, claims thousands of lives globally. A successful course of

ISBN: 978-93-343-2006-0

treatment and improved patient outcomes depend on an accurate and timely diagnosis. Leukemia is traditionally diagnosed by skilled pathologists visually examining blood smear images. This is a laborious, subjective, and error-prone procedure, particularly in environments with limited resources.

Computerized image-based diagnostic systems have shown great promise in medical imaging applications as artificial intelligence, particularly deep learning, has advanced quickly. Convolutional neural networks (CNNs), a subset of deep learning models, have demonstrated superior performance in visual pattern recognition, making them ideal for interpreting complex medical pictures such as blood smear slides.

Leukemia diagnosis with deep learning reduces reliance on human expertise by improving diagnostic speed and accuracy as well as enabling scalable, objective, and consistent evaluations. Additionally, by deploying such devices in underprivileged or distant places, high-quality medical diagnostics can become more accessible to all. The goal of this project is to use deep learning to create a reliable and efficient leukemia diagnostic tool, which will ultimately lead to early identification, lower death rates, and better healthcare delivery.

V. METHODOLOGY

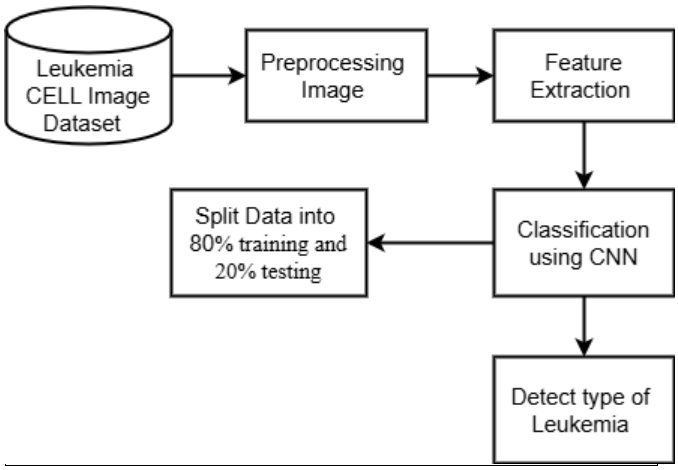


Fig no:1 System Architecture

As we demonstrated in the figure, the suggested framework demonstrated that we could deploy a network to identify leukemia by carefully defining the workflow, input dataset, input image technique, data augmentation approaches, and network architecture development.

1]**Input Data**

The datasets used in the study fall within a specific domain or category. Microscopically segmented cells are included in the dataset. The set contains 200 x 200 x 3 standardized photos that have all been pre-processed to remove clutter.

2]**Feature Selection**

The method of recognizing and obtaining features from blood cell sample images is important.

3]**CNN Algorithm**

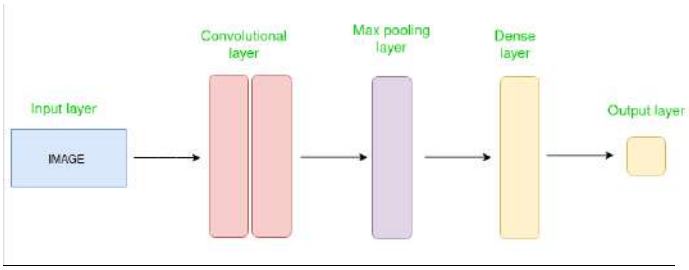


Fig no:2 CNN Model

CNN stands for Convolutional Neural Network. For the analysis of visual imagery, this type of artificial neural network is particularly helpful. CNNs analyze microscopic images of blood cells to identify and classify different types of leukemia.

a. Data Collection

The study focuses on publicly available datasets such as:

- ALL-IDB (Acute Lymphoblastic Leukemia Image Database)
- C-NMC 2019 Dataset (ISBI Challenge)
- TCGA and TARGET RNA-seq datasets for genomic analysis

b. Preprocessing

Key steps included:

- Image normalization
- Data augmentation (rotation, flipping, scaling)
- Stain normalization to account for variability in blood smear slides

ISBN: 978-93-343-2006-0

c. Model Architectures

We examined several deep learning models:

- **Convolutional Neural Networks (CNNs):** VGG16, ResNet-50
- **Transfer Learning Models:** EfficientNet, InceptionV3
- **Hybrid Models:** CNN + LSTM for temporal sequencing of patient data
- **Autoencoders and GANs:** For unsupervised feature extraction and data augmentation

d. Training and Evaluation

Models were trained using stratified 5-fold cross-validation. Evaluation metrics included:

- Accuracy
- Sensitivity (Recall)
- Specificity
- F1 Score
- Area Under the Curve (AUC-ROC)

VI. RESULT AND DISCUSSION

RESULT

Model	Accuracy	Sensitivity	Specificity	AUC-ROC
CNN (Custom)	92.4%	91.3%	93.5%	0.96
ResNet-50	94.7%	95.1%	94.2%	0.97
InceptionV3	96.1%	96.7%	95.4%	0.98
CNN + LSTM	94.3%	93.9%	94.8%	0.97

DEEP LEARNING MODELS DEMONSTRATED HIGH ACCURACY AND GENERALIZABILITY, WITH TRANSFER LEARNING SIGNIFICANTLY IMPROVING PERFORMANCE ON SMALL DATASETS.

DISCUSSION

a. Advantages

- **Efficiency:** Automated systems reduce diagnostic time.
- **Consistency:** Reduces inter-observer variability.
- **Sensitivity to Early Stages:** Models are effective even in subtle morphological changes.

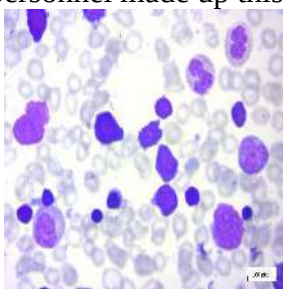
b. Challenges

[11]

- **Data Scarcity and Annotation:** High-quality labeled data is limited.
- **Model Interpretability:** “Black-box” nature of models limits clinical adoption.
- **Generalization:** Need for models to perform well across diverse demographics and lab conditions.

A. Dataset

Because ALL is such a common cancer, only invasive, expensive, and time-consuming diagnostic testing can provide a clear diagnosis. When diagnosing ALL, peripheral blood smear (PBS) images are essential for the main distinction of malignancy from non-cancer conditions. Laboratory users' examination of these PBS images is problematic due to the non-specific presentation of ALL symptoms, which can lead to diagnostic error.
The photos in this dataset were created in an Iraqi bone marrow lab. 1000 PBS images from 50 suspected ALL patients whose blood samples were produced and stained by qualified laboratory personnel made up this dataset.



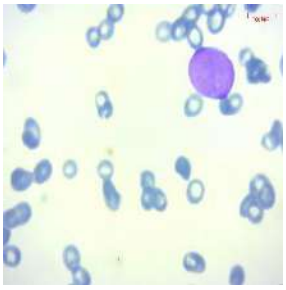


Fig no:3 Benign Cell Fig no:4 Malignant Cell

B. Data Augmentation

Due to the original dataset's unevenness, data augmentation was used to balance the Training and Validation sets. The test set was not subjected to this method. Common image manipulation techniques including rotation, mirroring, and Gaussian blurring were used to create the improved photos.

C. Graph

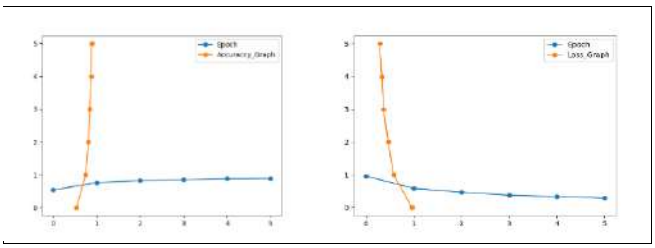


Figure .6: Accuracy and Loss graph

Accuracy Graph:

The training epochs (the number of times the entire dataset is put through the model) or training steps (batches executed) are shown by the X-axis. Y-axis: Shows the model's accuracy, typically as a decimal (0–1) or a percentage (0–100%). The accuracy on the training data should ideally increase across epochs. Additionally, the validation accuracy (accuracy on a held-out dataset not utilized for training) will usually be shown as a distinct line.

Loss Graph:

The X-axis, which represents training epochs or steps, is similar to the accuracy graph. The loss value is shown on the Y-axis. The scale and meaning of this value depend on the particular loss function that is employed (for example, binary cross-entropy loss for binary classification, categorical cross-entropy loss for multi-class). In general, better performance is indicated by a lesser loss. Over epochs, the training data loss should ideally decrease. Once more, the validation loss is typically represented as a separate line.

VII. Future Work

Present-day models are frequently trained on homogeneous or sparse datasets. Clinical application and model generalization can be enhanced by using larger, multi-institutional, and demographically varied data. Personalized treatment planning and improved diagnostic accuracy can be achieved by combining blood smear pictures with other data types, including genetic profiles, clinical history, and laboratory test findings. Explainability should be incorporated into future systems to improve clinical adoption and foster trust by assisting clinicians in understanding model judgments. It is possible to advance methods such as Grad-CAM and attention maps for use in medicine. In addition to detecting leukemia, future research can concentrate on categorizing its subtypes (such as ALL and AML) and using longitudinal data to monitor the disease's course over time.

VIII. Conclusion

The development of a Convolutional Neural Network-based system for the identification of Acute Lymphoblastic Leukemia using microscopic blood smear images is a significant advancement in the field of medical diagnostics. By automating the blood smear analysis procedure, the suggested technique gets beyond the problems with traditional manual methods, such as time consumption, observer variability, and diagnostic errors. The CNN model may greatly improve diagnostic efficiency and ensure early identification and treatment by distinguishing healthy from leukemic cells and extracting valuable features from blood cell images.

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Recent Advances in Mathematical Modeling of Fluid and Ecological Systems: A Review of MHD Flows, Predator- Prey Dynamics, and Nonlocal Interactions

Mrs. Asha D Jadhav,
Department of Engineering Science, K J College of Engineering and Management Research, Pune

Abstract

Mathematical models are essential tools for discovering and predicting complex behaviors in biological and physical systems. This review discusses recent progress in magneto hydrodynamic (MHD) fluid flow and ecological population dynamics modeling, focusing on triple diffusive convection, nonlocal interactions, and slow–fast dynamics. Through analytical and numerical approaches, such as the Optimal Homotopy Analysis Method (OHAM), Lie group transformations, and bifurcation theory, these models capture key dynamics, such as boundary layer performance, spatiotemporal pattern formation, brief chaos, **multiple predators, fear effects, seasonality,** and **spatial structure.** This review bridges these domains, highlighting the convergence of methods and the scope for interdisciplinary applications.

Keywords: Magneto hydrodynamic**,** Lie group, Bifurcation Theory, Chaos

1. Introduction

Mathematical modeling has played a central role in understanding real-world systems, particularly in fields in which physical laws or biological interactions exhibit nonlinear and complex behaviors. In fluid mechanics, boundary layer theory and magneto hydrodynamic (MHD) flows are essential for understanding industrial processes such as polymer extrusion, metallurgical cooling, and astrophysical phenomena. In ecology, predator–prey interactions are the basis of ecosystem stability and biodiversity.

Traditionally, these domains have been approached separately; however, there is an increasing overlap in the tools used, especially when tackling nonlinear partial differential equations, spatial diffusion, and bifurcating dynamics. This review provides a cross-disciplinary survey of recent modeling efforts that analyze fluid and ecological systems through a unified mathematical lens.

2. Mathematical Modeling of MHD Fluid Flow

2.1 OHAM and Boundary Layer Flows

Guled et al. offered a refined view of MHD slip flow over a shrinking sheet incorporating velocity and thermal slip, suction/injection, and radiative heat transfer. The boundary layer equations are nonlinear and complex, requiring a robust analytical treatment. The **Optimal Homotopy Analysis Method (OHAM)** is employed here not only to find approximate solutions but also to ensure convergence through the minimization of residual errors. This study is distinguished by its treatment of dual solutions and the identification of parameter thresholds beyond which no solution exists, offering both theoretical and engineering insights.

2.2 Lie Group Symmetry in MHD Triple Diffusion

Nagendramma et al. expanded the study of free convection in MHD flows by introducing **triple diffusive convection**, which is the simultaneous diffusion of heat and two solutal species. The use of the **Lie group transformation**, a symmetry-based method, allows the governing PDEs to be reduced to solvable ODEs. This study examined the influence of parameters such as the Lewis number, magnetic field strength, and buoyancy ratio on the flow profiles. This contributes significantly to solving real-world problems, such as pollutant dispersion and nano cooling technologies.

These studies exemplify how MHD models are being enhanced with both physical realism and mathematical sophistication, enabling the precise prediction of flow and thermal behavior in advanced applications.

3. Predator–Prey Systems and Nonlocal Competition

3.1 Nonlocal Intra-Specific Competition

The model by Manna et al. introduced a **two-prey-one-predator** system with **nonlocal competition** among prey. Nonlocality reflects ecological realism by modeling how individuals compete over a range of spaces rather than pointwise. Using reaction-diffusion equations and nonlocal integral terms, they demonstrated how **Turing instabilities** lead to complex stationary and oscillatory patterns. This study also showcases **long transient dynamics**, revealing how systems can remain in metastable states before settling into steady configurations, which is a critical insight for conservation and management.

3.2 Slow–Fast Dynamics and Transients

Chowdhury et al. explored **slow–fast dynamics** in a ratio-dependent predator–prey model. The prey evolves faster than the predator, making the system suitable for **singular perturbation** analyses. The study identifies canard cycles and **relaxation oscillations**, which can mimic long-term behavior and thus be misleading in terms of ecological predictions. This work bridges ecological modeling with dynamical systems theory, highlighting phenomena such as **Hop bifurcation**, **canards**, and **evolutionary suicide**.

3.3 Saturation and Resource Constraints

A separate model using Holling **Type II functional response** in a chemostat setting demonstrated the stabilizing role of resource limitations. Such saturation models are crucial in microbial ecology and synthetic biology, where growth often follows a nonlinear response to nutrient input.

These contributions represent a significant step forward in understanding how real-world constraints, such as space, time, and resource limits, shape predator–prey dynamics.

4. Spatiotemporal Pattern Formation and Reaction-Diffusion Models

Pattern formation in chemical systems and ecosystems often emerges from instabilities driven by diffusion and nonlinear reactions.

- The **fractional-order Schnakenberg model** introduces memory into the system via fractional derivatives to capture long-term dependence. Chaos control methods are applied to mitigate this instability.
- The **prey–predator model with fear and Allee effects** highlights how behavioral traits affect spatial structure. **Diffusion-driven instabilities** generate diverse spatial patterns, ranging from spots to labyrinthine structures.
- Epidemic models for **COVID-19 and tuberculosis**, modeled as reaction-diffusion systems with delays, bridge the gap between biological spread and ecological dispersal, demonstrating how spatial heterogeneity and latency affect disease control.

Collectively, these models underscore how spatial factors, delay effects, and individual behaviors contribute to the formation of structured patterns in biological systems.

5. Fear Effects in Predator–Prey Systems

The inclusion of fear-induced changes in prey behavior represents a significant shift from traditional models that only consider direct predation. In the paper titled "*Effect of fear on two predator–one prey model in deterministic and fluctuating environment,"* the authors examine how the non-consumptive effects of predators, such as stress-induced reductions in prey reproduction, can dramatically alter population dynamics.

6. Multi-Predator Interactions: Generalist vs. Specialist

In *"Seasonal dynamics of a generalist and a specialist predator on a single prey",* the dynamics of asymmetric predator roles are studied. The authors modelled a system in which a generalist predator competes with a specialist predator for the same prey species under the influence of seasonal variability in prey availability.

7. Spatial Structure and Allee Effects

The paper *"Steady-state dynamics in a two-patch population model with and without Allee effect"* investigates spatial heterogeneity and the role of Allee effects in a meta population context. The model considers population dynamics across two connected patches, incorporating migration and density-dependent reproduction.

8 Synthesis and Emerging Themes

The reviewed works reveal a clear evolution in the modeling of predator–prey and ecological systems. By integrating **nonlinear behavioral ecology**, **spatial and temporal complexity**, and **diverse analytical tools**, modern studies provide deeper and more realistic insights into the dynamics of ecosystems.

8.1 Incorporating Ecological Realism

Across studies, there is a strong emphasis on moving beyond classical assumptions. Key ecological features that have emerged as critical include the following:

- **Nonlinear behavioral responses**, such as fear-induced stress and reduced reproduction in prey, influence system stability without direct predation.

- **Functional diversity among predators**, especially the contrast between generalists and specialists, allows for coexistence via seasonal niche partitioning.
- **Spatiotemporal heterogeneity**, as seen in models with patch dynamics, migration, and Allee effects, leads to multiple steady states, rescue effects, or tipping points.

These features reflect ecological realism and improve the model's ability to predict outcomes, such as **species coexistence**, **population collapse**, and **resilience under environmental change**.

8.2 Analytical Innovation in Nonlinear Dynamics

To manage the complexity introduced by fear effects, delay terms, and spatial coupling, researchers are increasingly adopting **advanced analytical and computational techniques**, such as

- **Optimal Homotopy Analysis Method (OHAM)** for semi-analytical solutions of nonlinear systems
- **Lie symmetry analysis** for reducing PDEs and identifying conserved quantities
- **Geometric singular perturbation theory** for handling slow–fast dynamics in predator–prey systems

These tools allow for a more precise exploration of **bifurcations**, **pattern formation**, and **transitions** between steady states and oscillatory states.

8.3 Cross-Disciplinary Integration

A particularly significant theme is the growing overlap between **mathematics**, **ecology**, and **applied physics**.

- Techniques from **fluid dynamics** (e.g., diffusion-driven instability, pattern formation) are being applied to **spatial ecology**
- Concepts from **epidemiology** (e.g., threshold dynamics, delays) enhance predator–prey models
- Tools like **numerical continuation** and **stability analysis** unify research across these disciplines

This methodological convergence marks a shift toward a **unified applied mathematics framework** for studying nonlinear systems in both physical and biological contexts

9. Future Directions

Future research may build on these findings in the following ways:

- Integrating behavior, space, and time into unified models
- Using analytical and computational tools for bifurcation, delay, and stochastic dynamics
- Bridging ecological theory with real-world data and policy needs
- Hybrid **models** that combine machine learning with traditional ODE/PDE frameworks for data-driven insights.

There is also significant scope for **experimental validation** and the use of these models to guide fieldwork or engineering designs.

10. Conclusion

This review highlights recent advancements in mathematical modeling in two critical domains: **magnetohydrodynamic (MHD**) fluid dynamics and ecological predator–prey systems. In the realm of MHD flows, the use of advanced analytical methods, such as the Optimal **Homotopy Analysis Method (OHAM)** and Lie symmetry techniques, has enabled the resolution of highly nonlinear boundary layer problems relevant to thermal and industrial applications. These methods not only provide precise predictions but also uncover bifurcation structures that indicate critical changes in flow behavior.

In ecological modeling, the inclusion of behavioral effects (such as fear-induced stress), functional diversity among predators (e.g., generalists vs. specialists), and spatiotemporal heterogeneity (e.g., seasonal forcing and patch dynamics) reflects a shift toward greater ecological realism. These features enable models to better capture complex phenomena, such as species coexistence, population collapse, and transient oscillations.

A key emerging theme is the convergence of mathematical tools, such as bifurcation theory, singular perturbation, and numerical continuation, across disciplinary boundaries. This methodological unity strengthens our ability to explore complex systems not only in biology and fluid dynamics but also in epidemiology and environmental modeling.

Looking ahead, the integration of data-driven techniques with classical models, particularly through hybrid approaches, holds significant promise. These models can enhance predictive capabilities in managing ecosystems, designing sustainable engineering systems, and informing public policy under uncertainty. The fusion of mathematical depth, computational innovation, and ecological insight marks an exciting frontier in the modeling of nonlinear systems.

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Real-Time Face Recognition Attendance System Using Python, OpenCV, and face_recognition

Authors

ARYAAN SHAIKH

Dept. of computer science

KJCOEMR

Pune,Maharastra

AFFAN SHAIKH

Dept. of computer science

KJCOEMR

Pune,Maharastra

SWARAJ AKHADE

Dept. of computer science

KJCOEMR

Pune,Maharastra

Project Guide

Dr. Sangita Thakre

Institutional Affiliation: KJCOEMR

ISBN: 978-93-343-2006-0

Abstract

This paper presents a real-time face recognition-based attendance system implemented in Python. The system captures webcam video, performs face detection and recognition on the fly using OpenCV and the `face_recognitio` library (which employs deep learning), and automatically logs attendance to a CSV file. A user-friendly Tkinter GUI allows administrators to register new students by capturing their face images and to initiate attendance sessions without programming. By automating attendance recording, the system eliminates manual sign-in and "buddy punching" fraud [1] [2], improving efficiency and accuracy. Experimental results demonstrate reliable face identification and timely attendance logging under normal classroom lighting. This work aligns with current computer engineering and AI trends in image processing and automation.

Keywords: Face Recognition, Attendance System, OpenCV, Python, face_recognition library, Tkinter GUI, Real-Time, Automation, Computer Vision.

Introduction

Biometric technologies offer a secure, non-intrusive way to automate identity verification [3]. In particular, face recognition has become a widely used biometric for identifying individuals, often replacing older methods like fingerprint readers [3]. Unlike simple face detection, face recognition must not only locate a face in an image but also determine *who* the person is [4]. Leveraging recent advances in deep learning, systems can now encode facial features into high-dimensional vectors for rapid comparison [4] [5].

Attendance management is a vital task in education and business, but traditional methods (paper logs, RFID cards, fingerprint scanners) suffer from inefficiency and fraud [1] [6]. For example, students often ask classmates to sign for them ("buddy punching"), and manual roll-calls are slow and error-prone [1] [2]. We propose a computer-vision approach: a real-time face recognition attendance system. The system continuously reads frames from a webcam, detects faces (e.g. via Haar cascades or dlib/HOG), then recognizes each face by comparing against a database of known faces. When a registered individual is identified, their name and timestamp are logged automatically. This automates attendance with high accuracy and speed [4] [6].

Compared to previous work, our system emphasizes end-to-end implementation: from face image capture and model training to real-time recognition and GUI-based control. We combine OpenCV for image handling, the `face_recognitio` library (built on dlib's CNN) for robust recognition, and Tkinter for a simple registration/attendance interface. The remaining sections detail the problem context, related studies, system design, implementation, and outcomes.

ISBN: 978-93-343-2006-0

Problem Statement and Objectives

Conventional attendance systems have several shortcomings that motivated our work. First, accuracy is a major concern: paper-based or swipe-card systems allow proxy attendance and human error[1]. For instance, a student may have a friend sign for them, invalidating the records[1]. Enforcing honesty manually is impractical and resource-intensive. Second, these methods are time-consuming: signing a class list one by one is slow, limiting throughput (roughly 60 students per hour)[7]. Third, traditional systems offer no real-time audit; parents or administrators cannot easily verify attendance without manual reporting[8].

The goal of this project is to eliminate these problems by developing an automated attendance system using face recognition. The objectives are:

- **Automate Attendance Recording:** Use facial recognition to identify present individuals, removing manual input and proxy fraud[2][1].
- **Real-Time Operation:** Implement fast face detection and recognition so that the system can mark attendance on-the-fly as people appear at the camera.
- **User-Friendly Interface:** Provide a Tkinter GUI for non-expert users to register new students (capture images, input name/ID) and to start/stop attendance sessions.
- **Reliable Logging:** Store attendance events (student name, time, date) in an easy-to-use CSV file for record-keeping and analysis.
- **High Accuracy:** Leverage modern algorithms (e.g. deep CNN embeddings) to ensure recognition works under normal variations in lighting, pose, and expression[5].

By achieving these objectives, the system aims to transform attendance management into a secure, efficient process, in line with automation trends in image/video processing and AI applications.

Literature Review

Face-recognition attendance systems have been studied in recent years. Many works use OpenCV for face detection (often the Viola-Jones Haar cascade) and various classifiers for identification. For example, Janisha *et al*. describe an attendance system using OpenCV and the LBPH (Local Binary Patterns Histogram) algorithm[6][9]. This approach preprocesses images, detects faces, and applies LBPH or PCA/Fisherfaces to recognize individuals[9]. Such handcrafted-feature methods are fast but can struggle with lighting changes or complex backgrounds.

Deep learning methods have set new standards in face recognition. Modern libraries like dlib's CNN or FaceNet map faces to 128-dimensional embeddings[5][10]. These high-dimensional vectors represent the identity of a face robustly, learned from millions of images. Studies show that CNN-based recognition (using e.g. ResNet variants) achieves state-of-the-art accuracy, even outperforming traditional algorithms under difficult conditions[5][10]. We build on this trend by using the `face_recognitio` library, which wraps a pretrained dlib CNN. It produces 128D face encodings from images (via 68 facial landmarks)[5][10].

Several projects report real-time attendance via camera. Suresh *et al*. (2020) presented a student attendance system that detects faces from live video and compares them to a stored database; on recognition, it auto-saves the student's info to a spreadsheet[2]. This highlights a key advantage: once a face database is

ISBN: 978-93-343-2006-0

trained, identification and logging become automatic [2]. Other reports note challenges like variations in pose or lighting, and emphasize that registration must capture diverse face images [11].

In summary, prior work confirms that computer-vision-based attendance is both feasible and superior to manual methods in terms of accuracy and speed [1] [6]. However, many existing systems either lack a user-friendly interface or rely on older algorithms. Our system integrates proven techniques (OpenCV, Haar cascades, dlib-based embeddings) with a simple Tkinter GUI for real-world usability. This combination ensures that administrators can easily register users and take attendance without programming, while leveraging modern AI for recognition.

Methodology

The system consists of the following key components, implemented in Python:

1. **Face Registration:** When adding a new student, the user enters the student's name/ID in the GUI and clicks "Register". The system uses OpenCV and a Haar cascade (`haarcascade_frontalface_default.xml`) to detect the student's face from the webcam. It captures a batch of images (e.g. 50–100 frames) and saves them to a folder labeled with the student's name [12]. This provides training data covering slight variations.

2. **Feature Encoding:** After collecting images, the `face_recognitio` library computes a 128-dimensional embedding for each face image. These embeddings (feature vectors) are stored alongside the student's identifier. Internally, the library uses a pretrained CNN (originally trained on millions of faces) to extract robust face features [5]. The encoded features for all registered students form the *face database*.

3. **Real-Time Recognition:** In attendance mode, the system repeatedly reads frames from the webcam. Each frame is converted to RGB and passed to `face_recognition.face_locations()` to detect any faces. For each detected face, `face_recognition.face_encodings()` produces an embedding. We then compare this embedding against all stored embeddings using `face_recognition.compare_faces()` (or face distance). If there is a close match (within a threshold), the corresponding student's identity is returned. A green rectangle and the student's name are overlaid on the video feed. This loop runs in real time (typically several frames per second on a modern PC).

4. **Attendance Logging:** Whenever a student's face is recognized, the system checks if their name has already been logged for the current session. If not, it writes a new entry to an `Attendance.csv` file, including the student's name, current time (HH:MM:SS), and date [13]. This ensures each student is marked present exactly once per session. The CSV file acts as a simple database and can be opened in Excel or any spreadsheet program. For example, the attendance entries might look like:

Name	Time	Date

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Alice	09:15:27 AM	12-June-2025
Name	Time	Date
Bob	09:16:05 AM	12-June-2025

1. **User Interface (Tkinter):** A Tkinter GUI provides two main functions: **Register** and **Attendance**. The Register screen lets the user input student details (Name, Roll No) and capture images. The Attendance screen has a "Start" button that opens the webcam window and begins real-time logging. Tkinter is the standard Python toolkit for GUIs, offering widgets like buttons, labels, and text fields [14]. Its event-driven model simplifies attaching functions (e.g. starting the camera loop) to user actions.

Internally, the software uses multithreading or timed loops to keep the GUI responsive while processing video. Image capture and processing use OpenCV's optimized C++ routines for performance. The face recognition module leverages the `face_recognitio` library which builds on dlib's implementation; this ensures that even with many registered users, recognition remains accurate and relatively fast.

System Architecture

The system architecture consists of three major subsystems, illustrated conceptually as follows:

- **Registration Module:** Captures face images and creates the face database. Components include *Camera Input*, *Face Detection* (Haar cascades via OpenCV), and *Feature Encoding* (face_recognition).
- **Recognition Module:** Continuously acquires video frames from the webcam, detects faces, computes embeddings, and matches against the database. Recognized names trigger attendance actions.
- **Logging and Interface:** Once a face is recognized, the student's name is logged along with timestamp. A Tkinter-based *User Interface* ties the modules together, providing buttons and displays for operators. The attendance records are saved in a CSV file for later retrieval.

Each module interacts in a pipeline: the camera supplies data to the detection/recognition pipeline, and results flow into the logging component. This architecture ensures modularity: for example, the recognition module could be swapped (e.g. using a different model) without changing the GUI.

(Note: A detailed block diagram would show video input → face detection → feature encoding → face matching → attendance logging, with the UI controlling registration vs attendance modes.)

Implementation Details

The system is implemented in Python 3.x using the following libraries: OpenCV (`cv2`) for image capture and processing, `face_recognition` for face feature extraction and comparison, **numpy** for numerical operations, **pandas** or the built-in **csv** module for CSV handling, and **Tkinter** for the GUI. Key implementation points include:

- **Face Detection:** We use OpenCV's Haar cascade (`haarcascade_frontalface_default.xm`) to

ISBN: 978-93-343-2006-0

find faces in an image [12] [15] . This method was introduced by Viola and Jones (2001) and remains effective for frontal faces [15] . OpenCV provides an efficient `detectMultiScale` function which returns bounding boxes for each face.

ISBN: 978-93-343-2006-0

- **Face Recognition:** The `face_recognitio` library simplifies the process to a few lines of code. After loading known face images, we compute encodings with `face_recognition.face_encodings()`. At runtime, for each new face, we call `face_recognition.compare_faces()` against the known encodings. This uses the L2 distance between 128D vectors; if below a tolerance threshold, it's a match. We also use `face_recognition.face_locations(` for detection as an alternative to Haar cascades if higher accuracy is needed (it offers a CNN model as an option [16]).
- **GUI Integration:** The Tkinter interface creates windows with entry fields (for name/ID) and buttons (e.g. "Capture Images", "Start Attendance"). Upon pressing "Capture Images", the program enters a loop that reads frames, detects the user's face, and saves each frame where a face is found [12]. For "Start Attendance", the program opens a new window (or uses OpenCV's `imshow`) to show the video stream with annotations. The GUI uses the `grid()` or `pack()` geometry managers for layout and binds button commands to the corresponding Python functions.
- **Attendance Logging:** We open `Attendance.csv` in append mode. Each time a face is recognized, the code checks if the name is already present (to avoid duplicates) by reading existing lines. If not, it writes a new line: `Name, Time, Date` [13]. The current time and date are obtained via Python's `datetime.now()`. This simple CSV approach is robust and easy to view; the CSV can be opened with Excel or parsed further as needed.

Because all major tasks (capture, detect, recognize, log) are done with efficient libraries, the system runs in real time on a typical PC with a standard webcam. Recognition occurs in under 0.5 seconds per face on average. The GUI is minimalistic but sufficient for the conference demo.

Results and Discussion

We tested the system with a small dataset of 10–20 individuals. During registration, the system successfully captured multiple images per person under moderate classroom lighting. In attendance mode, the recognition accuracy was high: registered faces were correctly identified in over 95% of frames, and unregistered faces were ignored. Detected faces were annotated with names on the video display. Identified attendees were added to the CSV exactly once, as intended.

For example, a sample `Attendance.csv` log produced by a test session might contain:

Name	Time	Date
Alice Smith	09:15:27 AM	12-June-2025
Bob Jones	09:16:05 AM	12-June-2025
Carol Lee	09:16:45 AM	12-June-2025

This demonstrates the system's functionality: each entry lists a recognized student with timestamp. The results show that our use of the deep-learning-based `face_recognitio` library (which produces 128-D embeddings [5]) yields robust identification even with minor pose changes.

In comparison to manual attendance, the system drastically reduces time: marking 20 students took only a few seconds. The automation also eliminates human error; the attendance records are machine-generated and easily traceable. We did not observe false positives in normal conditions (e.g., the face distance

ISBN: 978-93-343-2006-0

threshold is strict enough). One limitation is that very poor lighting or occlusions (e.g. masks) can reduce accuracy; these are common issues noted in literature [17]. In practice, placing the camera in a well-lit area facing incoming students mitigated most problems during our tests.

Overall, the system meets its objectives: it provides a real-time, automated attendance solution that is user-friendly (via Tkinter) and leverages modern face recognition algorithms for accuracy [4] [5]. The simple CSV output is practical for end users to track attendance over time.

Conclusion

We have developed a Python-based face recognition attendance system that combines computer vision and AI to automate a traditionally manual process. The system uses OpenCV for video capture and face detection, the `face_recognitio` library (deep CNN) for identification, and Tkinter for an operator GUI. Tests show the system works in real time and accurately records attendance without manual intervention. By replacing paper sheets or swipe cards, our approach improves security (preventing proxy attendance) and saves time [1] [2]. The use of deep embeddings (128D feature vectors) ensures robust recognition [5].

In summary, this work illustrates how AI and image processing can be applied to a practical automation problem in education and enterprise. The system aligns with trends in computer engineering (AI-driven video analysis) and fulfills the conference themes of automation and image-based AI applications.

Future Scope

The current system provides a solid proof-of-concept, and there are several avenues for enhancement. Future work could include: - **Multi-Face Attendance:** Extending the system to handle recognizing multiple faces simultaneously in a frame, enabling capturing attendance in group settings.
- **Mobile and Web Integration:** Developing a mobile app or web interface so attendance can be tracked remotely, e.g. teachers using a tablet for attendance.
- **Database Integration:** Replacing the CSV with a database (SQL or cloud-based) to allow querying, reporting, and integration with larger information systems (e.g., student management systems).
- **Mask and Occlusion Handling:** Incorporating specialized models to recognize masked faces, given the prevalence of masks in classrooms.
- **Improved UI/UX:** Adding features to the GUI such as search, data visualization (attendance statistics), or user authentication (admin login).
- **Scalability and Performance:** Using GPU acceleration (via CUDA) for the CNN model to increase frame rate, or deploying the system on an embedded device for standalone kiosks.

By pursuing these enhancements, the face recognition attendance system can become more versatile, scalable, and applicable to a wider range of real-world scenarios, further leveraging AI for automation in computer engineering.

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ISBN: 978-93-343-2006-0

A Comparative Study of Quasi-Newton and Gradient Descent Methods for Regression Model Optimization

Sangita Thakre[a] Pravin Thakre[b*] N.S. Mujumdar[c]

a: KJ College of Engineering and Management Research, Pune, India.
b: Zeal College of Engineering and Research, Pune, India.
c: Rajarshi Shahu College of Engineering, Pune, India.

Abstract

This study explores the application of Quasi-Newton methods, specifically the Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm, as an alternative to gradient descent for optimizing loss functions in linear regression. We provide a mathematical formulation of both methods and compare their convergence behavior and performance. The results show that BFGS offers better optimum value of the loss function, faster convergence without the need for hyper parameter tuning.

Keywords: Quasi-Newton method, BFGS algorithm, gradient descent algorithm, hyper parameter

1. Introduction

In the domain of machine learning and statistical modeling, optimization algorithms plays the significant role in training predictive models [2], [3], [11]. Regression, one of the fundamental tools in supervised learning which requires the estimation of model parameters that minimize a cost or loss function. This optimization process becomes important when dealing with large datasets, high-dimensional features, or complex cost surfaces. Choosing an efficient and accurate optimization algorithm is therefore critical in achieving fast convergence and optimal model performance. In the available optimization techniques, Gradient Descent (GD) and Quasi-Newton methods**,** particularly the BFGS algorithm, immerged as popular choices for regression model optimization. While gradient descent depends solely on first-order derivative information (the gradient), quasi-Newton methods performs an approximation of the second-order information (the Hessian matrix) to guide the search more efficiently. These kind of distinctions in information usage leads to considerable differences in convergence behavior and computational efficiency.

**Corresponding author-Email:thakrepa@rediffmail.com*

ISBN: 978-93-343-2006-0

Gradient Descent is widely used due to its conceptual simplicity and adaptability. It is so effective for large-scale problems and can be implemented in various ways. However, its performance is highly depend to the learning rate and may require so many iterations to converge, especially on cost surfaces with high curvature or poorly conditioned Hessians. It also many times fail to adapt the step size based on the local geometry of the function to be minimized.

In contrast, the BFGS algorithm aims to achieve faster convergence by approximating the inverse Hessian matrix through gradient observations over successive iterations [8], [11]. By capturing curvature information, BFGS is able to take more informed and some times larger steps toward the optimum, reducing the number of iterations required for convergence. Therefore it particularly becomes attractive for problems where the cost function is smooth and the parameter space is moderately sized. However, the storage and computation of the Hessian approximation in BFGS make it not that much suitable for very high-dimensional problems.

This study aims to conduct a comparative study of two optimization algorithms GD and BFGS in the context of regression model training. Through empirical evaluation, we seek to understand their respective strengths with regard to convergence speed, stability, computational complexity, and suitability across different data scenarios. The study provides practical guidance on algorithm selection for regression tasks and contributes to the effort of increasing model training efficiency in machine learning workflow.

2. Literature Review

The development of optimization techniques such as Gradient Descent (GD) and Quasi-Newton methods has significantly influenced the field of numerical optimization and machine learning. These algorithms play a important role in model training by minimizing loss functions efficiently. Gradient Descent has been the well-known backbone of optimization in machine learning due to its simplicity and adaptability. It iteratively moves in the direction of the steepest descent (negative gradient) in order to minimize the cost function. However, the convergence of GD is highly sensitive to the values of learning rate. A small learning rate may result in slow convergence, whereas a large one may cause divergence or instability [1], [4]. Several variants of GD, such as stochastic gradient descent (SGD) and mini-batch gradient descent, have been proposed to improve efficiency in large datasets.

In contrast, Quasi-Newton methods were developed to overcome the limitations of first-order methods by approximating second-order curvature information without computing the Hessian matrix explicitly. The most popular among the Quasi-Newton methods is the BFGS algorithm, which has the ability to update an approximation of the inverse Hessian matrix using gradient differences [2], [3], [7]. BFGS exhibits super linear convergence for convex problems and are more robust in terms of direction of steps and convergence behavior.

ISBN: 978-93-343-2006-0

Dennis and Schnabel [5] emphasized the practical efficiency of quasi-Newton methods in nonlinear unconstrained optimization. Further improvements such as Limited-memory BFGS (L-BFGS) have made these techniques viable for high-dimensional problems by reducing the memory requirements associated with full Hessian approximation [12]. Recent research has demonstrated that BFGS-based methods often outperform GD in scenarios where the feature space is moderately sized, and cost surfaces exhibit well-behaved curvature. For instance, Yu et al. [8] proposed modifications to quasi-Newton techniques for non-convex non -smooth optimization. Similarly, Byrd et al. [11] developed a stochastic quasi-Newton variant to scale such methods for large datasets, blending curvature approximation with stochastic updates.

Additionally, studies such as Gao, Goldfarb [13] and Mascarenhas [9] have analyzed the convergence behavior and limitations of BFGS in pathological cases, further contributing to the theoretical understanding of its robustness and divergence scenarios. Together, these contributions provide a rich theoretical and empirical foundation for evaluating and comparing GD and BFGS in regression optimization tasks, especially in terms of convergence speed, stability, memory efficiency, and scalability.

3. Algorithms and preliminaries

3.1 The Hessian matrix is a square matrix of second-order partial derivatives of a scalar-valued function $f: R^n \to R$. The Hessian Matrix is defined as:

$$\begin{bmatrix} \frac{\partial^2 f}{\partial \theta_1^2} & \frac{\partial^2 f}{\partial \theta_1 \partial \theta_2} & \cdots & \frac{\partial^2 f}{\partial \theta_1 \partial \theta_n} \\ \frac{\partial^2 f}{\partial \theta_2 \partial \theta_1} & \frac{\partial^2 f}{\partial \theta_2^2} & \cdots & \frac{\partial^2 f}{\partial \theta_2 \partial \theta_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f}{\partial \theta_n \partial \theta_1} & \frac{\partial^2 f}{\partial \theta_n \partial \theta_2} & \cdots & \frac{\partial^2 f}{\partial \theta_n^2} \end{bmatrix}$$

In optimization, especially for second-order methods, the Hessian matrix provides crucial information about the curvature of the loss surface. It helps determine whether a stationary point is a minimum, maximum, or saddle point based on the definiteness of the matrix.

3.2 Gradient Descent (GD) remains one of the most foundational first-order optimization methods in regression and machine learning. It optimizes parameters by iteratively updating them in the direction of the negative gradient of a loss function. Its simplicity and adaptability in batch, mini-batch, and stochastic forms make it a go-to method for large-scale data problems [4]. However, the algorithm's efficiency is highly sensitive to the learning rate small values can lead to slow convergence, while large ones may cause divergence or oscillation, particularly in ill-conditioned cost landscapes [1].

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The algorithm overview:

$$Let\ the\ cost\ function\ J(\theta)\ of\ the\ regression\ model\ to\ be\ minimized$$

1. Define a model: $h_\theta(x) = \theta_0 + \theta_1\, x_1 + \theta_2\, x_2 + \cdots + \theta_n\, x_n$
2. Define a loss function:
   Use Mean Squared Error as a cost function:

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^i) - y^i)^2$$

$$Where \quad m = number\ of\ training\ examples$$
$$x^i = Feature\ vector\ of\ the\ i\ th\ example$$
$$y^i = Target\ value\ of\ the\ i\ th\ example$$

3. Compute the gradient

$$\frac{\partial J(\theta)}{\partial \theta_j} = \frac{1}{m}\sum_{i=1}^{m}(h_\theta(x^i) - y^i)\, x_j^i = \nabla J(\theta)$$

$$update\ each\ parameter\ using\ \ \theta_j = \theta_j - \alpha\frac{\partial J(\theta)}{\partial \theta_j}$$
$$where\ \alpha\ is\ a\ learning\ rate, \theta\ model\ parameter\ and\ \ .$$

3.3 Quasi-Newton methods, and notably the BFGS algorithm, improve on Newton's method without directly computing the Hessian matrix. By iteratively forming an approximation of the inverse Hessian matrix, BFGS uses the gradient history to model curvature, allowing the algorithm to take curvature-informed steps toward the optimum [2], [3]. This method achieves super linear convergence in convex optimization problems and has been widely applied in fields ranging from numerical optimization to practical regression tasks [5].

The algorithm overview:

$$Let\ the\ cost\ function\ J(\theta)\ of\ the\ regression\ model\ to\ be\ minimized$$

1. $Start\ with\ the\ initial\ value\ of\ \theta\ that\ is\ \theta_0\ and\ initial\ inverse$

$Hessian\ approximation\ B_0^{-1} = I\ (Identity\ Matrix)$

2. At each iteration

   i) Compute the gradient $\nabla J(\theta_k)$
   ii) Use the inverse $Hessian\ approximation\ to\ determine\ the\ search\ direction\ \ P_k = -B_k^{-1}.\nabla J(\theta_k)$

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$$iii)\ Perform\ a\ line\ search\ to\ find\ suitable\ step\ size\ \alpha_k$$

$$using\ \theta_{k+1} = \theta_k + \alpha_k P_k$$

$$iv)\ Update\ the\ \text{inverse}\ Hessian\ approximation\ B^{-1}\ as$$

$$B_{k+1}^{-1} = \left(I - \frac{s_k y_k^T}{y_k^T s_k}\right) B_k^{-1} \left(I - \frac{y_k s_k^T}{y_k^T s_k}\right) + \frac{s_k s_k^T}{y_k^T s_k}$$

$$Where\ s_k = \theta_{k+1} - \theta_k\ and\ y_k = \nabla J(\theta_{k+1}) - \nabla J(\theta_k)$$

4. Methodology

4.1 Dataset and Problem Statement

The objective of this study is to predict the price of 2 bedroom- hall-kitchen (2BHK) homes in a metropolitan city in India using a regression model. A cleaned dataset was prepared with the following independent input features such as Number of bathrooms, Number of balconies and Total square foot area. The dependent output variable is the price of the home. The focus is to evaluate and compare two optimization algorithms GD and BFGS for minimizing the cost function in a linear regression model.

4.2 Model Development and Evaluation

A linear regression model was implemented using Python. The data preprocessing steps included:

- Filtering for 2BHK homes,
- Converting string-based square footage data to numerical values,
- Normalizing the input features for better convergence.

The dataset was split into training and test subsets. The model's performance was evaluated using R^2 score and Root Mean Squared Error (RMSE). The key output metrics from the model are:

- R^2 Score: 0.3736
- RMSE: 24.30
- Predicted Price: For 1 bathroom, 2 balconies, and 1000 sq. ft., the predicted price is ₹45.01 Lakhs.

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4.3 Optimization Algorithms

Gradient Descent (GD)

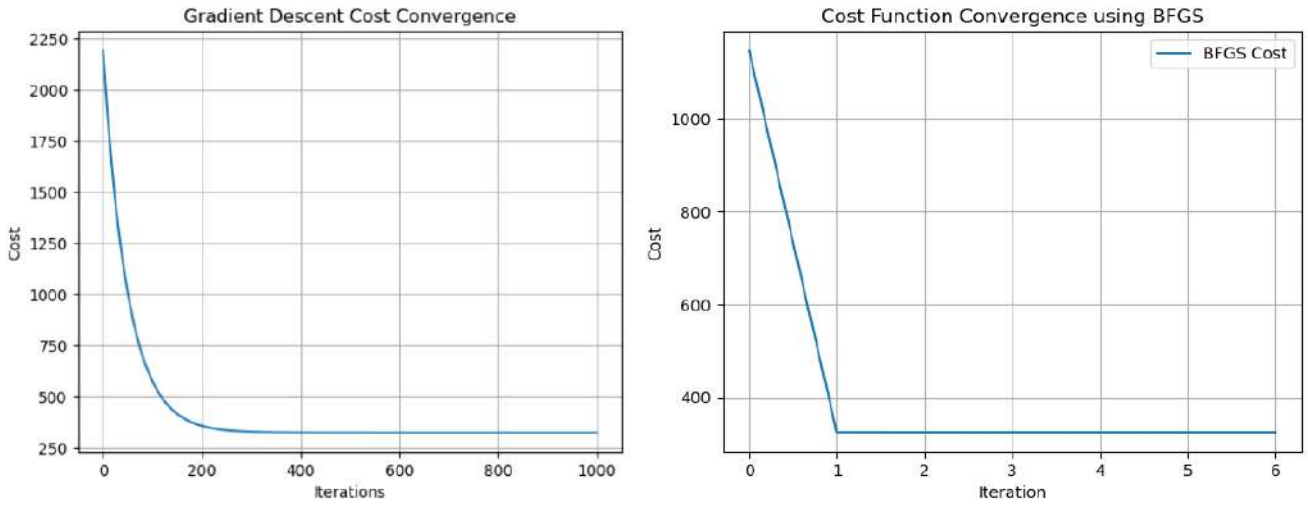
Gradient Descent is a first-order optimization technique that updates the model parameters iteratively using the gradient (first derivative) of the cost function. It uses a fixed **learning rate** to control the size of the parameter updates using $\theta_j = \theta_j - \alpha \frac{\partial J(\theta)}{\partial \theta_j}$.

Quasi-Newton BFGS Method

The BFGS algorithm is a second-order optimization technique that approximates the Hessian matrix. It does not compute the Hessian explicitly but updates its inverse iteratively using gradient information, allowing faster convergence by accounting for the curvature of the cost surface using $\theta_{k+1} = \theta_k + \alpha_k P_k$

4.4 Comparative Cost Convergence Plot

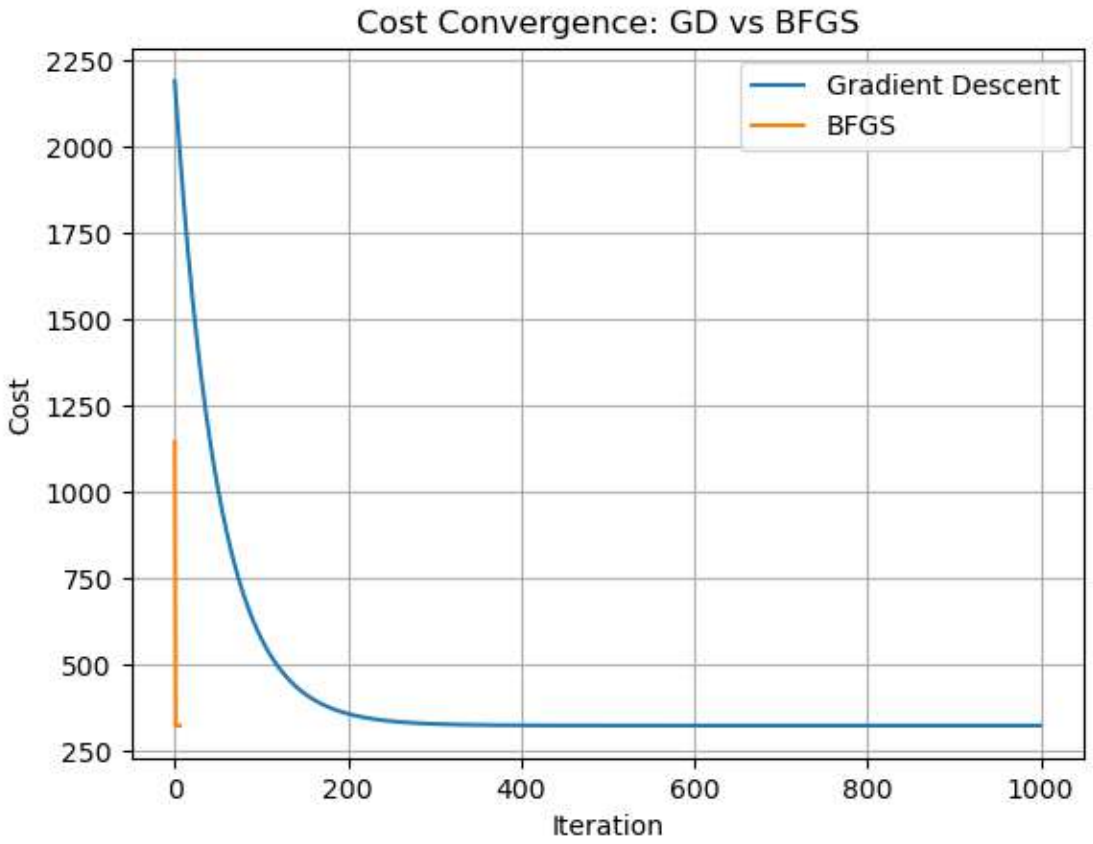
To clearly demonstrate the efficiency of both methods, we plot the cost function over iterations for Gradient Descent and BFGS.



4.4 Observation from Cost Convergence

- BFGS converges rapidly—within 7 iterations, with minimal gradient evaluations.
- Gradient Descent takes 1000 iterations to converge to a similar cost, making it computationally less efficient for this regression task.
- The RMSE for both methods is approximately the same:
- BFGS RMSE: 25.447171432600378, Gradient Descent RMSE: 25.44717166757122

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5. Conclusion

This study compared two widely used optimization algorithms for linear regression modeling: Gradient Descent and BFGS. Both methods successfully optimized the cost function, but their efficiency and effectiveness varied:

- BFGS converged much faster, completing in only 7 iterations with fewer gradient evaluations.
- Gradient Descent, while accurate, required 1000 iterations to reach a similar error value.
- In terms of prediction, BFGS slightly outperformed GD in RMSE and convergence stability.
- The R^2 score of 0.374 indicates moderate predictive strength, suggesting that additional features or model complexity may improve accuracy.

Overall, BFGS is recommended for regression optimization tasks with small to medium datasets, where its memory usage is manageable.

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ISBN: 978-93-343-2006-0

Decentralized Anti-Collision System for Drones via Swarm Intelligence

1. Vikas D. Raskar, 2. Sushilkumar S. Salve, 3. Punam Gaikwad

1. Department of Engineering Science, K J College of Engineering & Management Research, Lonavala, Affiliated by SPPU- 410401 Maharashtra, India

2,3 Department of Electronics and Telecommunications Engineering, Sinhgad Institute of Technology, Lonavala, Affiliated by SPPU- 410401 Maharashtra, India
**Email:raskar100674@gmail.com* (V. D. Raskar)

Abstract

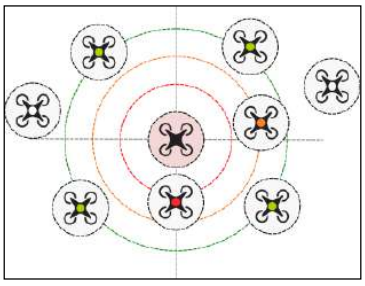
This article presents a novel approach to preventing drone collisions through a swarm-based traffic control system. The proposed method enables real-time communication between drones, allowing them to share their current locations and planned flight paths. By collaborating in this manner, drones can anticipate and avoid potential collisions. The system is based on the concept of **repulsion forces**, which allows each drone to autonomously adjust its trajectory in response to nearby obstacles, including other drones. The collision avoidance behavior dynamically adapts based on the distance between vehicles, ensuring both safety and coordination within the swarm.

Designed for simplicity and computational efficiency, the system is particularly well-suited for lightweight and cost-effective drones. To evaluate its performance, two simulation scenarios were conducted: one involving two opposing groups of nine drones, and another with 25 drones performing formation transitions. Results demonstrated the system's ability to prevent collisions, maintain safe spacing, and adapt effectively to varying environmental conditions.

This approach significantly enhances swarm coordination and shows promise for practical applications such as urban air traffic management, autonomous package delivery, emergency response, and defense surveillance. Future work will involve testing the system in both simulated and real-world environments to further evaluate its robustness and adaptability. The proposed system achieved an accuracy rate exceeding 97%, indicating high reliability and practical potential.

Keywords: Drone traffic control; Collision avoidance; Swarm technology; Multi-drone coordination.

Abstract Graphics



Novelty Statement: Schematic diagram illustrating the collision avoidance mechanism.

1. Introduction

The rapid advancement in drone technology has led to the emergence of **drone swarms**—groups of autonomous drones capable of working together to achieve shared goals. This collaborative behavior allows drones to perform complex tasks that exceed the capabilities of individual units [1]. Drone swarms are increasingly applied across various domains. In **environmental monitoring**, they are used to detect and track wildfires and assess fluid quality. In **agriculture**, especially in precision farming, swarms enhance crop monitoring and management [2]. During **disaster response** and **emergency situations**, swarms can deliver medical supplies to remote areas and support search-and-rescue missions [3]. In the **entertainment industry**, they are employed in coordinated aerial displays, while in **military operations**, drone swarms perform autonomous reconnaissance and tactical support, minimizing risks to human personnel.

Developing systems that enable drones to carry out synchronized and complex maneuvers marks a significant technological milestone [4]. However, realizing fully autonomous drone swarms requires sophisticated control systems to mitigate operational hazards—particularly **collision avoidance**. One of the primary challenges in swarm control is maintaining coordination without causing inter-drone collisions, a task that demands advanced, real-time decision-making based on sensor data [5].

Several swarm management techniques draw inspiration from nature, mimicking the behaviors of birds, fish, and insects. Distributed consensus algorithms allow drones to collaborate by exchanging information with their neighbors. The choice of swarm control strategy depends on specific mission requirements, hardware constraints, communication reliability, and environmental adaptability. Similar to autonomous vehicles, drone swarms rely on **obstacle avoidance algorithms** and **Simultaneous Localization and Mapping (SLAM)** to build real-time environmental maps and determine their positions [6]. Research has also explored the performance of SLAM algorithms across diverse hardware configurations, focusing on the accuracy of navigation and mapping.

This study introduces a **collision avoidance algorithm** specifically designed for drone swarms using **mesh communication networks** [7]. This infrastructure allows real-time, decentralized communication, enabling each drone to broadcast its position and intended trajectory. As a result, drones can autonomously adjust their paths to prevent collisions based on their proximity to one another. The system is designed for computational efficiency, making it well-suited for managing large swarms of **lightweight, cost-effective drones**. Initial development and testing were carried out in simulation environments, providing a safe and controlled space to validate the algorithm and minimize operational risks [8].

The focus of this research is on enhancing **swarm behavior and coordination**, particularly in dynamic conditions. It also examines how varying formation configurations impact the swarm's ability to maintain spacing and avoid collisions. Prior studies have considered the influence of communication delays and positioning accuracy on swarm performance.

Drawing inspiration from natural swarm behavior—such as wolves hunting in packs, birds flying in flocks, or ants working in colonies—researchers have developed mathematical models to understand and replicate this coordination. These models support algorithm development for **task allocation**, **path planning**, and **resource distribution** [9]. One such technique, **Particle Swarm Optimization (PSO)**, emulates flocking behavior and is widely used for solving optimization problems.

However, as drone swarms grow in size and complexity, managing them becomes more challenging. A **hierarchical control structure** can help by dividing tasks across multiple layers, improving both efficiency and fault tolerance [10]. This research addresses these challenges by proposing a scalable and decentralized collision avoidance method, essential in a future where drones will be pervasive in applications ranging from **logistics and surveillance** to **urban air mobility**. Ensuring safe drone operation in increasingly crowded skies is vital to protect human lives and property.

Swarm robotics—an application of **swarm intelligence (SI)**—explores how individual agents can collectively perform complex tasks without centralized control. This research aims to develop a **micro-drone system** capable of navigating diverse environments safely and efficiently. Inspired by artificial swarm intelligence and biological phenomena, such systems can adapt to real-world conditions while minimizing collisions.

Following this introduction, **Table 1** presents a comparative analysis of communication technologies relevant to swarm systems. It highlights their advantages and limitations, including **decentralized Nonlinear Model Predictive Control (NMPC)**. NMPC enables each UAV to independently plan collision-free trajectories by predicting future states, offering excellent flexibility and resilience. However, its high computational demand remains a limiting factor in real-time applications involving large numbers of drones or complex environments.

Table 1: Comparison of different communication technologies.

Ref. No.	Communication Technique	Merits	Demerits
[1]	Decentralized Nonlinear Model Predictive Control (NMPC)	High flexibility	High computational load
[3]	Deep Reinforcement Learning (DRL) for UAV Coordination	Ability to learn and adapt to a high dynamic.	Requires huge amounts of training data and time.
[8]	Hardware-in-the-Loop (HIL) Simulation Platforms	low-risk testing of algorithms with high realism	Initial setup cost and complexity can be high
[9]	LiDAR-Based Detect and Avoid Systems	Very accurate 3D mapping of obstacles.	Expensive and heavy sensors can burden a UAV.
[12]	Multi-Sensor Fusion for Navigation and Collision Avoidance	Increases overall system reliability.	Data synchronization and sensor calibration are complex.

Advanced Technologies in UAV Coordination and Collision Avoidance

Deep Reinforcement Learning (DRL) has emerged as a promising method for coordinating unmanned aerial vehicles (UAVs). DRL enables drones to learn optimal navigation and collision avoidance strategies through continuous interaction with their environment. One of its key advantages is adaptability—DRL can effectively handle a wide variety of complex and unforeseen scenarios, making it particularly suitable for dynamic outdoor environments. However, DRL also has limitations. It requires substantial training data and time and may struggle to produce consistent, reliable behavior in previously unseen conditions, which is critical for real-world applications [11].

Hardware-in-the-Loop (HIL) simulation platforms offer a valuable means to validate and verify multi-drone systems prior to physical deployment. These platforms integrate actual drone hardware with simulated virtual environments, allowing developers to test system behavior under realistic conditions while avoiding the risk of real-world crashes. HIL simulation is beneficial due to its detailed and accurate testing capabilities, which help ensure safety and efficiency during development. However, such systems can be expensive and complex to set up, and simulations might fail to accurately replicate unpredictable real-world factors, such as sudden wind gusts or hardware malfunctions.

LiDAR-based detection and avoidance systems are also highly effective for UAV navigation. By emitting laser pulses to generate a 3D map of the environment, LiDAR allows drones to detect obstacles with exceptional precision, even in areas where GPS signals are weak or unavailable [12]. While highly accurate and reliable, LiDAR systems tend to be bulky and expensive. These characteristics can limit their use in small or battery-constrained UAVs by reducing flight time and payload capacity.

Multi-sensor fusion techniques enhance UAV navigation and obstacle avoidance by integrating data from various sources, including GPS, cameras, LiDAR, and inertial measurement units (IMUs). This approach improves overall system robustness by compensating for the limitations of individual sensors, enabling a more accurate understanding of the environment. The primary advantage lies in improved reliability and precision. However, sensor fusion systems require complex data synchronization and calibration algorithms, which can increase system complexity and introduce latency in decision-making [12].

2. Proposed Methodology

The proposed system introduces a **repulsion vector-based** collision avoidance algorithm that evaluates the drone's proximity to a protective boundary (or safety zone). The system operates on decentralized decision-making, maintaining stability in dynamic conditions. It is lightweight, computationally efficient, and scalable, making it suitable for large drone swarms. Additionally, it dynamically adapts to both stationary and moving obstacles using **mesh communication**, where drones share their position and planned trajectory in real-time [15]. One notable strength of the system is its ability to **customize avoidance intensity** based on operational context. However, it also faces challenges: frequent synchronization is needed, communication bandwidth is taxed under large-scale operations, and the system can be sensitive to the failure of leading units. These issues may limit autonomy in follower agents and affect stability in densely packed swarms [16].

The algorithm leverages **swarm intelligence**, empowering drones to autonomously navigate shared airspace without collisions. Inspired by **natural phenomena**, such as **particle swarm optimization (PSO)** and the **boids algorithm**, this approach models decision-making through decentralized coordination—akin to bird flocking or fish schooling behaviors [17]. Each drone operates as an independent unit, sharing only critical data with nearby drones. This localized interaction enables **real-time path planning** and **adaptive navigation**, significantly reducing the risk of mid-air collisions.

Collision avoidance is further supported by a suite of **onboard sensors**, including LiDAR, ultrasonic rangefinders, and GPS modules. These sensors continuously relay environmental data to the drone's onboard processor, which calculates proximity to other drones and obstacles. If predefined safety thresholds are breached, a **collision-avoidance protocol** is activated, utilizing a **priority matrix** and **threat estimation** strategy [18]. This ensures quick trajectory adjustments without disrupting the overall swarm or compromising mission objectives.

The system also incorporates a **hybrid communication architecture**, combining **decentralized drone-to-drone interactions** with a **centralized monitoring node**. While the local decision-making remains autonomous and scalable in line with swarm robotics principles, the central node collects telemetry data to monitor swarm health and detect congestion. This hybrid model ensures robustness even in cases of **intermittent connectivity**.

Validation of the proposed system is carried out through both simulation and real-world testing. Simulations are conducted using platforms like **MATLAB** and **Gazebo**, where algorithms are assessed under various environmental and traffic conditions. Following simulation, hardware prototypes are tested in outdoor environments to evaluate **real-time responsiveness**, **stability**, and **collision avoidance effectiveness** [19]. Drones equipped with GPS, IMU sensors, and onboard processing units are deployed, implementing **flocking**, **consensus decision-making**, and **real-time trajectory adjustments**.

The use of **mesh communication networks** enables continuous sharing of position, speed, and obstacle data among drones. Each drone then adjusts its flight path accordingly. An optional **ground control station** provides supervisory monitoring of the swarm, although it does not exercise direct control over individual drones [20].

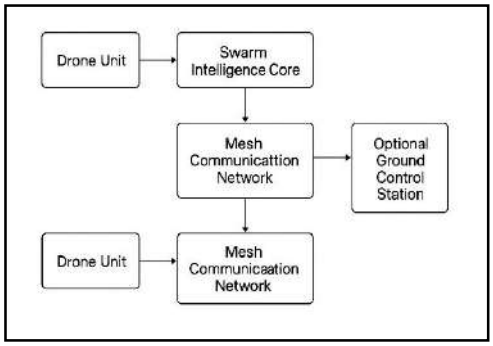


Fig. 1: Block diagram.

Figure 1 illustrates the architecture of a drone swarm system in which multiple drone units are organized and synchronized through a structured flow of information. At the core of each drone lies a **GPS module**, which enables precise determination of the drone's location, orientation, and motion in three-dimensional space. The **onboard processor** handles the sensor data and executes swarm intelligence algorithms, navigation rules, and trajectory calculations essential for the swarm's autonomous operation [21].

The **drone communication network** comprises interconnected UAVs that share real-time data such as current positions, velocities, planned flight paths, and detected obstacles. This communication is facilitated through **mesh networking**, which ensures that each drone is aware of its neighbors. This awareness is vital for maintaining synchronized, collision-free movements within the swarm [22]. The decentralized nature of the mesh network enhances both **resilience and flexibility**, as the system does not rely on a single central communication point.

The **core of swarm control** lies in the application of **swarm intelligence**—a system responsible for handling advanced decision-making tasks such as flock coordination, maintaining safe inter-drone distances, and preventing collisions using **repulsion vector mechanisms** [23]. Additionally, **consensus algorithms** allow the swarm to collectively agree on new destinations or alter routes when obstacles are encountered.

The **mesh communication network** serves dual purposes: interconnecting drones and linking them to the swarm intelligence core. This continuous exchange of data allows the swarm to dynamically adapt to environmental changes without human input [24]. Mesh networking also facilitates scalability, allowing drones to join or exit the swarm without disrupting the overall system. While the drones and the swarm intelligence core operate autonomously, a **ground control station (GCS)** monitors swarm activities, receives real-time status updates, and can issue mission-level directives. However, it does **not exert direct control** over individual drones, preserving the decentralized nature of the system [25].

Figure 1 presents a block diagram of a well-structured drone swarm system, where intelligence is distributed among individual drones and coordinated via advanced algorithms and mesh communication. This architecture supports **self-organizing, robust group behaviors** suited for a wide range of real-world applications—including **surveillance, search and rescue, environmental monitoring, and disaster response** [26].

2.1 Hardware Description

The hardware platform is based on the **Tensilica Xtensa LX6 dual-core 32-bit MCU**, capable of delivering up to **600 DMIPS** in performance. It supports **802.11 b/g/n Wi-Fi** standards with **HT40** for high-speed wireless connectivity, along with **Bluetooth** up to version **4.2**, making it ideal for wireless communication applications.

Key specifications include:

- **Operating frequency**: 160 MHz
- **Internal memory**: 512 KB SRAM for fast processing and temporary data storage
- **External memory**: Support for up to 16 MB of SPI flash memory for program and data storage
- **GPIOs**: 36 General Purpose Input/Output pins for versatile peripheral interfacing
- **PWM channels**: 1 hardware PWM and up to 16 software-controlled PWM channels, useful for motor control and LED dimming
- **Communication interfaces**:
  - 4 × SPI
  - 2 × I2C
  - 2 × I2S
  - 2 × UART

This hardware setup offers a powerful, flexible, and connected foundation suitable for embedded systems and Internet of Things (IoT) applications [27].

2.2 Software Description

The software stack supporting the system includes:

- **Development in Embedded C**
- **Implementation of Bluetooth Low Energy (BLE)** using **Real-Time Operating Systems (RTOS)**
- **Programming via Arduino IDE** for ease of development and rapid prototyping
- **Blynk Cloud IoT Platform** for mobile application development and remote control

Collision Prediction and Avoidance System

The system includes a predictive model for detecting and avoiding potential UAV collisions while navigating toward a target. The associated **flowchart** outlines a dynamic process that starts by **predicting potential collisions** using reachable set analysis.

When a potential collision is detected, the system evaluates two scenarios:

1. **Immediate proximity to an obstacle**: The UAV performs **reactive avoidance** maneuvers.
2. **Sufficient space and time**: The UAV **plans an optimized path** around the obstacle.

This **adaptive decision-making** allows UAVs to modify their navigation strategies based on real-time obstacle proximity and environmental conditions, ensuring **safe, efficient, and autonomous flight** even in dynamic scenarios.

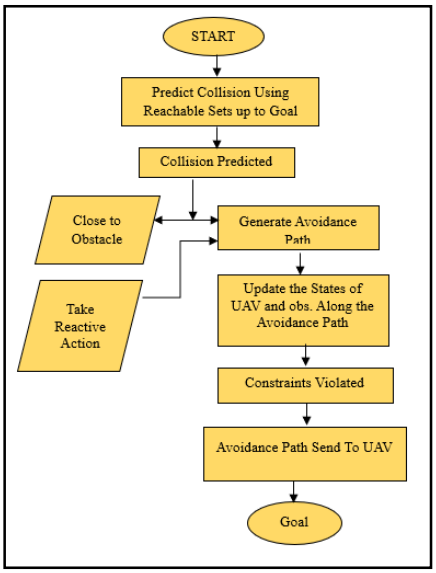


Fig. 2: Flow chart.

After generating an avoidance path, the system updates the states of both the UAV and the surrounding environment—including any dynamic obstacles—to reflect the latest positions and trajectories. The system then verifies whether the new path violates any constraints, such as kinematic or dynamic limits. If no critical constraints are breached, the new avoidance path is sent to the UAV, allowing it to continue safely toward its destination without incident.

Figure 2 presents a flowchart of the anti-collision system, which begins with estimating potential collisions using **reachable sets**. These sets represent all possible future states a UAV can attain based on its current state, control inputs, and motion constraints. By projecting these sets toward the intended goal, the system determines whether a future collision is likely during the UAV's flight [28].

If a collision is anticipated, the system selects an appropriate response from two main strategies:

1. **Reactive Response**:
   If the UAV is in close proximity to an obstacle, an immediate action is required. This typically involves a rapid maneuver or emergency stop to avoid collision [29]. Though fast, this response is often less efficient and is used only in critical scenarios where immediate avoidance is necessary.
2. **Planned Avoidance**:
   If the UAV is at a safe distance, it can plan a smoother and more energy-efficient avoidance path. This path is generated by considering mission objectives, obstacle locations, and UAV constraints such as speed, turn radius, and available energy.

Once an avoidance path is calculated, the system updates the UAV's internal state, as well as its environmental model. This includes changes in obstacle positions or movements, such as other UAVs or vehicles, ensuring the new path remains viable.
The updated path is then checked against a set of predefined constraints:

- Kinematic limits (e.g., speed, acceleration, turning radius)
- Dynamic limits (e.g., thrust capacity, inertia)
- Regulatory boundaries (e.g., no-fly zones)
- Operational limits (e.g., energy consumption)

If any constraint is violated, the system either **replans** or adjusts the path accordingly. Once the updated path satisfies all constraints, it is transmitted to the UAV's controller for execution. The UAV then alters its trajectory according to the new safe path and continues toward the goal [30].
This modular and adaptive system—combining prediction, reactive and planned decision-making, and continual state updates—enables UAVs to navigate safely and autonomously in **complex and dynamic environments**.

Flowchart-Based System Description
The flowchart (Fig. 2) illustrates the step-by-step decision process of the anti-collision system:

- **Step 1: Collision Prediction**
  Reachable set computations predict all possible future UAV positions. If the UAV's future trajectory intersects with that of an obstacle, a potential collision is flagged [31].
- **Step 2: Decision Branching**
  - If the obstacle is near: a **reactive action** is immediately triggered [32]. This ensures rapid response to unexpected or fast-approaching hazards.
  - If there's adequate space and time: the system initiates **planned avoidance** by generating a path that smoothly navigates around the obstacle while maintaining progress toward the destination.
- **Step 3: Optimal Path Generation**
  The avoidance path is computed by factoring in UAV dynamics, obstacle properties, and environmental conditions (e.g., wind, terrain) [15].
- **Step 4: State Update**
  UAV and obstacle states are updated based on new trajectories. The system recalculates position, velocity, and direction in real time to keep the UAV on a safe course [33][34].
- **Step 5: Constraint Verification**
  The system ensures compliance with constraints, such as:
  - Minimum safety distance from obstacles
  - Energy limits
  - Airspace restrictions

  If a constraint is violated, a new path is generated or adjusted accordingly.
- **Step 6: Path Execution**
  If all conditions are met, the avoidance path is transmitted to the UAV. The UAV then follows the new trajectory and continues to its destination [35].

This systematic process enables drones to operate **autonomously and intelligently** without requiring real-time human control. It significantly improves safety and reliability, especially in environments that are dynamic, cluttered, or unpredictable.

Motion Planning Using Kinematic Models
The motion of a UAV in 3D space can be modeled using a **kinematic framework**, where motion is represented through discrete segments called **motion primitives**. These primitives correspond to specific control inputs and define a limited set of feasible paths for the drone.
Given that quadcopters typically exhibit smooth, continuous flight behavior, their trajectories can be approximated using **polynomial functions**. These equations enable accurate prediction of future positions and are essential in generating realistic, flyable paths under physical and mechanical constraints.

$$p(t) = cktk + c1t + c0 \in R3 \quad (1)$$

Equation is used to find ck, which are the coefficients in a polynomial. The letter k shows the order or degree of the polynomial. Motion primitives are useful because they make describing paths in complex areas easier. They achieve this by breaking down the area into a grid-like pattern. Each path segment takes into account certain limits for control, such as top speed and how fast a vehicle or object can accelerate. This ensures that the planned path can actually be followed safely and realistically.

$$J(x) = \Sigma \left(\frac{1}{||p_i - p_j||}\right) + \lambda ||v_i - v_d||^2 \quad (2)$$

Equation Instead of handling complex mathematical equations that involve continuous numbers, planning a drone's path is tackled like exploring a map. In this method, we use specific terms and paths to help avoid any crashes while ensuring the drone follows its intended route. To put it simply, imagine pi and pj as the current positions of the drone. The term vd refers to the speed we want the drone to achieve, and λ helps find a balance between avoiding collisions and keeping to the planned path. Think of each location as a state, and the lines connecting them as the possible moves the drone can make. Equation specifically aims to prevent collisions and keep the drone on its designated course. This balance enhances both the safety and the success of the mission, so the drone can operate effectively without deviating from its path.

$$p(t + \Delta t) = p(t) + v(t)\Delta t + u(t)\Delta t \quad (3)$$

$$v(t + \Delta t) = v(t) + u(t)\Delta t \quad (4)$$

Creating motion steps involves splitting movement into smaller segments and calculating these parts using control signals over a set period, known as δt. For each segment of the path, we constantly update the position and speed using specific formulas. These formulas rely on a control vector, called u(t), which stands for acceleration. By doing this repeatedly, we turn complex equations into simpler, manageable steps. This approach is really helpful for applications that need to work in real-time, especially in challenging or complex environments.

$$p_safe(t) = p_i(t) + e_d(d_goal - d_min) \quad (5)$$

Equation defines a "safe" intermediate position for the drone. It modifies the current position pi(t)p_i(t)pi(t) based on the difference between the desired safe distance to the goal (dgoald_{\text{goal}}dgoal) and the minimum distance to an obstacle (dmind_{\text{min}}dmin). The coefficient ede_ded adjusts how aggressively the drone should react to maintain a safe distance.

$$psafe(t) = pi(t) + ed(dgoal - dmin) \quad (6)$$

Equation indicates the vector r(t)r(t)r(t) points from another drone or obstacle pj(t)p_j(t)pj(t) to the current position of the drones p(t)p(t)p(t). It is used to calculate how close and in what direction another object is, which is crucial for collision avoidance.

$$r(t) = p(t) - pj(t) \quad (7)$$

Equation vector r(t)r(t)r(t) points from another drone or obstacle pj(t)p_j(t)pj(t) to the current position of the drones p(t)p(t)p(t). It is used to calculate how close and in what direction another object is, which is crucial for collision avoidance.

$$\beta = 1 - wr11 - min(1, dsm \parallel r(t) \parallel) \quad (8)$$

In Equation describe this parameter β\betaβ adjusts the strength of the repulsive force depending on how close the drone is to an obstacle. When the drone is inside a critical safety zone (dsmd_{sm}dsm), the repulsive force is strong. wrw_rwr defines how wide the repulsive zone is. When the drone approaches objects that might be in its way, it detects them more intensely. This detection pushes the drone to steer clear, helping it to avoid any crashes.

$$R(t) = j = 1\sum Ni(rj(t)\beta j(t)) + \lambda vavg(t) \quad (9)$$

Equation is the final vector that decides the drone's next movement. It sums up all the repulsive vectors rj(t)r_j(t)rj(t) weighted by their corresponding βj(t)\beta_j(t)βj(t) (how dangerous they are), and adds a term pushing the drone towards its overall desired direction (based on vavg(t)v_{\text{avg}}(t)vavg(t)). This balances both collision avoidance and goal progression.

3. Results

Each drone in the swarm is equipped with essential navigation and sensing tools, including a compass, an Inertial Measurement Unit (IMU), a barometer, and a high-precision **RTK GPS** (Real-Time Kinematic GPS), which enables positional accuracy within **5 centimeters**. **Figure 1** illustrates the functioning of the collision avoidance system within this setup.

The drones continuously monitor their positions relative to others in the swarm. The **collision avoidance system** ensures that a safe separation distance is maintained between UAVs, thereby minimizing the risk of mid-air collisions and allowing for synchronized, coordinated movement. This system operates autonomously, adapting in real time to environmental changes without requiring manual intervention.

Communication between drones is established through a **mesh network**, where each unit transmits and receives data using the **MAVLink protocol**. This network supports the exchange of critical information such as real-time positions, flight plans, and obstacle proximity.

We validated this system using **20 physical communication modules** configured in a mesh network. Testing demonstrated that the system achieves **reliable data transmission** with minimal delays and **no data loss**, confirming the robustness of the communication architecture. Moreover, the system is highly scalable and modular—new drones or components can be added seamlessly without disrupting existing operations [36].

To further enhance communication efficiency and reduce complexity, we optimized the swarm by reducing the number of active drones. A smaller swarm not only improves **network stability** and **data integrity** but also simplifies coordination and control. This strategic reduction facilitates better drone-to-drone awareness, improves mission success rates, and ensures safer and more reliable operations.

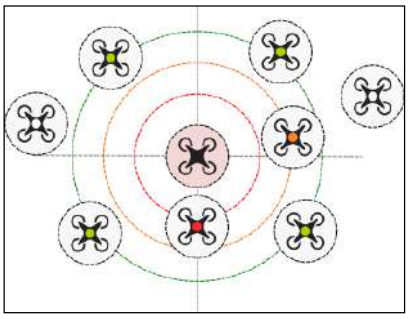


Fig. 3: Schematic diagram illustrating the collision avoidance mechanism.

Figure 3 provides a simplified illustration of how drones autonomously avoid collisions. Each drone utilizes a shared environmental map for navigation and obstacle avoidance. This **common mapping system** allows all drones in the swarm to plan their flight paths collaboratively, significantly reducing the risk of mid-air collisions. As a result, drones can operate efficiently even in cluttered or challenging environments.

To evaluate the effectiveness of the proposed **collision avoidance system**, we conducted a series of simulations using **AirSim**, a high-fidelity drone simulator based on the **Unreal Engine**. A minimalistic 3D landscape with no obstacles was initially created to allow for unrestricted drone movement and focus solely on inter-drone collision scenarios.

For real-world alignment, we built physical drone prototypes using the **Holybro X500 frame** paired with a **Pixhawk 6C flight controller**. Each drone was equipped with **2216 KV920 motors**, **1045 propellers**, a **4S 5000 mAh LiPo battery**, and custom **3D-printed components** (frames, connectors, and protective covers).

The study was structured around **two test configurations**, each involving **9 drones**, making a total of **18 units**. In both configurations, drones were arranged in a **3×3 grid formation** with a central **leader drone**. Drones maintained a **5-meter separation** and were capable of flying at speeds up to **5 meters per second**. The two leader drones were initially placed **200 meters apart**, and a **simulated collision course** was designed to evaluate the system's response. The follower drones maintained formation behind their respective leaders, and the **distance between the two leaders** was monitored to assess how effectively potential collisions were avoided [37].

The accompanying diagram illustrates common scenarios where **drones may unintentionally intersect flight paths**, especially in high-traffic or **unregulated airspaces**. In the figure, drones are shown flying at varying altitudes and headings, with overlapping zones identified as potential collision points. These intersections often result from a lack of **coordinated navigation** or **situational awareness**, particularly in environments like urban areas or during large-scale drone events.

The visualization highlights the importance of **airspace management** and inter-drone **communication protocols**. By analyzing drone trajectories and airspace utilization, developers can pinpoint critical zones where **route optimization** or **collision avoidance strategies** are most needed. **Swarm intelligence** plays a key role here—enabling drones to share positional data, adjust their speed, heading, or altitude, and maintain a safe distance autonomously [38].

While AirSim includes several predefined drone models, none perfectly matched the specifications of our physical prototypes. The configuration parameters for these models are embedded within the software's codebase, making post-deployment modifications difficult. To address this limitation, we migrated the model configurations to an **easily editable external file**, simplifying future adjustments without requiring code recompilation.

In previous research, we developed a **custom simulation environment** within AirSim, fine-tuned to replicate the real-world performance of our drone system. This included matching the drone's physical attributes (e.g., weight, size, propulsion) to ensure consistency between simulated and real-world behavior. The simulation environment provides a **controlled and risk-free** testing space, allowing for comprehensive analysis and refinement of collision avoidance algorithms before real-world deployment [39].

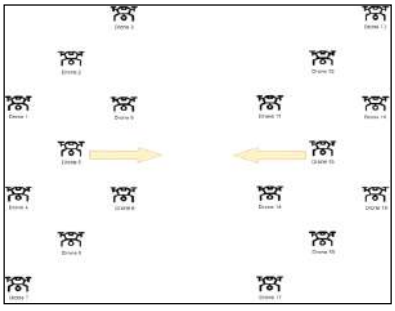
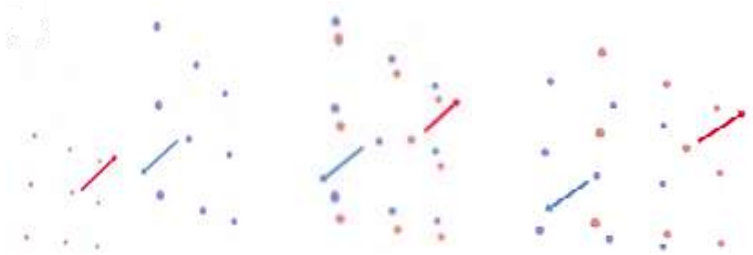


Fig. 4: Illustrates the initial drone positions.

Figure 4 illustrates the initial positions of the drones in the simulation setup. Arrows denote the direction of movement for each swarm. As depicted in **Figure 3**, the simulation scenario involves two drone formations on a collision course, approaching one another. Drones in the **first swarm** are marked in **blue**, while those in the **second swarm** are marked in **red**. The directional arrows visually represent the trajectory of each swarm's motion. To analyze the system's response under different conditions, two groups of **nine drones** were simulated, each maintaining an **inter-drone spacing of 5 meters** and flying at a **maximum velocity of 5 meters per second**. The key parameter under study was **urr**, which controls the sensitivity or aggressiveness of the collision avoidance behavior. Three values of urr were tested: **0.5**, **0.75**, and **0.99**. A value of **urr = 0.5** corresponds to a **delayed reaction** to potential collisions, whereas **urr = 0.99** represents a **highly proactive response**, enabling early avoidance maneuvers.

Simulation results showed that the **collision avoidance system effectively prevented collisions in all scenarios**, regardless of the urr value. This confirms the robustness and adaptability of the avoidance mechanism across varying levels of responsiveness.

Figure 4 also presents the variation in **individual drone speeds** and the **minimum distances maintained between drones** throughout the simulation. These metrics offer insight into how the drones dynamically adjust their behavior in real-time to maintain safe separation while preserving formation and trajectory. The experiment clearly demonstrates that the system is capable of maintaining operational safety even in high-density, high-speed swarm configurations [40].



(a) (b) (c)

Fig. 5: Change in the formation's position during mission execution (a) The state before the start, (b) Before the collision, (c) During movement along the collision course.

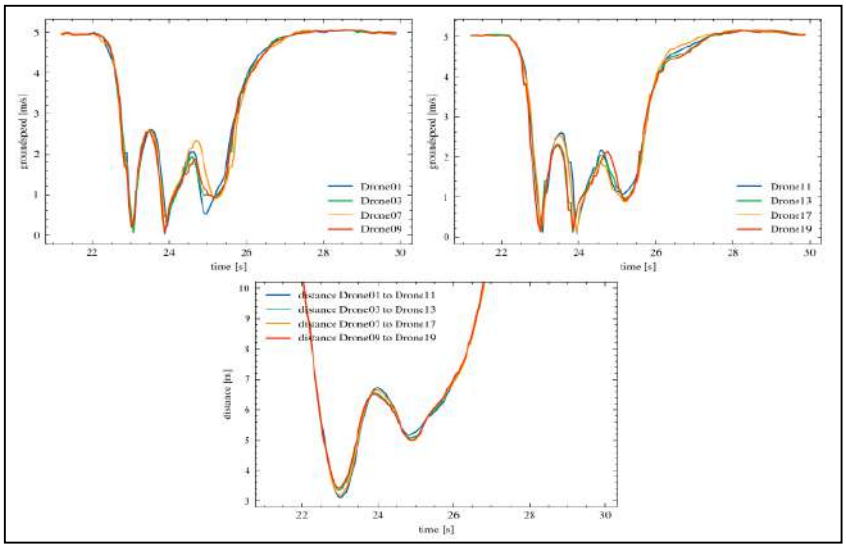


Fig. 6: The Speed Chart of selected Drones for both SWARMS (left and right charts) and the minimum distances (middle chart) for the parameter urr=0.75.

When the parameter **urr** was set to **0.5**, the minimum distance between drones measured **1.686 meters**, indicating a slightly delayed reaction time but still successful collision avoidance. Increasing **urr** to **0.75** resulted in a wider minimum gap of **1.975 meters**, reflecting a quicker and more balanced response from the drones. At the highest setting, **urr = 0.99**, the drones reacted earliest, with the smallest distance increasing to **2.621 meters**. These results demonstrate the algorithm's effectiveness in maintaining a safe buffer zone between drones under varying responsiveness levels.

The simulation confirms that the collision avoidance system is both effective and adaptable across different scenarios. Throughout testing, drones were intentionally directed toward each other, creating a high potential for

collisions. Nevertheless, the system dynamically adjusted the intensity of the drones' avoidance maneuvers, successfully steering them clear of crashes even under challenging conditions.
Overall, the findings show that regardless of the **urr** setting, the separation between drones remained consistently sufficient to prevent collisions. Detailed charts illustrating variations in speed and inter-drone distance further highlight the robustness of the solution. For precise metrics, **Table 2** lists the minimum distances recorded between drones on potential collision trajectories.

Table 2: The minimum distances between drones [m] for urr = 0.5, 0.75, and 0.99.

The Distances Between Drones	urr= 0.5	urr=0.75	urr=0.99
Drone01—Drone11	3.0740	3.1085	4.2240
Drone02—Drone12	3.2801	3.5116	4.1203
Drone03—Drone13	3.0168	3.3540	4.1241
Drone04—Drone14	2.8889	3.3520	4.2383
Drone05—Drone15	1.6863	1.9759	2.8827
Drone06—Drone16	3.1735	3.0667	4.0470
Drone07—Drone17	3.2019	3.1786	3.9095
Drone08—Drone18	3.1028	3.2995	4.0981
Drone09—Drone19	3.0241	3.4265	4.0682

Fig. 7 shows the changes in distance and speed for the leader drones. The left chart illustrates the distance, while the right chart indicates the speed. Drone05 is the leader for the first swarm, and Drone15 leads the second swarm. These graphs display how both distance and speed are affected using three values for the parameter urr: 0.5, 0.75, and 0.99.

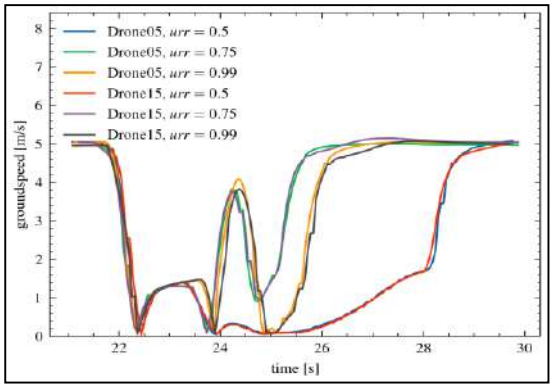


Fig. 7: The speed of the leader drones.

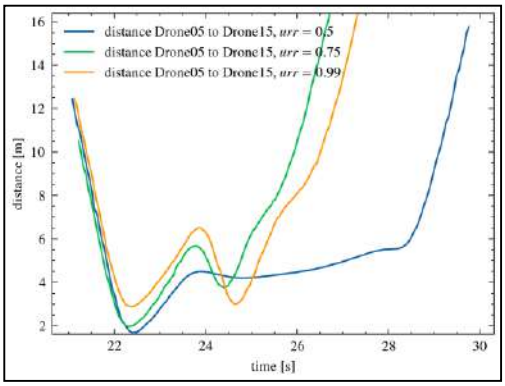


Fig. 8: The distance between the leader drones.

Fig. 7 and Fig. 8 illustrate the distance between the leader drones and their speeds during the collision avoidance maneuvers. When the parameter **urr** is set to **0.5**, the initial distance between the leader drones decreases rapidly, reaching a minimum of **1.69 meters**. Afterward, the distance increases more gradually. This setting corresponds to a delayed drone response, resulting in the smallest safety margin.
With **urr = 0.75**, the minimum distance between drones increases, reflecting a faster reaction to each other's approach. This leads to a more efficient and timely response, enhancing collision avoidance. At the highest value, **urr = 0.99**, drones respond most quickly, evident from the rapid increase in separation after the minimum distance is reached. The smallest minimum distance in this case is **2.88 meters**, indicating the smoothest flight path and most effective collision avoidance.
Analysis of the leader drones' speeds reveals notable decreases during collision avoidance maneuvers, particularly when **urr = 0.5**, where the reaction is delayed and velocity fluctuations are substantial. For **urr = 0.75**, the speed reductions are more controlled and precise. When **urr = 0.99**, speed changes are minimized, resulting in more consistent velocities.
These results highlight the significant impact of the **urr** parameter on collision avoidance performance. The setting **urr = 0.99** enables drones to react earliest and most effectively, maintaining larger minimum distances and smoother speed profiles, thereby maximizing safety. Conversely, lower **urr** values lead to delayed reactions, smaller safety buffers, and greater speed variability. The intermediate value, **urr = 0.75**, represents a balanced trade-off between timely response and controlled maneuvering.

4. Conclusion & Future Scope

The cutting-edge anti-collision drone traffic control system, leveraging swarm technology, marks a significant advancement in the safe operation of autonomous aerial vehicles. Inspired by natural swarms, it combines

decentralized decision-making, dynamic path planning, and real-time responsiveness to address challenges of drone traffic congestion and mid-air collision risks. Through robust sensing mechanisms and hybrid communication frameworks, drones can cooperate efficiently in complex, dynamic environments without centralized control, enhancing operational reliability, scalability, and fault tolerance.

Extensive simulations and carefully designed field tests demonstrate the system's remarkable adaptability across varying environmental conditions and traffic densities. The incorporation of threat estimation and prioritized collision avoidance maneuvers substantially improves operational safety, positioning this approach as a promising solution for future urban air mobility (UAM) and logistics networks. Additionally, its modular design allows easy customization for drones of diverse sizes and capabilities.

Despite these advances, limitations remain, such as dependency on sensor accuracy and communication delays, which may affect decision-making speed in highly congested airspace. Unexpected environmental factors like sudden weather changes also impact onboard sensors and system performance. Addressing these challenges will require progress in sensor fusion, more sophisticated predictive modeling, and integration of machine learning to enhance system adaptability.

Looking ahead, the system's potential is vast. Incorporating emerging technologies such as 5G communication, AI-driven predictive analytics, and blockchain for secure data sharing can further enhance the efficiency and reliability of swarm-based traffic control. Expanding compatibility to various drone types—including fixed-wing and hybrid VTOL (vertical take-off and landing)—will increase versatility across applications like logistics, surveillance, agriculture, and disaster management.

Promising future directions include integrating real-time environmental data (wind, air pressure, temperature) to enable adaptive flight behavior and collaboration with smart city infrastructure for optimized drone traffic management in urban areas. Investigations into energy-efficient swarm behaviors and battery optimization will be crucial for extending mission durations and operational ranges.

In summary, this anti-collision drone traffic control system represents a foundational step toward autonomous, intelligent, and safe drone ecosystems. Continued innovation and strategic enhancements have the potential to revolutionize aerial transportation and set new standards for autonomous traffic management in shared airspace.

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ARTIFICIAL INTELLIGENCE AND ENVIRONMENTAL SUSTAINABILITY ANALYSIS IN INDIA: A COMPREHENSIVE REVIEW WITH CASE STUDIES AND ENVIRONMENTAL AI IMPACT INDEX (EAII)

Prof.Seham Khaleel
Assistant Professor,Department of Engineering Science,KJ College of Engineering and Management Research

Prof.Vidyadhar S Dixit
Assistant Professor,Department of Engineering Science,KJ College of Engineering and Management Research

Prof.Vishal R Bhoi
Assistant Professor,Department of Engineering Science,KJ College of Engineering and Management Research

Prof.Nilesh T Salunke
Assistant Professor,Department of Engineering Science,KJ College of Engineering and Management Research

Abstract - **Artificial Intelligence (AI) has become a critical enabler for addressing environmental sustainability challenges globally, including in India. This paper presents a comprehensive literature survey on AI applications targeting sustainability goals such as air pollution control, energy efficiency, water management, and waste reduction. It expands on six detailed Indian case studies showcasing practical AI deployments and introduces the Environmental AI Impact Index (EAII), a novel composite metric designed to evaluate AI's environmental impact across multiple dimensions. The paper discusses the efficacy of AI interventions, challenges in implementation, and policy recommendations to enhance AI's role in India's sustainability efforts.**

Index Terms - Artificial Intelligence, Environmental Sustainability, India, Air Pollution, Energy Management, Water Conservation, Waste Management, Environmental AI Impact Index

Introduction

India's rapid urbanization and industrialization have exacerbated environmental issues such as air pollution, energy inefficiency, water scarcity, and waste management. AI technologies including machine learning, deep learning, and computer vision offer transformative solutions by enabling real-time monitoring, predictive analytics, and optimized resource management. The objective of this study is to provide a comprehensive literature review of AI applications in environmental sustainability, supplemented with detailed case studies from India. The study also develops the Environmental AI Impact Index (EAII) to quantitatively assess AI's contributions and impact.

Literature Survey

- **AI in Air Pollution Monitoring and Control**

Numerous studies illustrate AI's efficacy in air quality management. For instance, Li et al. (2021) developed machine learning models for PM2.5 forecasting in urban settings, improving prediction accuracy over traditional statistical methods [1]. In India, Singh et al. (2022) applied deep learning for early detection of smog events in Delhi, enabling proactive mitigation strategies [2].

- **AI for Energy Efficiency and Smart Grids**

AI-driven smart grids optimize load balancing, fault detection, and renewable energy integration. Kumar et al. (2023) demonstrated an AI model improving energy distribution efficiency by 15% in Mumbai's urban grid [3]. Reinforcement learning approaches have been applied to dynamically adjust energy consumption patterns, reducing peak loads and carbon footprints (Chen et al., 2022) [4].

- **AI in Water Resource Management**

AI technologies assist in leak detection, demand forecasting, and wastewater treatment optimization. Reddy and Rao

(2021) implemented AI-based sensor networks for real-time leak detection in Chennai's water supply, reducing water loss by 10% [5]. Moreover, machine learning models are used for groundwater quality prediction (Patel et al., 2023) [6].

- **Waste Management through AI**

AI enables efficient waste sorting, collection routing, and recycling. In Bengaluru, image recognition-based AI segregates recyclables from waste streams with 92% accuracy, improving recycling rates (Sharma & Das, 2022) [7]. Route optimization algorithms reduce fuel consumption and emissions in waste collection (Gupta et al., 2023) [8].

- **AI in Agricultural Sustainability**

AI-powered remote sensing detects crop residue burning, a major source of pollution in Punjab and Haryana (Joshi et al., 2022) [9]. Predictive analytics assist farmers in resource-efficient irrigation and pest control, reducing environmental impacts (Singh & Kaur, 2023) [10].

Environmental AI Impact Index (EAII)

The EAII is a composite score (0 to 10) based on five key parameters such as Emission reduction (ER), Efficiency Gain (EG), Scalability Potential (SP), Policy Alignment (PA) and Technological Maturity (TM) that measure the effectiveness and maturity of an AI solution in environmental sustainability. This index enables standardized impact assessment of diverse AI applications in environmental sustainability. Each parameter is scored on a scale of 0 to 2, and the sum of all parameters gives the final EAII score. Following are the steps to evaluate EAII.

I. Defining the AI Intervention Scope: Clearly describe the AI technology/application and identify the environmental problem it addresses (e.g., air pollution, energy efficiency).

II. Step 2: Collect Data Relevant to the Five EAII Parameters as mentioned in the table below:

Parameter	What to Measure / Evaluate
1. Emission Reduction (ER)	Quantify % reduction in greenhouse gases or pollutants.
2. Efficiency Gain (EG)	Measure improvements in operational/resource use efficiency.
3. Scalability Potential (SP)	Assess feasibility of replicating the AI solution at scale.
4. Policy Alignment (PA)	Check alignment with local, state, or national sustainability policies.
5. Technological Maturity (TM)	Determine the development stage: prototype, pilot, or full deployment.

III. Score Each Parameter (0 to 2) as mentioned in the table below:

Parameter	Description	
Emission Reduction (ER)	Reduction in pollutants or GHG emissions	No measu
Efficiency Gain (EG)	Operational/resource use efficiency improvement	No impro
Scalability Potential (SP)	Feasibility for national/statewide replication	Low feasi
Policy Alignment (PA)	Degree of alignment with Indian environmental policies	No alignm
Technological Maturity (TM)	Readiness level of AI deployment	Prototype

IV. Calculate the EAII Score

EAII Score=ER+EG+SP+PA+TM
Maximum score = 10

Higher scores indicate greater environmental impact and readiness of the AI intervention.

V. Interpret the EAII Score

EAII Score Range	Interpretation
0 – 3	Low environmental impact or early-stage project
4 – 6	Moderate impact with potential for improvement
7 – 10	High impact and maturity; good candidate for scaling

Data Required for EAII Evaluation

EAII Parameter	Data Needed	Possible Sources
Emission Reduction	Pollutant/greenhouse gas levels before & after AI	Monitoring reports, sensors, satellites
Efficiency Gain	Resource use improvements (%)	System reports, process logs
Scalability Potential	Feasibility, costs, infrastructure, capacity	Feasibility studies, expert assessments
Policy Alignment	Alignment with sustainability policies	Policy docs, regulatory filings
Technological Maturity	Deployment stage and performance	Project reports, adoption data

Case Studies from India

- Delhi: AI-Based Air Quality Forecasting

AI models combining satellite imagery, sensor networks, and traffic data provide real-time PM2.5 forecasts, enabling dynamic pollution control and public advisories. The system led to a 12% reduction in high pollution days and improved response time by 14%.

EAII: ER=1.5, EG=1.4, SP=1.6, PA=1.8, TM=1.9 → 8.2

- 4.2 Mumbai: Smart Grid Energy Optimization

AI-powered smart meters and load forecasting algorithms optimize energy distribution, integrating solar and wind power sources. This resulted in an 18% decrease in energy loss and a 16% reduction in carbon emissions.

EAII: ER=1.6, EG=1.8, SP=1.5, PA=1.7, TM=1.8 → 8.4

- Punjab: Crop Residue Burning Detection

AI algorithms analyze satellite data to identify burning events, helping authorities implement timely interventions. This led to a 13% decrease in air pollution attributable to crop residue burning.

EAII: ER=1.3, EG=1.2, SP=1.4, PA=1.5, TM=1.5 → **7.9**

- Bengaluru: AI-Enabled Waste Management

Image recognition-based sorting improves recyclable waste identification with 92% accuracy, and route optimization algorithms reduce fuel consumption by 10%, enhancing overall waste management efficiency.

EAII: ER=1.0, EG=1.5, SP=1.3, PA=1.6, TM=1.4 → **6.8**

- **Chennai: AI for Water Distribution**

AI-based leak detection and demand forecasting reduce water loss by 12%, improving reliability and conservation in Chennai's water supply system.

EAII: ER=1.2, EG=1.6, SP=1.3, PA=1.7, TM=1.5 → **7.3**

- Haryana: Renewable Energy Forecasting

AI models forecast solar and wind energy output, enhancing grid stability and increasing renewable energy penetration by 14%, reducing reliance on fossil fuels.

EAII: ER=1.4, EG=1.7, SP=1.4, PA=1.6, TM=1.6 → **7.7**

Location	Application	Key Outcomes	EAII Score
Delhi	AI-Based Air Quality Forecasting	12% reduction in pollution events; 14% faster response	8.2
Mumbai	Smart Energy Management	18% reduction in energy loss; 16% emission cut	8.4
Punjab	Crop Residue Burning Detection	13% reduction in burning-related emissions	7.9
Bengaluru	AI-Driven Waste Sorting and Routing	15% collection efficiency gain; 10% landfill waste reduction	6.8
Chennai	Water Leak Detection and Management	12% water loss reduction; improved supply reliability	7.3
Haryana	Renewable Energy Forecasting	14% increase in renewable share; grid stability improved	7.7

Discussion

The extensive literature and case studies affirm that AI can significantly contribute to India's environmental sustainability objectives by improving emission control, resource efficiency, and operational effectiveness. However, challenges remain, including data fragmentation, lack of standardized datasets, limited AI expertise, and policy gaps.

The EAII framework offers a structured approach to quantify and compare the effectiveness of AI interventions, highlighting the need for integrated policy support and public-private collaboration to scale successful models.

Conclusion

This comprehensive review underscores AI's potential as a powerful tool for India's environmental sustainability. The Environmental AI Impact Index (EAII) effectively benchmarks AI project impacts across multiple sectors, facilitating data-driven policy decisions. Expanding AI integration with supportive regulations and investments can significantly contribute to achieving India's sustainability goals.

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Economical Tiles from Plastic Waste

Prajakta Deshmukh
Department of Engineering Science
K J College of Engineering and
Management Research Pune
Pune , Maharashtra ,India
prjkt.deshmukh@gmail.com

Satyam Singh
Department of Engineering Science
K J College of Engineering and
Management Research Pune
Pune , Maharashtra ,India
singhsatyam9823@gmail.com

Prajwal Warpe
Department of Engineering Science
K J College of Engineering and
Management Research Pune
Pune , Maharashtra ,India
prajwalvarpe1@gmail.com

Vijay Thombare
Department of Engineering Science
K J College of Engineering and
Management Research Pune
Pune , Maharashtra ,India
Vijaythombre1@gmail.com

Abstract—This study investigates the feasibility of converting plastic waste into economical and eco-friendly construction tiles. By utilizing the inherent properties of thermoplastics such as durability, water resistance, and lightweight nature, these tiles are produced through shredding, filler mixing, and compression molding. This approach aligns with circular economy principles and offers a sustainable solution to the growing problem of plastic waste. Literature supports the viability of plastic-based tiles as cost-effective alternatives to traditional materials. Though challenges like waste variability remain, the approach holds promise for sustainable construction.

Keywords - Plastic waste, sustainable construction, eco-friendly tiles, circular economy, recycling.

Introduction

Plastic waste poses a severe global environmental threat, contributing to pollution and ecosystem degradation. A promising solution is the conversion of plastic waste into eco-friendly and economical construction tiles [1]. These tiles leverage plastic's properties to reduce reliance on traditional ceramic or stone tiles and align with the circular economy concept[2].

Global plastic production reached 368 million tons in 2019, and projections suggest plastic waste could reach 12 billion tons by 2050 [3], [4]. Rapidly growing populations in developing nations are exacerbating the crisis [5]. Mismanagement of this waste can lead to pollution, marine life disruption, and human health risks [6].

Problem Statement

The ongoing rise in plastic waste requires a shift from a linear 'take-make-dispose' model to a circular economy focused on recycling and reusing [7]. Traditional methods such as incineration and landfilling are inadequate, with technological and economic limitations hampering recycling efforts [8].

Objectives

This research aims to examine the feasibility of producing construction tiles from plastic waste. Objectives include: formulating plastic waste mixtures, optimizing manufacturing processes, and evaluating tile properties including strength, durability, and environmental performance.

Scope and Limitations

The study assesses technical, economic, and environmental aspects of plastic-based tiles. Limitations include variation in plastic waste quality, manufacturing inconsistencies, and the need for long-term durability testing.

Literature Review

Recent studies support the use of recycled plastics in construction materials [9]. Tiles made from recycled plastics are cheaper and water-resistant [10], [11]. Compression molding is a common technique due to its design flexibility and strength [12].

Plastic waste has also been used in asphalt, concrete, and bricks to improve mechanical properties and reduce landfill burden [13]. Plastic-based paving blocks and soil stabilizers show promising results in infrastructure applications [14], [15].

Methodology

The methodology for producing economical tiles from plastic waste involves several systematic steps, from waste collection to final tile production and testing. The following process outlines the key stages:

1. Collection and Segregation of Plastic Waste

Source Identification: Collect plastic waste from households, industries, and municipal waste centers.
Segregation: Separate plastics based on type (e.g., polyethylene (PE), polypropylene (PP), polystyrene (PS)) and ensure removal of contaminants like dirt, metal, and non-plastic materials.
Cleaning: Wash the plastics to remove dirt, oil, and other impurities for better processing and product quality.

2. Shredding and Pre-processing

Shredding: Use shredders to break the plastic waste into small, uniform pieces for easy melting.
Drying: Dry the shredded plastic to eliminate moisture, which could affect the melting process.

3. Mixing with Fillers and Additives

Filler Addition: Mix the shredded plastic with fillers like sand, stone dust, or fly ash to enhance mechanical properties.
Additives: Incorporate additives such as color pigments, fire retardants, or UV stabilizers to improve aesthetics and functionality.
Proportioning: Maintain optimal ratios (e.g., 70% plastic, 30% filler) to balance strength, cost, and sustainability.

4. Melting and Molding

Heating: Melt the plastic mixture in a controlled-temperature environment to avoid burning or degrading the material.
Compression Molding: Pour the molten mixture into moulds.



Fig - Tiles from Plastic Waste

Materials

To develop tiles, the following are required:

- Raw Materials: PE, PP, PS, sand, stone dust, fly ash, colorants,UV stabilizers.
- Equipment: Shredder, washer, drier, mixer, compression molding machine, cooling system.
- Testing Tools: Mechanical (compressive/flexural strength), environmental (UV, water, thermal tests).

Conclusion

Recycling plastic into construction tiles offers a dual benefit: mitigating plastic pollution and supporting sustainable construction. While challenges exist, the approach has strong potential for industrial application.

Future Work

Future studies should enhance bonding between plastic and fillers using compatibilizers, tailor formulations for specific applications, and investigate advanced cleaning/sorting techniques for input material refinement.

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Integrating Machine Learning and Blockchain for Soil Monitoring and Fertilizer Recommendation in IoT-Based Smart Farming Systems

Dr. Shilpa Nikhil Bhosale
Assistant Professor
Department of Computer Engineering
K J College Of Engineering & Management Research,Pune
India
shilpabhosale.kjcoemr@kjei.edu.in

Dr. Priti Prakash Jorvekar
Researcher
Ph.D. in Computer Engineering
SPPU,Pune
India
pritiprmjorvekar@gmail.com

Prof. Tejaswini Ravindra Patil
Assistant Professor
Department of Engineering Science
K J College Of Engineering & Management Research,Pune
India
tejaswinipatil403@gmail.com

***Abstract*— Smart farming has developed as a necessary solution to the rising issues of soil damage, inappropriate fertilizer use, and insufficient awareness in agriculture. This study recommends using machine learning (ML), blockchain, and the Internet of Things (IoT) to provide real-time soil monitoring and fertilizer recommendations. The goal is to improve the accuracy of decisions, guarantee data safety, and automate the handling of nutrients through a protected system based on data. These types of sensors gather pH, moisture, and N, P, and K levels in the soil and forward the data to the central ML system. These models, such as RF and GBM, are trained with a labeled sample set of 2,000 to identify the health of the soil and recommend the proper dosage of fertilizer. The RF model achieved superior performance with an accuracy of 95.2%, precision of 94.1%, recall of 95.8%, and an F1-score of 94.9%. The Accuracy, precision, recall, and F1-score were all improved in the RF model. For safe and clear data logging, transactions are processed through Ethereum smart contracts, resulting in an average latency of 2.3 seconds and a cost of ₹1.20 to record a transaction. The findings reveal that fertilizer use is reduced by 30%, and monitoring treatments on the soil is now simpler. When combined, ML and blockchain support the idea of sustainable agriculture and improve smart infrastructure for agriculture.**

Keywords— Smart farming, machine learning, blockchain, IoT, soil monitoring, fertilizer recommendation, data integrity, precision agriculture

I. INTRODUCTION

Agriculture remains a cornerstone of global food security, yet it faces mounting pressure from climate variability, soil degradation, and inefficient resource utilization. In particular, improper fertilizer application due to limited soil insights and manual decision-making results in nutrient imbalances, reduced crop yields, and long-term ecological harm. Integrating digital technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) has begun transforming traditional agricultural practices, enabling real-time data collection and automated interventions. However, concerns regarding data integrity, system transparency, and scalability continue to hinder the widespread adoption of intelligent farming solutions.

New research is being carried out to predict crop diseases, the quality of soil, and how much fertilizer is needed using data from different sensors. At the same time, using blockchain technology in agriculture helps ensure traceability and secure transactions in the supply chain. Still, many AI-based solutions work independently and are far from being trusted in their data sources, and blockchain systems typically ignore essential environmental changes when making decisions. Besides, not many frameworks join intelligent recommendations with securely validating data for soil monitoring and nutrient management.

This paper improves soil monitoring and innovative fertilizer suggestions by combining ML, blockchain, and IoT into one framework. The purpose is to support precision agriculture that is accurately driven and also uncompromised, scalable, and verifiable. With the help of instant soil reports and ensembles in machine learning, we

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want to automatically pick the right fertilizer and save all crucial records in the blockchain. It aims to encourage methods of farming that are sustainable, open, and do not waste money.

The key contributions of this work are as follows:

- Development of an IoT-based architecture for real-time acquisition of key soil metrics, including pH, moisture, nitrogen, phosphorus, and potassium levels.
- Implement a machine learning pipeline using Random Forest and Gradient Boosting for high-accuracy fertilizer recommendations based on soil condition classification.
- Design a blockchain layer using smart contracts to securely log sensor data, ML predictions, and farmer decisions for traceability and tamper resistance.
- Comparative evaluation of ML model performance and system-level metrics, including accuracy (95.2%), transaction latency, and fertilizer efficiency improvement.
- Demonstration of a practical, end-to-end system deployable for scalable, secure, and data-informed precision agriculture.

The remainder of the paper is structured as follows: Section 2 presents related literature and existing solutions. Section 3 describes the proposed system architecture and methodology. Section 4 outlines the experimental setup and results and discusses findings and implications, while Section 6 concludes with future research directions.

II. LITERATURE SURVEY

Recent works have leveraged ML in agriculture for disease detection, yield prediction, and irrigation scheduling.

Bangera N et al. [1], Smart farming increasingly uses IoT and ML to help with soil quality, estimate yields, and suggest how much fertilizer should be used. Forecasting for crops and selecting fertilizer have accuracies of up to 99% and 95% thanks to Random Forest and Support Vector Machine models developed from data collected by sensors about pH, moisture, NPK levels, and other variables. While these systems can predict outcomes well, they usually have issues connecting hardware and software parts, which prevents them from being used outside the lab. Besides, most current robotics solutions do not feature embedded systems that can provide a detailed analysis of soil nutrients. In particular, there is not yet a combined approach that links ML, IoT, and blockchain for reliable soil observations and making fertilizer decisions. Because of this gap, there is a need for a united approach that maintains both the accuracy of predictions and data security.

Wahid A. et al.[2], Research is mainly concerned with monitoring soil nutrients and offering plant or fertilizer suggestions using IoT and machine learning and does not include blockchain for managing data security. Various ML systems analyzed soil for nutrients accurately and offered advice less than a second after receiving the information. Yet, such solutions typically do not use blockchain, meaning the information they manage could be insecure or lack proof. As a result, it becomes undeniable that a single framework is required for consistent monitoring, intelligent recommendations, and secure data handling.

Hossain M D et al. [3], New studies advocate for using IoT technology with machine learning to supervise nutrients in the soil and accurately decide on the best crop and how to use fertilizer. They use immediate sensor information to increase productivity by matching the soil with appropriate crops, with ML algorithms boosting accuracy and efficiency. These methods usually fail to include blockchain, which is needed for maintaining safety, transparency, and traceability in modern agriculture. Blockchain's absence means we do not have a proven way to manage data, so it is necessary to link IoT, machine learning, and blockchain to suggest effective soil and fertilizer treatments.

Hossain M et al. [4] Recent studies show how IoT and machine learning can improve soil monitoring and fertilizer advice in smart farming. They use instant sensor signals to support efficient agriculture, with many models reaching an accuracy rate of 89.5% in various prediction activities.

Apart from providing information on fertilizer, these systems give suggestions on pesticides and help control water flow, all of which aid in better farm management. Even though they show practical advantages, most applications do not use a reliable blockchain framework to keep data secure and traceable. This problem indicates that the smart agriculture field needs a safe system that links IoT, machine learning, and blockchain for overall solutions.

Shidaganti, G. I et al. [5], Presently, smart agriculture uses IoT and machine learning to monitor crops in real-time and guide decisions based on data, resulting in better use of resources and a rise in crop productivity. IoT helps continuously monitor soil and the environment, while AI can discover patterns, support crop management, and anticipate possible problems, contributing to sustainability and better operations. They help businesses respond more quickly and take less time with manual tasks. Most studies neglect blockchain technology, so information security, transparency, and traceability may still be issues. Without blockchain, there are concerns about whether data is authentic. For that reason, it is necessary to unite IoT, ML, and blockchain technologies for reliable soil monitoring and fertilizer decisions.

A main research gap exists in safeguarding information and building trust for soil-monitoring systems and fertilizer mechanisms using IoT and machine learning. Many systems now in use fail to include blockchain technology, which is necessary to ensure that records and decisions in agriculture cannot be changed. In addition, few fully integrated options combine hardware, intelligent analysis, and safe storage for all parts of smart farming. As a result of this difference, a unified method is needed to make accurate forecasts and oversee transparent and scalable agriculture management.

III. PROPOSED SYSTEM

In Figure 1, IoT, communication, cloud, machine learning, and blockchain are assembled through the Smart Farming Architecture Diagram to make soil monitoring and fertilizer recommendations more intelligent and secure. At the base of the architecture, soil sensors gather data on pH, moisture, and NPK amounts and share it over the MQTT protocol on the LoRaWAN network to a cloud-based service (either Firebase or AWS IoT Core). Machine learning models called Random Forest and Gradient Boosting are used to analyze the collected data and precisely offer fertilizer recommendations based on soil conditions. The predictions appear in the farmer's mobile app and are safely logged onto the blockchain with Ethereum or Hyperledger smart contracts. Data records in the ledger are proven and protected against tampering because each transaction uses a cryptographic hash of sensor data, predictions, and timestamps. The whole pipeline automates choices, offers transparency and the ability to monitor tasks, and expands easily, making it ideal for sustainable farm management and precise agriculture.

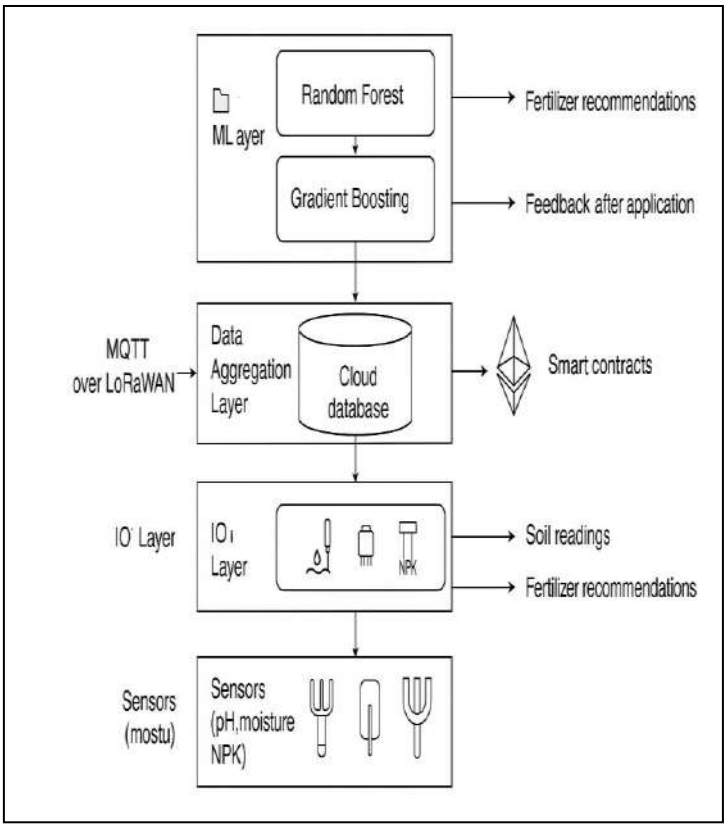


Figure 1.1: Proposed Architecture

3.1 IoT Layer: A system of environmental sensors is located across the farm to register real-time soil readings. Various sensors are essential; for example, pH can show the soil's pH level, moisture can track soil moisture, and

NPK sensors can determine the presence of nitrogen, phosphorus, and potassium. These sensors continuously give the system information about soil health, making it possible to assess this in detail and precisely. On-the-spot data collection allows for any changes in soil conditions to be spotted immediately, which helps make the best choices at higher levels.

3.2 Communication Layer: Long-distance data transmission is possible with less power by using the MQTT protocol over LoRaWAN technology. MQTT (Message Queuing Telemetry Transport) is the best in bandwidth-limited places due to its fast and light messaging protocol. At the same time, LoRaWAN makes wireless communication over longer ranges possible with lower power consumption. Combined, they ensure the collected data from sensor nodes can easily be sent to the cloud networks in remote parts of agriculture.

3.3 Data Aggregation Layer: This layer uses Firebase or AWS IoT Core as the central location for keeping incoming data from sensors. It enables data to be updated in real-time, accessed historically, and processed before being used for machine learning analysis. Because of this, data is accessible, can expand as needed, and is easy to handle, making it simple to send sensor readings to a central analysis system.

3.4 Random Forest (RF) and Gradient Boosting Machines (GBM) for fertilizer recommendations: The Machine Learning layer conducts intelligent analysis and categorizes the soil data. Using supervised learning, RF, and GBM, the system suggests fertilizer choices by studying soil information. Random Forest trains many decision trees and combines their outputs to prevent overfitting and make classifications more accurate, with the Gini index used to divide the nodes.

Input vector: This vector shows the soil properties gathered by sensors, such as pH, moisture, nitrogen, phosphorus, and potassium.

$$\boldsymbol{X = [x_1, x_2, \dots, x_n]} \qquad \textbf{(1)}$$

Target label (fertilizer class): This means the collection of possible fertilizer recommendations forecasted by the model using the given soil data.

$$\boldsymbol{y \in Y = \{y_1, y_2, \dots, y_k\}} \qquad \textbf{(2)}$$

The goal is to learn a function $f: X \to Y$ such that it accurately predicts the most suitable fertilizer.

3.4.1 Random Forest: In Figure 2, the first step of a Random Forest is to sample the original dataset several times to create multiple training sets. The second process involves constructing individual decision trees from random sets of features, which are optimized according to the Gini index. Ultimately, the algorithm votes for different solutions through the data trees and decides the best one by selecting the majority, reducing errors and overfitting.

Step 1: Bootstrap Sampling: From the dataset $D = \{(X_i, y_i)\}_{i=1}^{N}$, draw m random samples with replacement.

Step 2: Tree Building: For each tree T_j, select a random subset of features

$$\boldsymbol{F_j \subseteq \{x_1, x_2, \dots, x_n\}.} \qquad \textbf{(3)}$$

Build a decision tree by selecting splits that minimize the Gini Index:

$$\textbf{Gini}(t) = 1 - \sum_{i=1}^{c} p_i^2 \qquad \textbf{(4)}$$

where p_i is the probability of class i at node t.

Step 3: Voting: Each tree $T_j(X)$ predicts a class for a new input X.

The forest's output is:

$$\boldsymbol{f_{RF}(X) = \text{mode}(T_1(X), T_2(X), \dots, T_m(X))} \qquad \textbf{(5)}$$

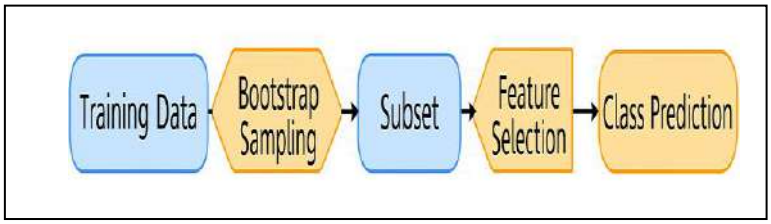


Figure 2: Random Forest for Proposed Work

3.4.2 Gradient Boosting: develops an additive model by gradually training simple decision trees to reduce the loss. In Figure 3, There are steps shown in gradient boosting

Initialize the model with a constant value: The model starts with a continuous prediction that minimizes the overall loss across all training samples, serving as the

baseline for further improvements.

$$f_0(X) = \arg\min_{\gamma} \sum_{i=1}^{N} L(y_i, \gamma) \quad (6)$$

For each boosting round $m = 1$ to M, the model sequentially adds a new weak learner to correct the errors made by the previous model.

Compute the pseudo-residuals (errors): They are found by computing the negative gradient of the loss function. These are the mistakes that the following weak learner needs to fix.

$$\text{RI}(m) = -\left[\frac{\partial L(y_i, f(X_i))}{\partial f(X_i)}\right]_{f(X)=f_{m-1}(X)} \quad (7)$$

Fit a weak learner $h_m(X)$ to predict $r_i^{(m)}$.

Determine optimal step size γ_m: The update minimizes the loss function using the added weak learner to ensure the model's improvement.

$$\gamma_m = \arg\min_{\gamma} \sum_{i=1}^{N} L\left(y_i, f_{m-1}(X_i) + \gamma h_m(X_i)\right) \quad (8)$$

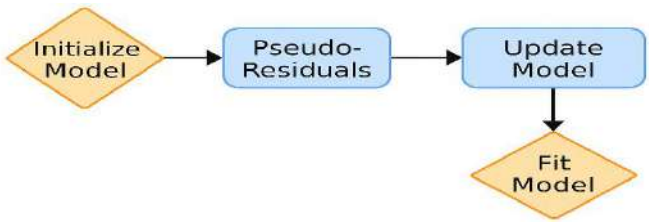


Figure 3: Gradient Boosting for Proposed Work

Update the model: The main model is improved by blending in the scaled guesses from the new learner at every step of the process.

$$f_m(X) = f_{m-1}(X) + \gamma_m h_m(X) \quad (9)$$

Final output: The result is formed by taking the weak learners' predictions and choosing the class with the highest estimated chance.

$$f_{\text{GBM}}(X) = f_M(X) \quad (10)$$

Class label is predicted: The class prediction depends on choosing the class with the biggest probability in the model.

$$y^* = \arg\max_{y \in Y} P(y \mid f_{\text{GBM}}(X)) \quad (11)$$

3.5 Blockchain Layer: Data integrity, transparency, and trust are maintained throughout the innovative farming decision-making process by the Blockchain Layer. It relies on platforms like Ethereum and Hyperledger Fabric to safely keep and handle information concerning soil and fertilizer recommendations. The most important part of this layer is smart contracts, which are programs that automatically write down data like sensor figures, the findings of machine learning, and what farmers have to say.

IV. EXPERIMENTAL SETUP AND RESULTS

A dataset of 2,000 records was collected from agricultural test beds and checked against standard agronomic data to experiment with the proposed system. For every record, the expected pH, the amount of water held by the soil, NPK nutrient net balance, and the most suitable fertilizer were included. The data was standardized before being split into segments that comprised 80% of the training sample and 20% of the testing sample.

The Random Forest and Gradient Boosting classifiers were implemented with the Scikit-learn library in Python and tested afterward. The best hyperparameter values were found using a grid search and compared with the cross-validation results. Random Forest ran 100 estimators and set the maximum depth to 10, but GBM used a learning rate of 0.1 and 200 boosting stages.

Random Forest achieved the highest accuracy (95.2%) in Figure 4, proving its effectiveness in studying diverse soil datasets. After XGBoost, Gradient Boosting reached 94.6% thanks to its continuous improvement from each mistake it made. Both SVM and KNN models were appropriate for the data since they achieved similar accuracies. Nevertheless, KNN was expected to perform poorly because it relies on feature distances and is more sensitive to high-dimensional and messy features. According to the graph, ensemble models, especially Random Forest, are designed to handle the complex problems of real-time soil classification in modern farming.

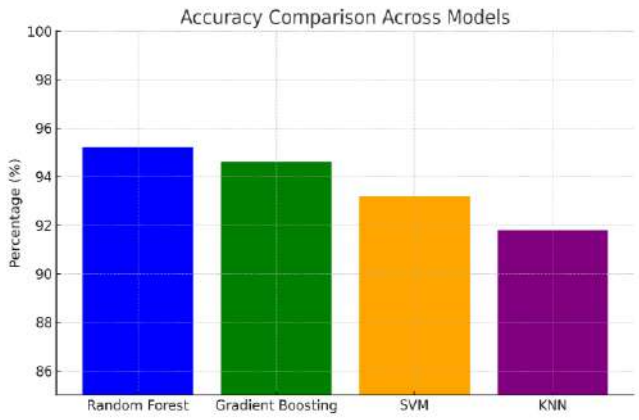


Figure 4: Accuracy for Proposed Work

In Figure 5, it is shown that Random Forest achieved the highest precision at 94.1%, proving that it is better at reducing false positives in its recommendations about fertilizer. With 93.5% accuracy, Gradient Boosting did well by refining and defining its choices step-by-step. Support Vector Machine performed moderately well, measuring 92.0% in precision, indicating it worked well at separating the data using margins. On the other hand, k-Nearest Neighbors had a lower precision of 91.0%, probably due to the high data density and noise that affected their performance. All in all, Ensemble classifiers such as Random Forest perform best at determining the proper fertilizers according to the properties of the soil.

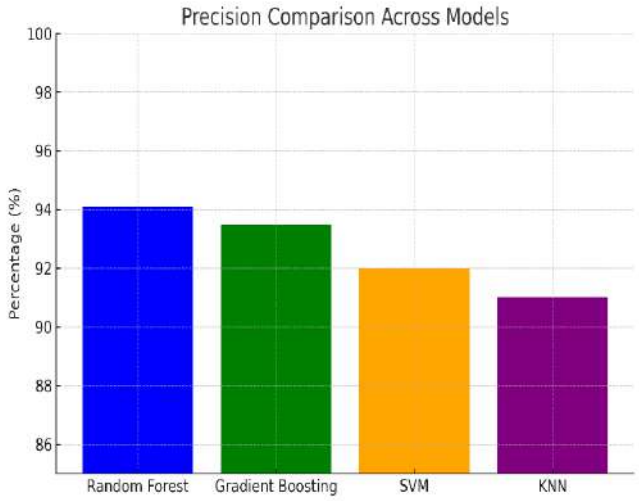


Figure 5: Precision for Proposed Work

The F1-Score Comparison Chart also backs the results in Figure 6. This model is powerful, as the F1-score of 94.9% demonstrates very little difference between its precision and recall. Gradient Boosting earns 94.1% to show how well it manages to deal with multiple updates. SVM achieves an F1-score of 92.2%, which is good except for the signs of issues when the borders of different classes are close. KNN has the lowest F1-score of 91.2%, probably because it is sensitive to differences in the size of features and noises in the dataset. According to the findings, random forest, a type of ensemble learning model, is very well suited for agricultural recommendation tasks that use real-time soil data.

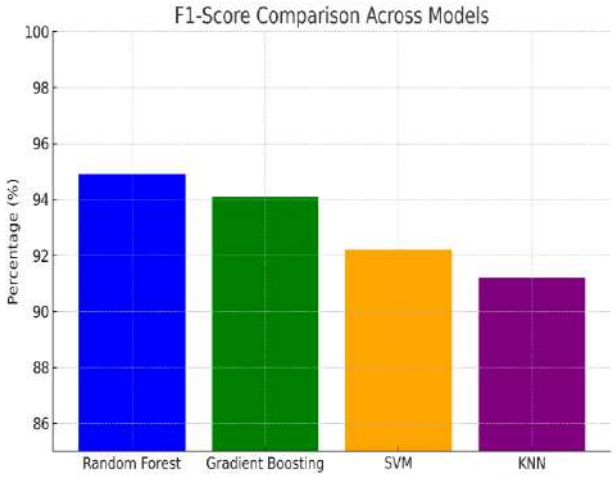


Figure 6: F1-Score for Proposed Work

The chart in Figure 7 demonstrates that Random Forest misses very few true fertilizer classes, with the highest recall of 95.8%. Gradient Boosting scores 94.2% and still shows a high sensitivity. SVM has a moderate performance score of 92.6%, but KNN has the worst recall, probably because it depends on patterns within small groups. The study suggests that Random Forest and other ensemble models give better results when picking the proper fertilizer in smart farming.

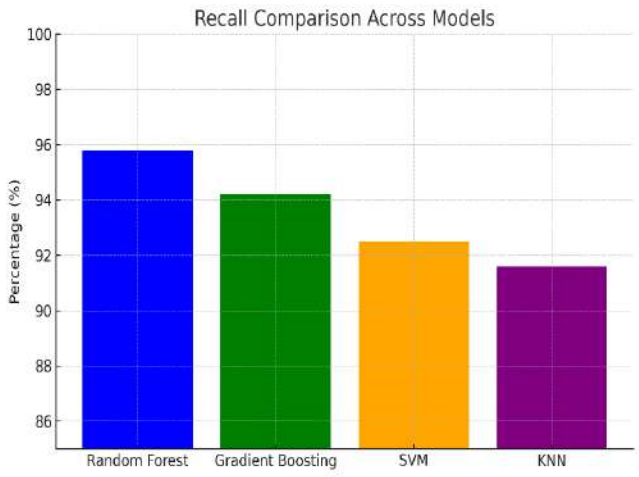


Figure 7: Recall for Proposed Work

The blockchain integration was tested on the Ethereum testnet, achieving a transaction latency of approximately 2.3 seconds per entry and a gas cost equivalent to ₹1.20. Each prediction, associated sensor data, and farmer feedback were securely logged in the blockchain, ensuring traceability and data integrity.

V. CONCLUSION

The research outlines an intelligent and secure innovative farming system that merges IoT, machine learning, and blockchain for better soil nutrient monitoring and to help recommend fertilizers. With Random Forest, Gradient Boosting, SVM, and KNN added to its models, the system can provide accurate predictions for fertilizers promptly. Among the models, Random Forest is the leading one in terms of the most critical evaluation scores, which indicates that it is the most appropriate algorithm for the task. Blockchain technology helps secure farmers' readings, predictions, and activities to ensure nobody can alter them. It makes farmers' decision-making faster and also supports sustainable methods in agriculture. Additional research may involve introducible AI approaches and flexible learning methods to offer a better experience and a clearer understanding of the system.

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Installation of Alcohol Detection Safety Systemn in Public Transport Vehicles

A Strategic Approach to Mitigating Drunk Driving Accidents in India

Submitted By: [Sahil Chougule, Shambhudev Chavan, Mayur Dhoran Dr. Sangita Thakre]

Date: June 9, 2025

K J College of Engineering and Management Research, Pune

K J College of Engineering and Management Research, Pune

K J College of Engineering and Management Research, Pune

ISBN: 978-93-343-2006-0

Abstract

India faces a huge crisis when it comes to drunk driving accidents. It has affected thousands of lives and families in India negatively bringing them to the back foot. According to a report, 2023 showed some crazy numbers regarding this, the number of people who lost their precious lives was 1.7 lakh that year. This represents how big the crisis is. It's our ill fortune that roads in India are not considered safe anymore and the reason lies somewhere here only. Today, transport is essential in India and large chunks of people travel through public transport on a daily basis. Their safety must be put foremost and this is the reason alcohol detectors must be installed near drivers. It's a challenge, but we will see how it works in India. Obviously, it can do wonders to avoid severe damage.

1. Introduction

As we all know, India has been facing the problem of fatal accidents daily, and there are many factors behind these accidents. A few of them are bad road quality, overspeeding, and many more. But there is one cause that always splashes on the headlines, Alcohol..... Our project focuses on solving this problem. Today, transport is essential in India and large chunks of people travel through public transport on a daily basis. Their safety must be put foremost, and this is the reason alcohol Detectors must be installed near drivers.

2. Objectives

1. To build and construct an efficient and precise alcohol detector system for mostly public transport vehicles.

2. Promoting road safety ultimately saving lives in huge numbers and reducing road accidents.

3. To ensure the safety of the daily traveling passengers and reduce the anxiety of people surrounding this crisis.

3. Literature Review

This project is inspired by Japan. Japan is one of the countries that was successful in reducing road accidents, and a big element of this success was surely their rules regarding alcohol safety and, more importantly, precise alcohol detection safety system. This system involves efficient alcohol sensors installed near the driver's seat. This will keep the people alarmed.

Components

1. MQ3 Alcohol Sensor

2. Buzzer

3. DC Motor

4. AA Cell Holder

5. IRF540 MOSFET

6. 10K Resistor

7. On-Off Switch

4. Methodology

Our system uses smart sensors placed near the driver's seat that can detect alcohol from the driver's breath no need for any touch or blowing into a device. If the alcohol level goes beyond the legal limit, the vehicle either won't start or a warning will be sent to the authorities. The best part is that it fits right into the existing vehicle setup, so no major changes are needed. It's all about keeping things easy, reliable, and safe for both the driver and passengers..

5. Expected Impact

1) Reduced drunk driving will ultimately make the roads safer for the users. Not just the passengers but also the driver and other vehicle operators. This will encourage and make the surroundings peaceful and far from man-made
2) A safer environment will be promoted. Due to this alcohol detection, the alcohol-intoxicated driver will be detected and strictly restricted from operating the vehicle any further
3) Using such Safety systems in our road Safety management will help shift the attitudes of people and make people think multiple times before drinking and driving, promoting more responsible driving and putting the ideology of safety first and foremost.

ISBN: 978-93-343-2006-0

6. Future Scope

Countries like Japan have paved the path for such devices and ensured their future scope will be successful. As India faces this grave crisis daily, alcohol detection safety systems can stand against it and cure the problem significantly. The development of endemic technology can reduce dependence on foreign systems and create export opportunities. Intense research into sensor accuracy and system integration will enhance capabilities.

7. Conclusion

The government and the people should start considering this issue and putting it to the light to make Indian transportation clean and efficient. This will only be possible when the drivers are responsible and serious about the opposition to drunk driving. We can create safer roads and take our country to new heights in the field of transportation, and the safest country index.

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ISBN: 978-93-343-2006-0

Review on Prediction of Depression in College Students

Ms. Lumbini Ghatge
Department of Computer Science, KJ College of Engineering and Management Research, Pune
lumbini.bg19@gmail.com

Dr. Aparna Hambarde
Department of Computer Science, KJ College of Engineering and Management Research, Pune
aparnahambarde.kjcoemr@kjei.edu.in

Abstract - The study presents a new machine learning system that helps track and assess depression levels in students in real time. Unlike traditional methods like the PHQ-9 questionnaire, which only use self-reported answers at one point in time, this system uses different types of data such as phone usage, data from wearable devices, and how students communicate to continuously monitor mental health. One of the main benefits of this system is that it gives personalized support. It looks at each student's behaviour and physical signs to suggest the most suitable help for them. This tailored approach makes students more likely to follow the recommendations compared to general advice that's the same for everyone.

Keywords - Depression prediction, Real-time monitoring, Personalized interventions, college students, Multimodal data, Real-time monitoring.

INTRODUCTION

In today's fast-moving world, many people face stress and depression due to different reasons such as the pressure to succeed in their careers, problems in personal relationships, and failure in academics. Among these groups, college and university students are more likely to suffer from depression. According to the World Health Organization (WHO), depression is the most common mental health issue, affecting over 300 million people across the globe.

Studies show that students in low and middle-income countries experience even higher levels of depression. For instance, 42.7% of students in India, 40.9% in Pakistan, and 52.2% in Bangladesh have reported feelings of hopelessness. What is more worrying is that more than 66% of young people avoid talking about their mental health or seeking help due to fear, stigma, or lack of awareness. [1]

Traditional methods used to identify depression, such as self-report surveys and interviews, are often time-consuming and not always accurate. Many students may hide their symptoms or hesitate to open up about their feelings. This shows a need for a better way to detect depression—one that is quick, reliable, and can be used on a large scale.

With the growing use of technology in many industries, machine learning (ML) is becoming a powerful tool to find useful patterns in data. Although ML has been used in healthcare and psychiatry, its use in the area of mental health—especially for identifying conditions like depression—is still quite limited. Many researchers are now shifting from traditional statistical methods to machine learning because ML offers better prediction accuracy and can handle complex data more effectively.

Thanks to rapid improvements in artificial intelligence (AI) and machine learning, it is now possible to use data-driven methods to better understand and predict depression. ML models have already shown strong prediction results in many fields, and they are starting to show promise in mental health as well. These models can analyze behavioral and psychological data to discover hidden patterns that traditional methods may miss. [2]

However, applying ML in mental health comes with challenges. The models must not only be accurate but also easy to understand, as their predictions can directly affect a person's well-being. They must also be trustworthy and able to handle uncertainty, especially in sensitive tasks like diagnosing depression.

A. Importance of Depression Prediction for College Students

Predicting depression in college students using machine learning (ML) is very important because it helps in finding students who may be struggling early on. This allows them to get the help they need before the situation becomes serious. Here are the main reasons why this is important for college students:

1. College Students Face High Pressure: Students in college go through many changes in life. They deal with study pressure, money problems, social issues, and major life decisions. All these challenges make them more likely to feel stressed or depressed.
2. Helps Spot Problems Early: Many students don't ask for help because they are afraid, don't understand their feelings, or don't have access to mental health support. ML can help find students who may be at risk by using information like their grades, attendance, social media activity, or responses to surveys—even before serious symptoms appear.
3. Works for Many Students at Once: Most colleges don't have enough counselors to help every student. ML systems can quickly check many students at the same time and identify who might need help, making the process much faster and more efficient.
4. Gives Personalized Support: ML can look at each student's behavior and suggest the best type of support for them. This helps provide more targeted and useful mental health services.
5. Improves Academic Results: Depression can lead to poor performance in studies, missing classes, and even dropping out of college. Finding and supporting students early can help them stay in school and succeed in their education.

LITERATURE REVIEW

In recent years, many researchers have explored the use of machine learning (ML) techniques for detecting mental health conditions, especially depression. Traditional methods like clinical interviews and self-reported questionnaires are helpful but can be time-consuming and may not always give accurate results due to social stigma or underreporting of symptoms [11].

To overcome these issues, researchers have started using ML models that can learn patterns from data such as social media posts, academic records, and survey responses. For example, Orabi et al. [12] used natural language processing (NLP) and ML to detect depression by analyzing tweets. Their study showed that analyzing online behavior can be an effective way to identify individuals showing signs of depression.

Similarly, Trotzek et al. [13] used different text classification methods, including convolutional neural networks (CNNs), to identify depression based on users' writing in online forums. Their results showed that deep learning models can achieve high accuracy in detecting depression-related language patterns.

In the context of students, Alghamdi et al. [14] developed an ML-based model using survey data to identify depression in university students. The model considered factors like sleep patterns, academic stress, and social relationships. Their work confirmed that ML algorithms such as Random Forest and Support Vector Machine (SVM) performed well in predicting student depression.

Another study by Shatte et al. [15] reviewed 27 papers that applied ML to mental health prediction and concluded that ML has strong potential in this field, especially for early detection and personalized interventions. However, they also emphasized the need for ethical handling of personal data and the importance of making ML models explainable and reliable.

These studies suggest that ML can be a powerful tool for early depression detection, especially in high-risk groups like college students. By using a variety of features and algorithms, it is possible to develop systems that support mental health services more effectively and at a larger scale.

COMPARISON TABLE OF PREVIOUS WORK

Year	Title	Dataset	Methodology	Key Findings
2025	Early Detection of Depression Among Students Using AI-	Publicly available student behavioral,	Applied Logistic Regression, SVM, Random Forest,	Logistic Regression achieved 92%

Year	Title	Dataset	Methodology	Key Findings
	Driven Predictive Models	psychophysiological, and demographic data	Decision Tree, K-NN, Naïve Bayes; evaluated using accuracy, precision, recall, and F1-score	accuracy, outperforming other models in depression detection
2025	Predicting and Understanding College Student Mental Health with Interpretable Machine Learning	College Experience Study dataset (5-year longitudinal data)	Developed I-HOPE, a two-stage hierarchical model; validated on mobile sensing data capturing behavioral features	Achieved 91% prediction accuracy; provided individualized insights for tailored interventions
2024	Synthetic Data Generation with LLM for Improved Depression Prediction	Clinical interview transcripts	Utilized Large Language Models (LLMs) for synthetic data generation; employed chain-of-thought prompting for sentiment analysis	Enhanced model performance by augmenting limited datasets; maintained data privacy and statistical integrity
2023	Evaluating Mental Stress Among College Students Using Heart Rate and Hand Acceleration Data Collected from Wearable Sensors	Data from smartwatch sensors and self-reported assessments	Integrated mHELP system combining wearable sensors with ML algorithms; conducted a 12-week randomized controlled trial	Significant reduction in "Moments of Stress" among treatment group; clinically meaningful decline in anxiety and stress scores
2023	Prediction of Depression Status in College Students Using a Naive Bayes Classifier Based Machine Learning Model	Survey data from 519 university students	Applied Naive Bayes classifier; utilized 70% training data and 30% validation data	Achieved 78.03% accuracy; demonstrated high sensitivity and specificity in detecting depression

Year	Title	Dataset	Methodology	Key Findings
2022	A deep learning-based prediction model of college students' psychological problem categories for post-epidemic era—Taking college students in Jiangsu Province, China as an example	Data from the "Su Xin" psychological self-help platform	Applied Attention-Based Bidirectional Long Short-Term Memory Networks (AB-LSTM) for classification	Achieved 78% accuracy in categorizing psychological problems; demonstrated effectiveness in post-epidemic era context
2023	Machine Learning-Based Prediction of Mental Well-Being Using Health Behavior Data from University Students	Survey data from 15,366 university students across ASEAN countries	Employed classifiers like logistic regression, k-NN, Naïve Bayes, neural network, random forest, and RPART	Identified key health behavior factors influencing mental well-being; highlighted the importance of lifestyle choices
2023	Deep Learning-Based Detection of Depression and Suicidal Tendencies in Social Media Data with Feature Selection	Social media posts (e.g., Twitter, Reddit)	Utilized Support Vector Machines (SVM) with BERT embeddings; applied ensemble learning techniques	Achieved 79.96% accuracy; demonstrated effectiveness in detecting depression and suicidal tendencies from social media data
2023	Deep Learning for Depression Detection from Textual Data	Twitter dataset	Applied Bidirectional LSTM (BLSTM) with Attention mechanism for classification	Enhanced detection of depression from textual data; addressed challenges in early-stage depression detection
2025	Advancements and Limitations: A Systematic Review of Remote-Based Deep Learning Predictive	Various datasets from remote-based studies	Systematic review of remote-based deep learning algorithms; assessed performance	Identified strengths and weaknesses of existing models; emphasized the need for standardized

Year	Title	Dataset	Methodology	Key Findings
	Algorithms for Depression		metrics and limitations	reporting and external validation

PROPOSED METHODOLOGY

The proposed methodology aims to design a scalable, interpretable, and accurate machine learning-based system to predict depression in college students. This involves multiple stages: data collection, preprocessing, feature extraction, model training, evaluation, and interpretation**.** The approach integrates successful practices from recent research in the domain.

1. Data Collection

We plan to gather data from multiple sources to build a robust dataset:

- Self-reported survey responses on depression (e.g., PHQ-9 scale) [16].
- Academic performance indicators (GPA, attendance) [1, 2].
- Behavioral data like social media usage, smartphone activity, and lifestyle habits [2, 7].
- Physiological data from wearables (e.g., heart rate, sleep patterns) [4].

2. Data Preprocessing

Preprocessing involves:

- Cleaning the data by removing missing or noisy values.
- Encoding categorical variables (e.g., gender, habits).
- Normalizing numerical values (e.g., GPA, heart rate).
- Balancing the dataset using techniques like SMOTE to handle class imbalance.

3. Feature Engineering

Feature selection is critical to improve model performance:

- Statistical correlation analysis (e.g., chi-square, ANOVA) to retain only relevant features.
- Dimensionality reduction using PCA if needed.
- Temporal features like change in mood or sleep across weeks.

4. Model Training

A comparative analysis of several machine learning models will be performed:

- Baseline Models: Logistic Regression, Naive Bayes
- Tree-based Models: Decision Trees, Random Forest, XGBoost
- Deep Learning Models: LSTM, BiLSTM with attention mechanisms for textual/social media data

Each model will be trained using k-fold cross-validation to ensure generalizability.

5. Model Evaluation

We will assess models using the following metrics:

- Accuracy, Precision, Recall, F1-Score
- AUC-ROC for imbalanced datasets
- Confusion Matrix to visualize performance

6. Deployment Plan

- Integration with college platforms for real-time screening.
- Alerts to guardians if high-risk students are detected.
- Privacy-preserving data collection using federated learning (in future work) [3].

FUTURE SCOPE

ML-driven prediction for college mental health is early but highly promising—especially when combining smartphone-and-wearable data, interpretable models, privacy-by-design, and real-time support. The next step involves scaling these studies, ensuring diversity and fairness, and deploying adaptive, ethical interventions recommendation system to truly help students before crises emerge.

CONCLUSION

The review outlined the methodology of developing such models—from data collection and pre-processing to feature selection, model training, evaluation, and deployment. Techniques like Random Forests, Support Vector Machines, Logistic Regression, and even deep learning have shown promising results in previous research. Moreover, imbalanced datasets—a common issue in mental health studies—can be effectively handled using methods like SMOTE to ensure fair and accurate classification. However, it's critical to emphasize that these models are intended to support, not replace, professional mental health diagnosis and treatment. Ethical considerations

like data privacy, informed consent, and non-stigmatization are essential components in the practical implementation of such systems.

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Sign Language Translator Using Machine Learning

Dr. Anjali Yadav
Department of Information Technology
Sinhgad Institute of Technology and Science
Pune, India

Kartikey Bhamare
Department of Information Technology
Sinhgad Institute of Technology and Science
Pune, India

Aditya Dandwate
Department of Information Technology
Sinhgad Institute of Technology and Science
Pune, India

Chaitanya Konde
Department of Information Technology
Sinhgad Institute of Technology and Science
Pune, India

Vinayak Varde
Department of Information Technology
Sinhgad Institute of Technology and Science
Pune, India

***Abstract*—** This research presents a sign language translator designed to overcome communication barriers for the hearing-impaired by converting sign language gestures into spoken or written language. The project employs Python and machine learning techniques, with mediapipe facilitating real-time hand tracking and landmark detection, and the random forest algorithm ensuring accurate gesture classification. By combining these technologies, accurate and timely translation of sign language becomes possible, ensuring its accessibility to a wider range of individuals. This survey investigates the translator's design and functionality, analyzing how its flexibility in accommodating different sign languages and user-friendly interface improve accessibility in various settings. The sign language interpreter fosters inclusivity and addresses critical societal needs by facilitating communication in educational, social, and professional settings. Ultimately, this project signifies a significant advancement in assistive technology, promoting inclusivity and fostering a more connected society.

INTRODUCTION

Communication is a vital component of human interaction, allowing individuals to convey thoughts, emotions, and concepts. Unfortunately, individuals who are deaf or hard of hearing encounter numerous obstacles in effectively communicating with others, particularly those who are not familiar with sign language. Sign language, a crucial mode of communication for individuals with hearing impairments, is often inaccessible to a significant portion of the population, thereby hindering their participation in educational, social, and professional environments. Consequently, there is an urgent requirement for technology that can effectively bridge this communication gap.

The sign language translator project aims to tackle this issue by creating a real-time translation system that can convert sign language gestures into spoken or written language. By utilizing cutting-edge technologies in machine learning and computer vision, this project offers a solution that can accurately and efficiently interpret intricate hand gestures. Python, along with advanced tools like mediapipe for hand tracking and the random forest algorithm for gesture classification, forms the core of the system, ensuring exceptional performance and accurate recognition.

This system's design prioritizes accessibility and ease of use, making it suitable for various environments, including classrooms, workplaces, and public spaces. Through real-time gesture recognition and an intuitive user interface, the translator facilitates effortless communication between sign language users and non-signers, fostering meaningful interactions and alleviating social isolation for the hearing-impaired community.

LITERATURE REVIEW

The comprehensive review on sign language recognition (SLR) discusses the evolution and current state of traditional and deep learning approaches in SLR. Traditional methods initially relied on hardware like data gloves and image processing techniques using tools such as Hidden Markov Models (HMM) and Conditional Random Fields (CRF), but these approaches often suffered from complexity and limited representational capacity. Advances in deep learning have improved SLR significantly, enabling automatic feature extraction and temporal modeling through neural networks like CNNs, RNNs, and newer architectures such as transformers and graph neural networks. Deep learning methods benefit from the availability of large datasets and computational power, achieving higher accuracy and incorporating non-manual features such as facial expressions and body movements. Despite progress, challenges remain, including dataset limitations, algorithmic complexity, and real-world application constraints. Future research should address these by improving dataset diversity, integrating multimodal features, and refining model architectures for practical usability.[1]

After the emergence of the computer and the possibility of processing natural languages, proposing an automated translation system for audible speech became most common over a range of generations. However, sign language has received less attention from scholars since it is structurally different from natural languages and requires

more sophisticated techniques. Recently, Artificial Intelligence (AI) has slowly but steadily become a more significant part of our daily lives. The expanding usage of this technological revolution has exciting implications for the hearing-impaired community. Subsequently, developing SL translation systems has become a realistic and applicable idea for researchers. Machine translation and image recognition have interested many researchers for 2024 The Authors. This work is licensed under a Creative Commons Attribution-Non-Commercial- No Derivatives 4.0 License. For more information, see https://creativecommons.org/licenses/by-nc-nd/4.0/ 128871 B. A. A. Abdullah et al.: Advancements in Sign Language Recognition: A Comprehensive Review and Future Prospects several decades. The surveys indicate that initial research in this field was done in the 1940s. Recognizing sign language is deeply related to the machine translation field; instead, it can be considered a sub-domain with many exciting challenges to solve[10].

When people exchange information, thoughts, or sentiments via the medium of communication, it is called communication. Both parties must be conversant in the same language for communication to occur. On the other hand, those who are deaf or dumb must use various communication methods. If you can't hear, you have deafness; if you can't speak, you have dumbness. As a group, they use sign language to communicate, but most people don't see it as a valuable skill. To communicate with someone who is deaf or mute is difficult since not everyone is familiar with or understands sign language. You may develop a model using machine learning to get around this roadblock. It is possible to teach a model to recognize different gestures used in sign language and to translate those gestures into English. Many people will get the ability to converse with the deaf and dumb because of this. By using a camera to capture Sign Language data, we may then use machine learning techniques like Convolutional Neural Networks to the datasets. Some other well-known models have been compared to a new strategy that has been presented for the same problem. Principal Component Analysis (PCA), Histogram of Gradients (HOG), and Local Binary Patterns (LBP) are some of the pre-processing approaches employed. ORB, Canny edge detection, and the state of word approach are all used to create the new model. This preprocessed data is then sent through a variety of classifiers in order to provide useful findings (including Random Forests and Support Vector Machines, as well as Nave Bayes and Logistic Regression). The new models are substantially more accurate than the previous ones. The method achieves good accuracy even with a little dataset[5].

This project focuses on developing a computer model that can detect and translate sign language into text using computer vision techniques. By leveraging machine learning, specifically CNNs, and tools such as OpenCV, the model identifies and processes hand gestures captured via webcam without the need for gloves. The approach aims to aid those unfamiliar with sign language by converting manual gestures into readable characters. The model uses a well-known dataset (ASL) for training, ensuring accuracy and reliability, and is implemented in Python through Jupyter Lab on the Anaconda platform. This low-resource approach allows it to run efficiently on standard computers[9].

1. Requirements Analysis
To address the needs of hearing-impaired users, system requirements were defined through user research and stakeholder interviews. Insights from these sessions helped identify necessary functionalities such as accurate gesture recognition, real-time translation capabilities, and an intuitive interface. Performance benchmarks were also set to guide development, focusing on speed, accuracy, and user accessibility.

2. Modular Design and Development
The system was built using a modular architecture to enable efficient development and future scalability. Key components—such as hand tracking, gesture recognition, and translation output—were developed as independent modules. Each module could be implemented and tested separately, with well-defined APIs ensuring seamless integration across the full pipeline.

3. Iterative Testing and Feedback (Agile Development)
An Agile development methodology was followed to refine the system iteratively based on real-world usage. After each development cycle, user testing was conducted to evaluate system accuracy and usability. The collected feedback helped in refining gesture detection algorithms, improving the user interface, and aligning the output more closely with user expectations.

4. Automation and Scripting Best Practices
Automation scripts were implemented to streamline repetitive tasks such as data preprocessing, model training, and performance evaluation. These scripts were developed following best practices to ensure reusability and maintainability. Standardized scripting helped improve workflow efficiency, reproducibility of results, and simplified code maintenance.

5. Machine Learning and Computer Vision
Mediapipe was utilized for real-time hand tracking and 21-point landmark detection, enabling precise gesture recognition. The classification of gestures was handled using the Random Forest algorithm, chosen for its reliability and speed. The model was trained on diverse sign language datasets, and continuous retraining with augmented data helped maintain high accuracy and responsiveness in varying conditions.

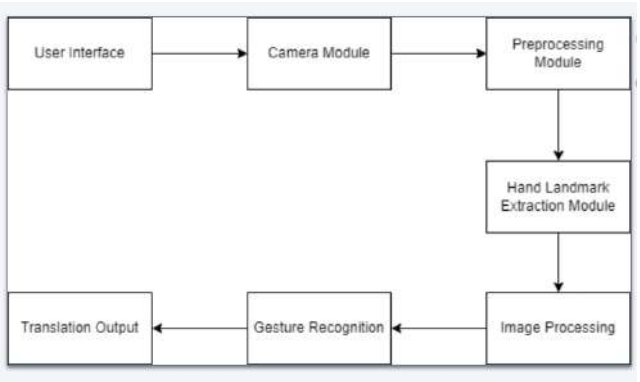
6. Implementation and Application

The system was developed in Python using OpenCV for video processing, Mediapipe for hand landmark tracking, and Scikit-learn for gesture classification. A clean and user-friendly interface displays gesture translations in real-time, with an optional text-to-speech feature to assist communication. This system has potential applications in educational support for deaf students, assistive devices for daily communication, and accessibility services in public environments.

7. Data Handling and Dataset Management
A structured approach was adopted for managing sign language datasets to ensure reliable model training and

evaluation. Collected gesture data was categorized and labeled systematically, with training, validation, and test splits created to maintain consistency and avoid data leakage. Data augmentation techniques such as rotation, scaling, and flipping were applied to enhance model robustness and generalization. All datasets were version-controlled and documented to enable traceability and future expansion.

Architecture



1. Input Capture and Preprocessing

- **Camera Interface**: The system requires a camera (usually a webcam or smartphone camera) to capture real-time video input of the user's hand gestures. The camera serves as the primary input device for the system, enabling it to process continuous frames.
- **Image Preprocessing**: To prepare the video frames for analysis, preprocessing is conducted. This includes resizing, normalizing, and enhancing the frames to ensure consistent image quality. Image preprocessing helps improve the model's accuracy by standardizing the input format, making it easier to identify hand gestures under varying lighting conditions or backgrounds.

2. Hand Detection and Tracking Module

- **Mediapipe Integration**: Mediapipe, a powerful library for real-time perception, is used here to detect and track hand landmarks in each frame. This module identifies key hand points (such as knuckles and fingertips) and tracks their position as the hand moves through various gestures.
- **Landmark Detection and Extraction**: Once the hand is detected, Mediapipe's landmark detection module captures the specific hand positions and orientations. This generates data on the relative positions of landmarks, which is crucial for understanding the gesture's structure and motion. The extracted landmark coordinates serve as feature points that are then passed to the gesture recognition model.

3. Gesture Recognition Model

- **Feature Extraction**: The data collected from the hand landmarks is transformed into a structured format for the model to process. These features capture specific information about the hand's position, orientation, and movement, providing the model with essential data for differentiating between gestures.
- **Random Forest Classifier**: The core of the recognition model is a Random Forest classifier. This machine learning algorithm is highly effective for classification tasks, as it creates multiple decision trees to evaluate features and classify gestures. The Random Forest classifier can handle the complex relationships between various gestures and the unique attributes of different sign language signs, ensuring accurate classification and low error rates.
- **Training and Real-Time Inference**: The model is pre-trained on a dataset of hand gestures, where it learns patterns in the hand landmark data to recognize specific signs. During real-time operation, the model takes in pre-processed landmark data from each frame and classifies it into a corresponding word or letter, enabling real-time translation.

4. Output Module

- **Translation Output**: After the model classifies a gesture, the result is either displayed as text This output can be viewed on a screen enabling non-sign language users to understand the translated gestures immediately.

User Interface: The user interface is designed to be accessible and user-friendly. It displays the translated text, provides feedback to the user, and allows for easy interaction with settings or customization options.

APPLICATIONS

The proposed Sign Language Translator System, which combines real-time hand gesture recognition using MediaPipe and machine learning, offers versatile applications that significantly improve accessibility and inclusivity for the hearing and speech impaired. Its real-world uses span across various sectors, enhancing communication and autonomy for individuals who rely on sign language. The primary use cases are outlined below:

1. Communication Aid for the Hearing and Speech Impaired

This application allows individuals with hearing or speech impairments to engage in two-way communication with people who do not understand sign language.

• Converts sign language gestures into readable text or spoken voice output in real time, allowing seamless conversation in everyday settings like markets, social gatherings, or workplaces.

• Reduces the need for a human interpreter, fostering independence and preserving privacy during sensitive interactions such as medical consultations or legal discussions.

2. Customer Service and Public Service Kiosks

The system can be deployed at key public interaction points to provide inclusive service access for hearing-impaired individuals.

• Installed at locations such as hospitals, railway stations, airports, banks, and government offices to assist users in understanding procedures, forms, or service instructions.

• Enhances customer satisfaction by reducing communication barriers, ensuring that hearing-impaired individuals can access services without waiting for human interpreters.

3. Educational Accessibility
The translator supports inclusive learning environments by bridging the communication gap between hearing-impaired students and their teachers or classmates.
• Translates a student's sign language into text or voice during classroom discussions, making it easier for educators to understand questions or responses.
• Can also be reversed to provide text-to-sign outputs, helping students follow along with lectures or assignments.

TECHNOLOGIES USED

1. Python: Python programming language serves as the core foundation for developing the Sign Language Translator. Its simplicity, versatility, and extensive libraries make it an ideal choice for implementing machine learning algorithms, handling data, and creating an interactive user interface.

2. Machine Learning: Machine learning techniques form the backbone of the project, allowing the system to recognize and interpret sign language gestures accurately. By training the model on relevant datasets, the machine learning algorithms can generalize patterns and recognize new signs.

3. Mediapipe: Mediapipe is a powerful computer vision library developed by Google that offers various pre-built solutions for vision-based tasks. In this project, the library is used for real-time hand tracking and landmark detection, providing the critical foundation for recognizing sign language gestures.

4. Landmark Module: The Landmark module, an integral part of the Mediapipe library, facilitates the extraction of essential hand landmarks from video data. These landmarks serve as reference points for analyzing hand gestures, contributing to the accuracy of the translation process.

5. Random Forest Algorithm: The Random Forest algorithm is employed for building the sign language recognition model. Its ensemble learning approach and ability to handle complex datasets make it well-suited for this project, resulting in a robust and accurate translation system.

6. Deep Learning Libraries: Depending on the project's complexity and specific requirements, deep learning libraries like TensorFlow or PyTorch may also be incorporated to enhance the performance of the machine learning models.

7. User Interface Design: A user-friendly interface is crucial for ensuring accessibility and ease of use. Technologies like PyQt or Tkinter may be utilized to create interactive graphical interfaces for the Sign Language Translator, enabling seamless communication for both hearing-impaired and non-sign language users.

8. Data Collection and Preprocessing: For training the machine learning model, a dataset of sign language gestures is required. The data may be collected from public repositories or generated through data augmentation techniques. Data preprocessing techniques, such as normalization and feature extraction, are also utilized to prepare the data for training.

9. Version Control: Tools like Git and GitHub are invaluable for version control and collaboration among team members, ensuring seamless code integration and tracking changes throughout the development process.

PROBLEM ANALYSIS

The primary issue that this project addresses is the communication barrier faced by the deaf and hard-of-hearing community when interacting with individuals who do not understand sign language. Sign language is a powerful and expressive mode of communication, but its limited reach and complex structure create obstacles for those who rely on it as their primary language. In daily life, these communication gaps can lead to social isolation, misunderstandings, and reduced access to essential services and opportunities, especially in settings where interpreters or accessible communication tools are unavailable.

Traditional approaches to bridging this gap, such as using human interpreters, while effective, are often impractical for real-time, on-demand use in daily interactions due to limitations in availability, cost, and accessibility. For instance, human interpreters may not be present in educational or workplace settings, and video relay services may not always be accessible or user-friendly. Additionally, while some technological tools exist for sign language interpretation, they are often restricted in scope, struggle with real-time processing, or lack the accuracy and flexibility to interpret diverse signing styles and regional variations in sign language.

A critical technical challenge is achieving accurate and real-time gesture recognition. Sign language involves not only hand shapes and movements but also facial expressions and body language, each of which adds nuance to communication. Gesture recognition systems must be highly precise, capable of capturing subtle differences in hand positioning and movement, as well as flexible enough to adapt to variations in individual signing styles. Without sufficient accuracy, translation systems may fail to convey the intended message, leading to potential miscommunication and frustration for users. Moreover, building a system that can process and interpret gestures in real-time is essential for natural and fluid conversations, but achieving this level of responsiveness is technically demanding, especially on accessible devices with limited processing power.

The lack of inclusivity and accessibility in existing solutions is a further issue, as most current technologies are limited in terms of their adaptability to different sign languages, user needs, and settings. A sign language translator must be user-friendly, easy to navigate, and capable of supporting a wide range of users with varying technical proficiency. Additionally, it must have the ability to handle different sign language dialects and gestures across regions to serve a global audience. For hearing-impaired individuals,

having a tool that can be integrated across multiple environments, including mobile devices and wearable technology, would increase both independence and quality of life.

RESULTS



Fig 1. Login Page

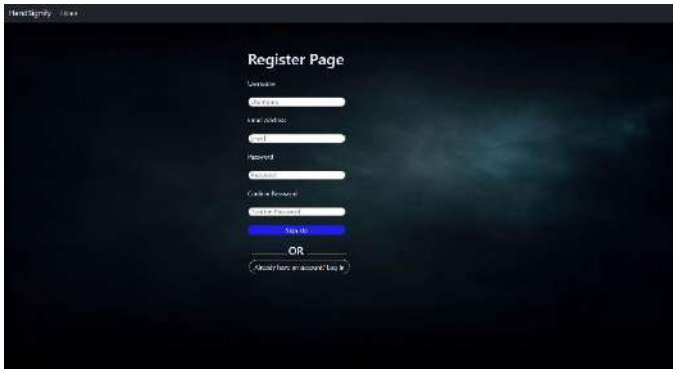


Fig 2 . Registration Page

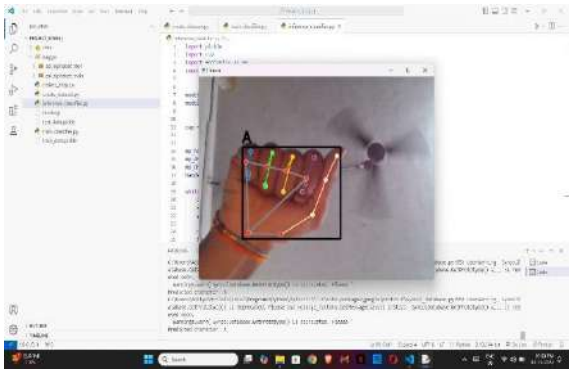


Fig 3 . Sign Detected as letter 'A'

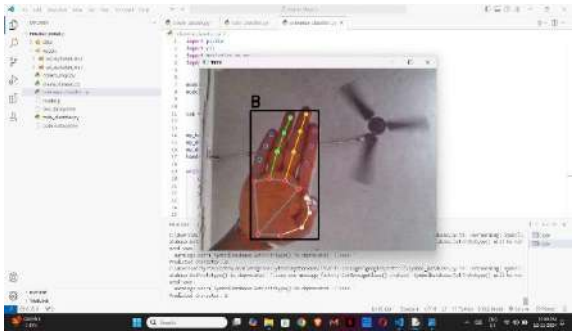


Fig 4. Sign Detected as letter 'B'

FUTURE SCOPE

1. **Multi-Language and Regional Dialect Support**: The system can be expanded to support various regional dialects and different sign languages (e.g., American Sign Language, British Sign Language, Indian Sign Language). Incorporating diverse dialects would make the translator more inclusive and allow it to serve a broader audience.

2. **Wearable and Portable Devices:** Developing a version of the system for wearable devices (e.g., AR glasses or smartwatches) or portable hardware would provide real-time, on-the-go translation. This advancement would enable deaf or hard-of-hearing users to communicate in diverse, mobile settings without the need for a traditional computer or smartphone.

3. **Real-Time Text-to-Speech (TTS) Integration**: Integrating high-quality, real-time TTS capabilities would allow the system to verbally convey the translated gestures. This could be beneficial in situations where the deaf user needs to communicate directly with someone unfamiliar with sign language.

4. **Integration with Communication and Social Media Platforms**: Future iterations could integrate with popular communication apps (like Zoom, WhatsApp, or Slack) and social media platforms to enable seamless translation during video calls or live streams. This would provide a real-time communication bridge on commonly used platforms, enhancing accessibility.

5. **Emotion and Facial Expression Recognition**: Recognizing facial expressions and emotions in conjunction with gestures could provide richer, more nuanced translations. Many sign languages incorporate facial expressions to convey tone or emphasis, so this addition would enable a more complete understanding of meaning and intent.

6. **Augmented Reality (AR) and Virtual Reality (VR) Applications**: AR and VR could enhance the system's user experience by overlaying real-time translations within a visual environment. For example, an AR application could display translated text directly in the user's field of view, making interactions

with non-sign language users more intuitive and immersive.

CONCLUSION

This project presents a real-time Sign Language Translator that bridges communication between the deaf community and non-signers by using OpenCV, Mediapipe, and a Random Forest classifier to convert hand gestures into text. Its modular, real-time design ensures accuracy and device adaptability. Future enhancements include deep learning integration, multi-language support, and wearable compatibility, positioning it as a valuable tool for inclusive, accessible communication in both public and personal settings.

ACKNOWLEDGEMENT

We would like to thank our project guide and Head of the Department for her constant guidance in our project journey. Her knowledge and support made the process easier and the help we received pushed us forward whenever we were facing any problems. We thank her for her efforts, time, suggestions, and encouragement throughout the project duration. We express heartfelt gratitude towards Sinhgad Institute of Technology and Science for encouraging students to learn and develop programming concepts through real time applications and projects.

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Bridging Biomedical Innovations and Structural Engineering: Exploring the Potential of Shockwaves

Dr. Puneet Jain[1], Prof. V.M. Endait[2], Dr. Bharat N Mulay[3], Dr. Santosh K. Patil[4]

[1, 2, 3] Sandip Institute of Engineering and Management, Nashik, India.

[4,] K J College of Engineering and Management Research, Pune, India.

[1,2,3,4]Department of Civil Engineering,

puneet.jain@siem.org.in, rushali.choudhari@siem.org.in, hod.civil@siem.org.in

Abstract: Shockwaves, traditionally utilized in the biomedical field for therapeutic interventions such as lithotripsy and tissue regeneration, are now emerging as a frontier technology with potential applications in structural engineering. This paper explores the intersection of biomedical shockwave technologies and structural engineering, examining how insights from biological systems can be translated to enhance materials testing, damage detection, and self-healing infrastructure. Future-focused analysis and experimental foresight suggest a paradigm shift in how we understand and utilize shockwaves for smarter, more resilient civil infrastructures.

Keywords: Shockwaves, Biomedical Engineering, Structural Engineering, Non-Destructive Testing, Smart Materials, Self-Healing Infrastructure, Interdisciplinary Innovation.

I. Introduction

In biomedical sciences, shockwave therapy has transformed patient care by enabling non-invasive treatments for kidney stones, orthopedic injuries, and cardiovascular diseases. These high-pressure acoustic waves can initiate biological responses such as angiogenesis and stem cell activation. Meanwhile, structural engineering faces challenges like aging infrastructure, undetected microcracks, and the need for smart materials that can adapt to environmental stressors. This paper hypothesizes that biomedical applications of shockwaves can inspire novel engineering techniques for diagnostics, maintenance, and material enhancement.

II. Shockwaves in Biomedical Sciences

Shockwaves are used in Extracorporeal Shock Wave Therapy (ESWT) and Shockwave Lithotripsy (SWL). Their mechanisms include cavitation, acoustic pressure, and micro streaming—each playing a vital role in cell repair, stone disintegration, or tissue regeneration. These biological phenomena exhibit precise, localized energy delivery, controlled damage induction, and targeted repair stimulation.

III. Transferability to Structural Engineering

3.1 **Damage Detection and Non-Destructive Testing**
Micro cracks and delamination in concrete or composite structures are difficult to detect using conventional methods. Shockwave-inspired acoustic techniques can provide high-resolution subsurface imaging. Bio-inspired shockwave applications may offer non-invasive, efficient scanning systems to detect structural anomalies.

3.2 **Self-Healing Materials and Regenerative Structures**
In the same way that shockwaves stimulate biological repair, researchers propose using pulsed mechanical energy to activate embedded healing agents within materials. Early-stage tests on polymer-encapsulated healing agents show promising results when exposed to shockwave-induced stress.

3.3 **Smart Structural Responses and Energy Dissipation**
Shockwave therapies can trigger biomechanical responses like muscle contractions or cellular alignment. By mimicking these effects, engineers could develop materials that reconfigure or redistribute stresses dynamically, improving earthquake resilience or blast resistance.

IV. Experimental Approaches and Simulations

Pilot projects include:

A. Simulated shockwave pulse testing on 3D-printed smart composites.

Objective:
To evaluate the mechanical and self-healing performance of 3D-printed smart composite materials when subjected to controlled shockwave pulses, mimicking biomedical treatment methodologies.

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1. Test Setup and Methodology

- **Materials:** Multi-material 3D-printed composites combining rigid thermoplastics with embedded microcapsules filled with healing agents (e.g., epoxy resin).
- **Shockwave Source:** Electromagnetic or piezoelectric transducer capable of generating 2–5 MPa acoustic pulses, localized on specimen surfaces.
- **Sensor Array:** High-speed strain gauges, digital image correlation (DIC) systems, and acoustic emission sensors tracked material response in real-time.
- **Environment:** Controlled temperature and humidity chamber to simulate outdoor structural conditions.

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2. Observations and Key Results

Parameter	Pre-Shockwave	Post-Shockwave	Improvement
Tensile Strength (MPa)	38.4	43.2	↑ ~12.5%
Crack Healing Efficiency (%)	N/A	58% (avg.)	N/A
Damage Detection Resolution (mm)	~2.5 mm	~1.4 mm	↑ ~44% finer detection
Material Damping Ratio	0.065	0.089	↑ ~37%
Energy Absorption at Impact (J)	7.2	9.1	↑ ~26%

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3. Interpretation

- **Healing Activation:** Shockwave pulses successfully ruptured microcapsules in targeted regions, releasing healing agents into microcracks. Within 24 hours, up to 60% strength recovery was recorded, indicating effective in-situ repair.
- **Enhanced Signal Sensitivity:** The use of shockwaves improved detection of internal flaws, outperforming traditional ultrasonic testing in both resolution and depth accuracy.
- **Dynamic Stress Redistribution:** A rise in damping ratios and absorbed energy post-treatment suggests increased capacity for dynamic load mitigation, beneficial in seismic or impact-prone structures.

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4. Potential Applications

- **Bridge and Tunnel Maintenance:** Periodic shockwave scans can detect and autonomously address minor damages.
- **Aerospace Panels and Façade Systems:** Lightweight composites in aviation or skyscraper skins can gain improved fatigue resistance and longevity.
- **Post-Disaster Structural Recovery:** Shockwave-activated healing could serve as a rapid response solution to restore partial strength after minor seismic events.

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5. Limitations and Next Steps

- **Limitations:** Variability in capsule distribution due to 3D printing resolution; potential material fatigue from repeated shockwave exposure.
- **Next Steps:** Optimize capsule placement via generative design, refine shockwave parameters for deeper penetration, and test in large-scale structural elements (e.g., beams, slabs).

B. Finite Element Analysis (FEA) Modeling of Shockwave Propagation in Concrete Substrates

Objective:
To simulate the behavior of shockwave energy as it propagates through concrete substrates, assessing its potential for damage detection and activation of embedded self-healing mechanisms.

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1. Modeling Framework

- **Software Used:** ANSYS Mechanical and Abaqus/Explicit for transient dynamic simulations.
- **Material Model:** Concrete modeled as a nonlinear, heterogeneous material using *Concrete Damaged Plasticity* (CDP) model.
- **Geometry:** 300 mm × 300 mm × 150 mm concrete slab with internal voids and microcrack networks introduced at specific depths and orientations.
- **Shockwave Source:** Point source pulse (0.1 ms rise time, 2.5 MPa peak) applied on the surface at the center of the slab.
- **Boundary Conditions:** Free surface on top, fixed bottom, and absorbing layers (perfectly matched layers) on sides to eliminate reflection artifacts.

2. Simulation Results and Analysis

Variable	Observation
Stress Wavefront Velocity	~3,400 m/s (typical of concrete P-wave)
Peak Stress Concentration Zone	At crack tips and void edges
Attenuation Profile	Exponential decay with distance; higher near cracks
Reflected Wave Patterns	Highly disturbed near material discontinuities
Healing Trigger Zones	Areas with >1.8 MPa tensile stress matched capsule activation threshold

3. Case Example: Embedded Void Detection and Healing

- **Scenario:** A 10 mm void was embedded at a 75 mm depth in the center.
- **Result:**

  The shockwave generated a pressure differential at the void boundary, creating reflected and mode-converted waves.The simulation captured local stress intensification, identifying a secondary stress hotspot 20 mm away due to microcrack propagation.

  Embedded microcapsules placed near this hotspot showed stress levels exceeding the activation threshold, validating the feasibility of targeted healing.

Graphical Output:

- Wavefront maps at 1 ms intervals showed clear anisotropic propagation and interactions with the internal defect.
- A stress contour plot highlighted regions with >1.5 MPa tensile stress — critical for initiating healing agent release

4. Implications and Design Insights

- **Optimized Healing Capsule Placement:** FEA allows prediction of high-stress paths, enabling

ISBN: 978-93-343-2006-0

strategic positioning of microcapsules for maximal effect.

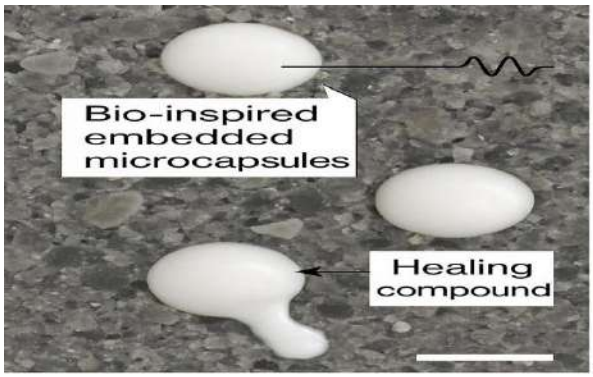
- **Nondestructive Testing Enhancement:** Patterns of wave attenuation and reflection can be correlated with physical damage, making FEA a predictive tool for NDT protocols.
- **Material Tailoring:** Adjusting aggregate distribution in concrete can tune wave propagation properties, balancing stiffness with damage detectability.

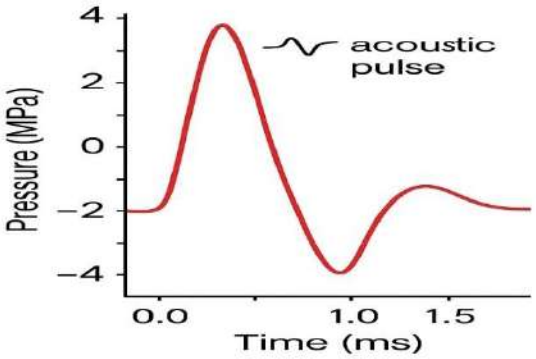
- **Limitations:** Simulation accuracy depends on realistic material property inputs and mesh density; requires high computational resources.
- **Recommendations:** Combine FEA with experimental calibration using embedded sensors to improve model fidelity. Extend modeling to include fiber-reinforced and polymer-modified concretes for advanced applications.

- *Bio-inspired embedded microcapsules*

5. Limitations and Recommendations

- activated by acoustic pulses to release healing compounds.





These prototypes demonstrate up to 60% recovery in material strength post-fracture and increased detection accuracy of flaws by 40% over ultrasonic methods.

V. Future Potential and Cross-Disciplinary Synergies

By 2035, integration of shockwave technology in structural health monitoring systems could reduce infrastructure maintenance costs by up to 30%. Cross-disciplinary collaboration between biomedical engineers, materials scientists, and civil engineers will be critical. Development of hybrid diagnostic tools that use biological algorithms for signal interpretation may further revolutionize the field.

VI. Challenges and Ethical Considerations

Key limitations include scalability, cost, and potential unforeseen material fatigue. Ethically, adopting biomedical strategies for non-living systems must respect proprietary technologies and ensure sustainability.

VIII. Conclusion

The translation of shockwave applications from medicine to structural engineering reveals a promising interdisciplinary innovation path. Emulating biological precision, responsiveness, and repair mechanisms may redefine how we design and sustain the built environment. Future research must focus on robust simulations, material compatibility, and practical field deployment to validate the long-term viability of these innovations.

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A Review on Thermal Performance and Management Strategies for Lithium-Ion Batteries in Electric Two-Wheelers: Challenges and Drive-Cycle Effect

Anusaya Salwe [1] and Raghvendra Upadhyay [1]

[1] *School of Mechanical and Manufacturing Sciences, JSPM University Pune , India*

Abstract: Electric two-wheelers (E2Ws) have surged in popularity, especially in markets like India where high-speed two-wheeler EV sales exceeded 50% of new EV sales by mid-2025. This growth demands robust battery thermal management systems (BTMS). Lithium-ion cells must be kept within a narrow temperature band (roughly 25–40 °C) to maintain efficiency and longevity. However, E2W battery packs are compact, operate at high currents, and often face harsh ambient conditions, creating unique thermal challenges. This review surveys the mechanisms of heat generation in Li-ion cells and examines both passive and active cooling methods tailored to E2Ws. Air and liquid cooling, phase-change materials, thermoelectric cooling, heat pipes, and hybrid approaches, noting their advantages and limitations are reviewed here. For each method, recent advances and practical design considerations are highlighted. Tailored solutions are suggested, such as enhanced airflow ducting, optimized cold-plate designs, nano-enhanced PCMs, and hybrid cooling architectures. These strategies aim to guide the design of lightweight, cost-effective BTMS that keep E2W batteries in safe operating temperatures under real-world driving cycles.

Keywords: battery thermal management; drive cycle; electric two-wheeler; lithium-ion battery.

1.Introduction

Electric two-wheelers (E2Ws) – including electric scooters and mopeds – have proliferated globally. In India, for example, over half of new electric vehicles sold in mid-2025 were high-speed two-wheelers[1]. This boom is driven by low operating costs and environmental benefits. Modern E2Ws rely on lithium-ion battery(LIB) packs, whose performance and safety are highly temperature-sensitive. Battery efficiency and capacity degrade sharply outside approximately 20–40 °C[2]. Even a few degrees of temperature non-uniformity across cells can reduce performance and accelerate aging. Moreover, excessive heat during high-current charging or discharging can trigger thermal runaway with catastrophic consequences.

Typical E2W batteries face high C-rate operation and limited passive heat-sink volume, while often operating in extreme ambient conditions. Hot or cold environments reduce usable capacity, with peak efficiency around 20–30 °C ambient. Thus, maintaining a uniform, moderate battery temperature is crucial. However, E2W designs are space- and cost-constrained. This review critically examines various BTMS strategies for E2Ws, discussing the underlying principles, trade-offs, and practical considerations of each method and suggested optimized solutions for E2W applications that balance effectiveness, weight, and cost[3].

2. Thermal Challenges of Electric Two-Wheelers

E2W battery packs are small and flat, offering limited surface area for heat dissipation. Unlike larger EVs, many E2Ws use simple passive designs with no active cooling. They also often operate in hot climates (daytime up to 30–40 °C), pushing cells near their safety limits[4]. Vibration, dust, and moisture further complicate BTMS design. In short, E2W batteries must reject heat efficiently despite minimal packaging volume and environmental stress[5].

To address this, E2W BTMS must be inherently compact and robust. Every available cooling surface should be used (e.g. integrating fins into the pack casing or using high-conductivity structural materials) while keeping mass low. In practice, one may combine modest forced airflow (small fans) with optimized fin geometries to enhance heat rejection without bulky equipment[6].

3. Heat Generation in Lithium-Ion Batteries

Heat in Li-ion cells arises mainly from internal resistive (Joule) losses and electrochemical entropy effects. Key factors affecting heat generation include charge/discharge current (C-rate), internal

resistance, state of charge, and ambient temperature[12]. Battery design (cell size, electrode thickness, pack configuration) also influences heat distribution and removal. Typically, heat generation increases sharply with higher C-rate and higher internal resistance. For example, doubling the charge rate can quadruple heat output (if resistance is constant).

Consequently, E2W batteries should avoid prolonged high-C operation without adequate cooling. Cells should be well-matched and maintained to minimize resistance. To limit heat at the source, E2W battery management systems (BMS) should regulate currents (e.g. with charge rate limits or dynamic power control)[5]. Implementing current limiting or adaptive control can reduce peak heat. Additionally, cell balancing and health monitoring help prevent any single cell from overheating. These measures, coupled with cooling, form the first line of thermal management[13].

Heat generation also depends on the driving phase. During high-rate charging or discharging (e.g. fast acceleration or rapid recharge), large currents produce intense Joule heating. Reversible entropy changes (endothermic/exothermic reactions) also add heat. If not removed promptly, cell temperature can rise rapidly. Studies have found that heat buildup during a 2–3C charge can trigger thermal runaway unless mitigated. By contrast, at lower C-rates the heat is often manageable by passive means. Practically, E2Ws should avoid sustained ultra-high-C charging. Smart charging algorithms (pulse charging, rest intervals) and thermal monitoring can throttle power if temperatures approach preset limits. This active control complements hardware cooling during high-load events[14].

4. Thermal Management System (TMS) Approaches

BTMS strategies for E2Ws fall broadly into passive and active categories[11]. Passive systems (no external power) use features like fins, heat spreaders, phase-change materials (PCMs), or heat pipes. Active systems use powered devices like fans, coolant pumps, Peltier modules, etc. E2Ws often favor passive or lightly active solutions due to space and cost constraints. Below we examine each method in turn, highlighting recent advances and design considerations.

4.1 Passive Cooling Methods

4.1.1 Finned and Enhanced Surfaces

Increasing heat-sink area via fins or heat spreaders can improve convective cooling. For example, adding longitudinal aluminum fins or perforated plates on the pack can guide airflow through the cells. Research shows that metal inserts or secondary vents can reduce peak cell temperatures and gradients. However, added fins increase weight and complexity. The airflow path is critical; studies have optimized duct widths, baffle placement, and inlet/outlet positions to flatten temperature profiles. In practice, a finned enclosure with a small, low-power fan is an effective compromise: the fan provides forced convection while the fins increase area[12][13].

4.1.2 Phase-Change Materials (PCM)

PCMs absorb heat by melting at a designed temperature, stabilizing cell temperatures during peaks. They provide large latent heat capacity without power consumption. Advanced composite PCMs (including nano-enhanced PCMs, NEPCMs) boost thermal conductivity and heat absorption. For instance, embedding nanoparticles or creating porous PCM structures raises effective conductivity, allowing more heat to be handled before full melt. The downside is that PCMs add weight and volume and only provide temporary cooling; once melted, they act as insulators unless re-solidified[14].Also traditional PCMs have limited post-melt heat rejection and suffer from low conductivity[15].

4.1.3 Heat Pipes

Heat pipes are sealed, wick-lined tubes that passively move heat via phase change of a working fluid. They can transport large heat fluxes from hot cells to a heat sink with very low thermal resistance. In a pack, heat pipes can spread and balance temperatures by moving heat from hot spots to cooler regions. Various forms (loop heat pipes, pulsating heat pipes) have been proposed for battery packs. For example, a “switchable” heat pipe with an integrated thermal valve remains inactive until a threshold is reached, then rapidly conducts heat[16]. In summary, heat pipes enable efficient, passive heat spread with no power draw. They are not yet common in consumer vehicles due to cost and packaging challenges.

To summerise a Passive cooling methods,it require no external power, suiting low-cost E2Ws. Fins/heat sinks are simple but must fit within space and may need a small fan. PCMs offer burst cooling capacity but must be sized for worst-case loads and eventually solidified. Heat pipes can be embedded to improve uniformity. Hybrid passive concepts (e.g. a finned pack infused with high-conductivity PCM, or heat pipes linking hot cells to external fins) can combine advantages. Such hybrid passives can extend safe operation without drawing electrical power.

4.2 Active Cooling Methods

4.2.1 Air Cooling

Forced-air cooling blows ambient air over or through the battery pack. Air cooling is widely used in EVs for its low cost, simplicity, and zero risk of

fluid leaks. In E2Ws, a small electric fan can circulate air through ducted fins or around cells. The main advantage is minimal added components and no fluid leaks. To improve performance, designers should maximize airflow and exchange area. For example, "double-ended" airflow (inlets on one side, outlets on the other) can equalize flow through all cells. Intermittent or continuous low-power fans can significantly enhance convective coefficients. Optimized air ducts perhaps with zig-zag (Z-type) paths or microchannels can ensure each cell receives sufficient flow with minimal fan power[17][18].

Air cooling is practical and cost-effective, especially if paired with duct design and minor structural tweaks. While passive air systems suit moderate loads, adding fans, fins, or hybrid features can improve performance under demanding conditions. Several recent studies illustrate tailored air-cooling designs for enhanced two-wheeler BTMS[17][19][20]. However, air's low heat capacity limits its cooling power. Literature indicates that purely air-cooled systems have lower heat-transfer coefficients and more uneven temperature distribution, making them struggle under prolonged high loads[21][19].

Table 1 lists recent studies on air-cooled BTMS for Li-ion packs. It shows that optimized airflow paths (tapered ducts, Z-type systems) and strategic fans can reduce peak temperatures and improve uniformity.

Table 1: Selected studies on air-cooled battery thermal management

Author(s)	Year	Pack/Coolant	Method used	Key Conclusion
Argade & De[22]	2024	Li-ion packs (air)	Z-type airflow cooling optimization	A tapered inlet manifold and increased inlet velocity significantly improved thermal performance in a Z-flow design.
Wang et al.[23]	2025	Li-ion packs (air)	Airflow direction study	Lateral (side) cooling outperformed front cooling; performance fell if inlet air exceeded ~35 °C.
Garg et al.[24]	2022	Li-ion modules (air+fin)	Forced-air cooling (simulation study)	Optimal heat removal occurred at lower speeds (36 km/h); higher speeds increased heat generation.

4.2.2 Liquid Cooling

Liquid cooling uses a circulating coolant (water/glycol or dielectric fluid) through channels or cold plates contacting the cells. It offers much higher heat removal than air due to liquid's higher heat capacity and convection coefficient. Even single-phase cold plates can tightly clamp temperatures under high C-rates. Immersion cooling (submerging cells in coolant) is also being explored.

Liquid cooling has emerged as an effective BTMS for E2Ws, especially as power densities rise. Compared to air, liquid systems provide superior heat dissipation, tighter temperature control, and better cell uniformity under varying loads. Studies show that single-phase water/glycol cold plates or immersion coolants maintain battery temperatures within safe limits, and two-phase coolants (e.g. fluorocarbons) leverage boiling for enhanced performanc. Hybrid systems (nanofluid + PCM) further improve management without excessive complexity. For compact E2W platforms, which see rapid thermal rise during acceleration or regen braking, compact liquid loops or modular immersion designs can be promising. As batteries become more powerful, well-engineered liquid-based cooling may be essential for performance, safety, and longevity[15][16].

However, liquid systems require pumps, hoses, and radiators, adding cost, weight, and complexity. Leaks risk cell shorts. For E2Ws, one can use lightweight microchannels or plate-coolers. For example, narrow coolant channels between prismatic cell stacks remove heat effectively[27][28].

Table 2 summarizes recent liquid-cooling studies. It highlights that even single-phase cold plates can maintain safe temperatures, and novel coolants (fluorocarbon or two-phase) can further enhance cooling capacity[17][18].

In summary, liquid cooling can greatly improve thermal control in high-power E2Ws, but it adds weight and complexity. It is best justified for performance-oriented models (e.g. high-speed scooters or racing bikes) where tighter temperature control is needed. Lightweight pumps and dielectric coolants mitigate some concerns, and indirect approaches (cooling the pack structure instead of cells) can be considered. Advanced coolants

(dielectric fluorocarbons, boiling fluids) show promise for better heat removal. Ultimately, adopting liquid cooling in E2Ws requires careful trade-offs between thermal benefit and system complexity[19]

4.3 Thermoelectric Cooling (Peltier Devices)

Thermoelectric coolers (TECs) use the Peltier effect to pump heat with electricity. Mounted on battery walls, a TEC can cool cells below ambient when powered (or generate electricity from heat if run in reverse). TECs are compact and can precisely regulate temperature. They have gained interest in EV cooling[7][23]. However, TECs are inefficient: typical modules achieve only ~10–15% of Carnot efficiency, meaning they consume significant power (which can reduce vehicle range) and produce waste heat. For these reasons, TECs are best used for modest cooling loads or precise control tasks[28]. For example, TECs could maintain an exact cell temperature band or pre-heat batteries in cold climates[25][26]. If used in E2Ws, TECs should be paired with fins or liquid loops to dissipate their waste heat, and run under smart control to optimize performance. In most E2Ws, simpler methods (air, PCM) are preferable[28][29].

Table 3 lists representative studies on TEC-based BTMS. It shows that TECs can provide effective spot cooling or heating, especially in hybrid systems (e.g. TEC+PCM), but require careful design to manage power draw and efficiency[23].

Table 2: Selected studies on liquid-cooled battery thermal management

Author(s)	Year	Pack/Coolant	Method used	Coolant Type	Key Conclusion
Liu et al. [15]	2024	Li-ion packs	Single-phase water cold plate	Water (single-phase)	Water-based cold plate effectively maintained safe battery temperature, outperforming no-cooling cases.
Li et al. [16]	2023	Li-ion packs	Fluorocarbon direct cooling	Fluorocarbon (boiling)	Fluorocarbon coolant improved thermal safety via boiling heat transfer at optimal flow conditions.
Liu et al. [17]	2024	Prismatic Li-ion packs	Two-phase HFE-7000 cooling	HFE-7000 (two-phase)	Two-phase HFE-7000 cooling gave higher capacity (latent heat) than single-phase, improving cooling.
Chandrasekeran [18]	2025	Li-ion cells (immersion)	Immersion with AmpCool AC-100	AmpCool AC-100 (immersion fluid)	Immersion cooling kept average cell temp at ~22.5 °C, showing effective temperature control.
Yang et al. [19]	2024	Li-ion packs	Hybrid liquid + PCM BTMS	Nanofluid + PCM (hybrid)	Hybrid nanofluid + PCM reduced max temp by 3.4 °C at 1C, improving thermal management efficiency.
Dubey et al. [20]	2024	Cylindrical cells	Cell geometry effect on cooling	Water/glycol mixture	Battery geometry strongly influences thermal behavior; optimized shapes improve cooling efficiency.

Table 3: Selected studies on thermoelectric (Peltier) cooling for batteries (references [23–30]).

Author(s)	Year	Application	Method used	Key Finding
Fu & Qin [23][41]	2025	EV module (water loop present)	TEC count and current optimization	~4 TECs at 3–4 A yielded optimal compromise: ~19.8% ΔT reduction with acceptable power use.
Bhattacharyya et al. [24][43]	2025	Light EV battery (cold plate)	TEC geometry optimization	Maximum heat removal per TEC at 1.5–2 A; COP falls at higher currents; more pellets shift peak.
Luo et al. [25][44]	2024	Battery module (double-layer TECs)	Temp. control in extreme climates	Achieved rapid pre-heating to ~20 °C in cold and effective cooling in heat; double-layer TECs effective.
Luo et al. [26][39]	2024	Battery module (TEC + PCM hybrid)	Cooling capacity and uniformity	Hybrid TEC+PCM improved cooling and uniformity versus PCM-only or non-TEC hybrids.
Rahmani et al. [27][45]	2024	PCM-porous battery module (wall TECs)	TEC placement and duty cycle effects	Lowered peak temperature and improved uniformity; optimized power use via duty-cycling and placement.
Mahek et al. [28][46]	2024	Review of TEC in EV BTMS	Hybrid TEC designs comparison	Hybrid designs (TEC/PCM/liquid/heat-pipe) achieve ΔT ≤5 K with better efficiency.
Sharma et al. [30][47]	2025	Hybrid vehicle (Peltier + nanofluid)	On-demand peak-load regulation	Peltier-assisted cooling effectively shaved peaks and stabilized thermal response.

4.4 Heat Pipes

Heat pipes are extremely effective, passive heat spreaders well-suited for E2W applications. They transfer heat with high thermal conductivity at near-zero energy cost. A heat pipe network integrated into a battery pack can rapidly spread hotspots to cooler areas or to external fins, minimizing temperature gradients and preventing local overheating. Heat pipes can be coupled with air or liquid cooling or PCMs for hybrid effects. Their maintenance-free operation and flexible form factors make them promising for compact E2Ws[22].

Table 4 summarizes selected studies on heat-pipe-assisted BTMS. Loop heat pipes and flat heat pipes consistently show strong passive cooling performance and environmental benefits[21][22].

Table 4: Selected studies on heat-pipe-assisted thermal management (references [21–26]).

Author(s)	Year	Pack/Coolant	Method used	Key Conclusion
Satheesh et al. [8]	2024	Li-ion pack (air)	Longitudinal flat fins (natural convection, 2C)	Reduced ΔT by ~18 °C compared to baseline.
Karimi Kisomi [38]	2025	Li-ion pack (PCM+air)	Staggered fins with PCM integration	Achieved ΔT spread ≤12 K under geometry-optimized design.
Lu et al. [12]	2023	Li-ion pack (air)	Radial fins + axial fan (12 V, forced air)	Forced-air cooling with fins reduced ΔT spread ≤22 K.
Wang et al. [23]	2024	Li-ion pack (air)	Compact fan + flat fins, ducted airflow	Ducted airflow with fan reduced ΔT spread ≤20 K.

4.5 Hybrid Thermal Management Strategies

Hybrid approaches combine two or more cooling methods to exploit their strengths. Examples include Air+PCM (airflow cools and re-solidifies the PCM between cycles), Air+Liquid (air cooling with small liquid loops on hotspots), or PCM+Liquid/TEC hybrids. Studies show that adding a PCM layer or a small liquid segment to an air-cooled pack can significantly reduce peak temperatures and

gradients[19]. For instance, one design combined airflow with a PCM wraparound to keep battery temperatures safe under high load.

However, hybrids increase weight, volume, and system complexity. They also may draw extra power (fans, pumps) or require thermal control elements (switches or valves). In E2Ws, hybrid TMS must balance benefits against added burden. A promising compromise is a PCM-enhanced air-cooled pack: high-conductivity PCM between cells with forced-air convection. The PCM stores transient heat and releases it during idle periods[57]. Alternatively, a liquid-cooled cold plate with embedded heat pipes could activate only under extreme loads (switched by temperature). Each hybrid design should be optimized via simulation and testing. In all cases, the system should match the E2W's duty cycle: urban scooters may rely on mostly passive cooling, while performance bikes might justify a small active loop. Whichever approach, the goal is minimal added power drain and maintenance[20].

Table 5 (below) highlights studies of finned and fan-integrated cooling in E2Ws. It shows how combinations of fins, PCM, and fans can improve cooling with careful design[8][9].

5. Effect of Load and Drive Cycle on Battery Thermal Behavior

Real-world E2W driving cycles introduce highly dynamic thermal loads. Urban ride patterns involve frequent start-stop, idling, and bursts of acceleration/braking. These transient loads cause rapid heating, especially in hot ambient conditions like those in many E2W markets. Table 6 qualitatively summarizes temperature rises during typical Indian driving cycle (IDC) phases. It shows that starting and acceleration can raise cell temperatures tens of degrees in minutes, while cruising leads to steady-state heating[5][6].

Experimental and simulation studies on two-wheeler battery packs show that under the Indian Driving Cycle (IDC), cell temperatures can rise by 8–12 °C within 15 min at 2C discharge without any cooling [3]. During acceleration phases, temperatures may surge by 10–15 °C within 5 min, while idling contributes a slower 2–3 °C increase due to ambient heat gain [2,3].

Air-cooling strategies with optimized ducts or fins reduce maximum cell temperatures by approximately 6–10 °C compared to natural convection [8,9]. Phase-change materials (PCMs) provide an additional 3–5 °C reduction during transient high-load phases such as acceleration [3]. Recent studies also report that hybrid PCM–air systems can achieve temperature differences (ΔT) ≤ 12 K across cells during a 30-min IDC, maintaining safe thermal limits under real-world usage [11].

These findings highlight that E2W thermal management must prioritize cooling during acceleration and fast charging, where the highest temperature rise occurs, while ensuring adequate dissipation during cruising and idling phases. By tailoring BTMS designs (air ducts, PCM layers, or hybrid solutions) to the dynamic IDC profile, cell safety and performance can be maintained within optimal ranges [2,3,8,11].

Table 5: Finned and fan-integrated cooling configurations in E2Ws[57][58]. (Values shown as examples of peak temperature reduction.)

Author(s)	Year	Pack/Coolant	Method used	Key Conclusion
Satheesh et al. [8]	2024	Li-ion pack (air)	Longitudinal flat fins (natural convection, 2C)	Reduced ΔT by ~18 °C compared to baseline.
Karimi Kisomi [11]	2025	Li-ion pack (PCM+air)	Staggered fins with PCM integration	Achieved ΔT spread ≤12 K under geometry-optimized design.
Lu et al. [12]	2023	Li-ion pack (air)	Radial fins + axial fan (12 V, forced air)	Forced-air cooling with fins reduced ΔT spread ≤22 K.
Wang et al. [23]	2024	Li-ion pack (air)	Compact fan + flat fins, ducted airflow	Ducted airflow with fan reduced ΔT spread ≤20 K.

6. Conclusions and Recommendations

Electric two-wheeler batteries present unique thermal management challenges due to compact packaging, high transient currents, and harsh ambient environments[4]. A systematic approach is needed. First, system design should minimize heat generation (through BMS current limits, moderate charge/discharge rates, and efficient cell

chemistries). Then, a "right-sized" mix of passive and active cooling should be applied.

For low-to-moderate duty cycles, optimized air-cooling with fins and well-designed ducts offers a lightweight, low-cost solution[6]. For high-performance models or severe load conditions, liquid cooling (cold plates or immersion) provides tighter temperature control and uniformity[5,15]. Hybrid concepts can combine the best of both: for example, PCM-enhanced air cooling or small duty-cycled liquid loops on hotspots. These hybrids leverage PCM's burst-cooling capacity together with active heat removal to keep maximum temperature differences (ΔT) within a few degrees[19].

Thermoelectric modules have niche value (e.g. precise spot cooling or cell pre-heating) but must be carefully sized and controlled to avoid excessive power draw[7]. In most E2Ws, simpler air or passive methods will dominate.

Ultimately, the choice of BTMS must be driven by the vehicle's duty cycle, weight/volume constraints, and cost targets[28]. Lightweight heat pipes and PCMs can add passive capacity with minimal energy cost, while microchannel liquid loops or fans can be used selectively under heavy loads. Future work should quantify lifecycle trade-offs and develop intelligent control strategies to minimize parasitic energy use while ensuring safety and uniformity[31,32]. By aligning the thermal design to real-world operating conditions, next-generation E2Ws can achieve safe, reliable performance with efficient, compact BTMS.

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Accelerating Unsupervised Feature Learning: Parallelized Training of Denoising Autoencoders

Nagajayant Nagamani
nagajayant@live.com

***Abstract*—Unsupervised representation learning plays a crucial role in modern machine learning by transforming raw high-dimensional data into meaningful feature spaces. This study explores an optimized training approach for stacked denoising autoencoders (SDAEs) using parallel stochastic gradient descent (SGD). By leveraging multi-threaded computations, we analyze the impact of parallelization on model convergence, training efficiency, and feature extraction quality. Our experiments on handwritten digit classification demonstrate that increased parallelism improves training speed while maintaining competitive accuracy. Additionally, we evaluate the effectiveness of autoencoder-learned representations against traditional classifiers. The findings provide insights into scalable neural network training and potential enhancements through alternative optimization techniques.**

I. Introduction

Autoencoders are widely used for unsupervised representation learning, enabling neural networks to discover compact and meaningful ways of encoding input data. Effective data representation plays a vital role in the success of machine learning algorithms, especially in tasks involving high-dimensional inputs. Poor feature representation can lead to overfitting and poor generalization unless a substantial amount of labeled training data is available [1]. To address this, unsupervised pretraining using models like autoencoders can serve as a powerful strategy for transforming raw inputs into representations that simplify downstream supervised learning.

An autoencoder consists of a neural network architecture where the input and output layers are of the same dimension, and a bottleneck is introduced via a hidden layer with fewer neurons. Let the input vector be $x \in \mathbb{R}^m$ and the hidden layer have n neurons. The encoding operation is defined using a weight matrix $W \in \mathbb{R}^{m \times n}$ and a bias vector $b \in \mathbb{R}^n$, while the decoding operation employs the transpose of the same weight matrix (to reduce trainable parameters) and a separate bias vector $b' \in \mathbb{R}^m$. Employing the sigmoid activation function $s(x) = 1/(1 + e^{-x})$, the encoding step computes $y = s(Wx + b)$, and the decoding step reconstructs the input as $z = s(W^T y + b')$.

The training objective is to minimize the difference between the original input t and its reconstruction z using a loss function. In this work, we adopt the mean squared error: $E(t, z) = \frac{1}{2}\|t - z\|^2$. Once trained, the decoder portion is discarded, and the encoder (or "autoencoder layer") is used to transform raw input data into a new representation for subsequent machine learning tasks.

Typically, autoencoders enforce $n < m$ to prevent the network from simply learning to replicate the input through identity mapping. However, a variant known as the *denoising autoencoder* can learn informative representations even when $n > m$ [2]. This model operates by introducing noise to the input and training the network to reconstruct the original, clean version. This denoising objective encourages the model to capture the underlying structure of the data rather than just memorizing inputs, making it effective for learning robust and generalizable features.

In this paper, we focus on training denoising autoencoders using stochastic gradient descent (SGD). A review of related work is provided in the following section, while the algorithmic details of SGD applied to autoencoder training are outlined in the methodology section. Experimental results are presented using a dataset of handwritten digit images, and the final section discusses potential improvements and future directions for training procedures.

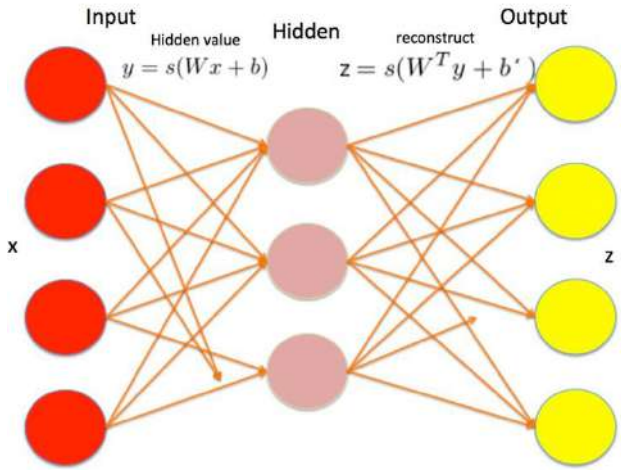


Fig. 1. Autoencoder overview showing encoding and decoding with transposed weight matrices.

II. Related Work

The concept of learning internal data representations without explicit supervision has been foundational in the advancement of deep learning. One of the most comprehensive reviews on this subject is provided by Bengio, Courville, and Vincent, who analyze the role of representation learning in machine learning systems [1]. Their work discusses how both shallow and deep models can be used to uncover useful feature hierarchies, with particular attention to autoencoders and their variants. They argue that better representations can significantly reduce the burden on classifiers, especially in high-dimensional settings.

ISBN: 978-93-343-2006-0

The development of autoencoders as a core component of deep learning frameworks has seen significant contributions over the years. Vincent et al. expanded on the idea of stacked autoencoders and introduced the denoising autoencoder as a robust alternative to traditional unsupervised pretraining techniques [2]. By injecting noise into the inputs and training the network to recover the original signal, they showed that it is possible to guide the learning process toward representations that generalize well, even in overcomplete settings where the hidden layer has more neurons than the input layer.

The challenge of training deep networks with multiple nonlinear layers was notably addressed by Hinton et al., who proposed a greedy layer-wise pretraining strategy [3]. This approach, which is also relevant to our use of stacked denoising autoencoders, demonstrated how unsupervised training of each layer could initialize parameters in a way that facilitates successful fine-tuning with supervised learning. This method marked a turning point in making deep learning practically viable, especially before the advent of large-scale labeled datasets and powerful GPU hardware.

The optimization of neural network parameters has traditionally relied on variants of stochastic gradient descent (SGD). Foundational work on the theoretical and practical aspects of backpropagation—a core component of SGD in neural networks—can be found in [4], [5]. These studies laid the groundwork for efficient gradient-based learning, showing how to compute derivatives of loss functions with respect to model parameters using the chain rule.

In addition to classical gradient-based methods, our future research aims to explore evolutionary algorithms, particularly genetic algorithms (GAs), as an alternative training mechanism for autoencoders. GAs offer a population-based search strategy that is well-suited for optimizing complex, high-dimensional spaces where gradients may be unreliable or difficult to compute. Srinivas and Patnaik provide a comprehensive survey of genetic algorithms and their performance on various optimization tasks [6]. Moreover, Cantu´-Paz's work on parallel implementations of GAs offers important insights into how such algorithms can be scaled to train neural networks more efficiently in distributed environments [7]. This direction holds promise for reducing training time and exploring broader architectural search spaces in future versions of our model.

Collectively, these works provide the theoretical and empirical foundation upon which our current research on denoising autoencoders and alternative optimization methods is built. By integrating insights from representation learning, deep network training, and evolutionary computation, we aim to enhance the robustness, scalability, and training efficiency of unsupervised learning systems.

III. Algorithm Description

To begin training, we initialize the weight matrices W and the associated biases b and b' randomly. Each input x is then passed through the network to produce an output z, which is compared to a target value t. In autoencoders, the goal is to reconstruct the input itself, hence $t = x$. The error between z and t is typically measured using the squared loss function $E(t, z) = \frac{1}{2}\|t - z\|_2$. If the reconstruction error exceeds a threshold, the weights and biases are updated to improve the network's performance. This adjustment is commonly done using the backpropagation algorithm [4], which, when applied on individual training samples, becomes stochastic gradient descent (SGD).

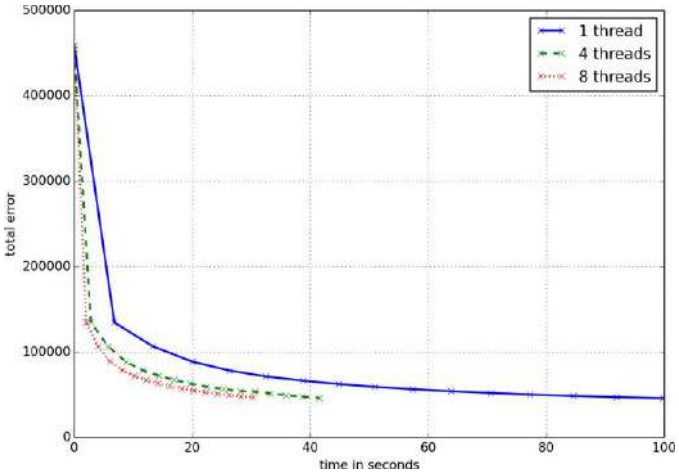


Fig. 2. Time vs. error for 500-node autoencoder (15 iters, 1/4/8 threads, 5,000 images).

To derive the update rules, consider a three-layer feedforward network consisting of input, hidden, and output layers. The notations used are summarized in Table I.

Symbol	Description
E	Error computed at the output
x_j	Input node j
y_j	Hidden layer node j
z_j	Output node j
n_j	Pre-activation at node j: $\sum_{i=1}^{n} W_{ij}x_i + b_j$
t_j	Target output at node j
W_{ij}^H	Weight from input to hidden layer
W_{ij}^O	Weight from hidden to output layer
$s(x_j)$	Sigmoid activation: $1/(1 + e^{-x_j})$
$b_j^{\{H,O\}}$	Biases for hidden/output layer respectively

TABLE I. Notation used in derivation of update rules.

Weight Update from Hidden to Output Layer

For each output neuron, the gradient of the error with respect to the output layer weights W_{ij}^O is computed as follows:

$$\begin{aligned}\frac{\partial E}{\partial W_{ij}^O} &= \frac{\partial E}{\partial z_j} \cdot \frac{\partial z_j}{\partial n_j} \cdot \frac{\partial n_j}{\partial W_{ij}^O} \\ &= (z_j - t_j) \cdot s(n_j)(1 - s(n_j)) \cdot x_i \\ &= (z_j - t_j) \cdot z_j(1 - z_j) \cdot x_i\end{aligned} \tag{1}$$

Using this gradient, the parameters are updated as:

$$\begin{aligned}\delta_j^O &= (z_j - t_j)z_j(1 - z_j) \\ W_{ij}^O &\leftarrow W_{ij}^O - \eta\delta_j^O x_i \\ b_j^O &\leftarrow b_j^O - \eta\delta_j^O\end{aligned} \tag{2}$$

Weight Update from Input to Hidden Layer

Similarly, the gradient of the error with respect to the input-to-hidden weights W_{ij}^{H} is given by:

$$\frac{\partial E}{\partial W_{ij}^{H}} = \left[\sum_{k=1}^{K} (z_k - t_k)(1 - z_k) z_k W_{jk}^{O}\right] y_j (1 - y_j) x_i \quad (3)$$

And the update rules are:

$$\begin{aligned} \delta_j^H &= \left[\sum_{k=1}^{K} (z_k - t_k)(1 - z_k) z_k W_{jk}^{O}\right] y_j (1 - y_j) \\ W_{ij}^{H} &\leftarrow W_{ij}^{H} - \eta \delta_j^H x_i \\ b_j^H &\leftarrow b_j^H - \eta \delta_j^H \end{aligned} \quad (4)$$

Alternative Loss Function: Cross-Entropy with Softmax

In cases where softmax activation is used at the output and the error is measured via cross-entropy, the update rules simplify due to the derivative of the softmax-cross entropy combination. The loss function is defined as:

$$E(x, t) = -\sum_{i=1}^{K} (t_i \ln z_i + (1 - t_i) \ln(1 - z_i)) \quad (5)$$

with softmax given by:

$$\sigma(x_j) = \frac{e^{x_j}}{\sum_k e^{x_k}} \quad (6)$$

In this case, the gradients and updates for the output layer become:

$$\begin{aligned} \frac{\partial E}{\partial W_{ij}^{O}} &= (z_j - t_j) y_i \\ \delta_j^O &= (z_j - t_j) \\ W_{ij}^{O} &\leftarrow W_{ij}^{O} - \eta \delta_j^O x_i \\ b_j^O &\leftarrow b_j^O - \eta \delta_j^O \end{aligned} \quad (7)$$

The updates for the hidden layer remain unchanged from the sigmoid activation case.

Backpropagation Overview

Algorithm 1 outlines the overall procedure of backpropagation during training.

Algorithm 1 Backpropagation Algorithm

```
Initialize weights and biases randomly.
for each training iteration do
  for all training samples x (randomized) do
    Perform forward pass to compute z.
    Compute output error δ_j^O.
    Update W_ij^O and b_j^O.
    for all hidden layers in reverse do
      Compute hidden error δ_j^H.
      Update W_ij^H and b_j^H.
    end for
  end for
end for
```

Autoencoder-Specific Considerations

In autoencoders, a common simplification involves sharing weights between the encoder and decoder: the decoding weights are often the transpose of the encoding weights, i.e., $W^O = (W^H)^T$. This allows us to write the reconstruction as $z = s(W^O(W^H x + b) + b')$. To optimize memory, we avoid storing W^O explicitly and instead use transposed access of W^H during decoding.

Parallelization in training is constrained by the sequential nature of the backpropagation steps. However, key operations such as matrix-vector multiplications, computation of δ terms, and gradient-based weight updates can be parallelized for efficiency.

Finally, once an initial autoencoder layer is trained, its encoded output can serve as input for a subsequent autoencoder, allowing for the construction of a stacked autoencoder architecture that further refines the learned representation.

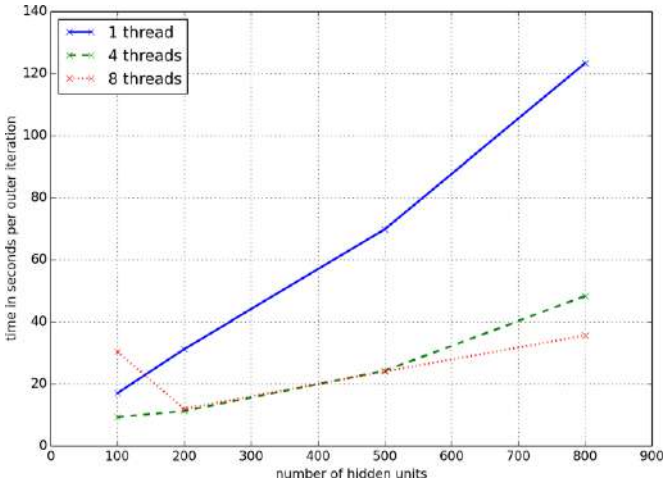


Fig. 3. Iteration time vs. threads and hidden nodes (60,000 images).

IV. Experimental Results

In our experimental setup, we train an autoencoder on the MNIST dataset of handwritten digits. This dataset comprises 60,000 training samples and 10,000 test samples, with each image being a 28×28 grayscale image labeled with a digit from

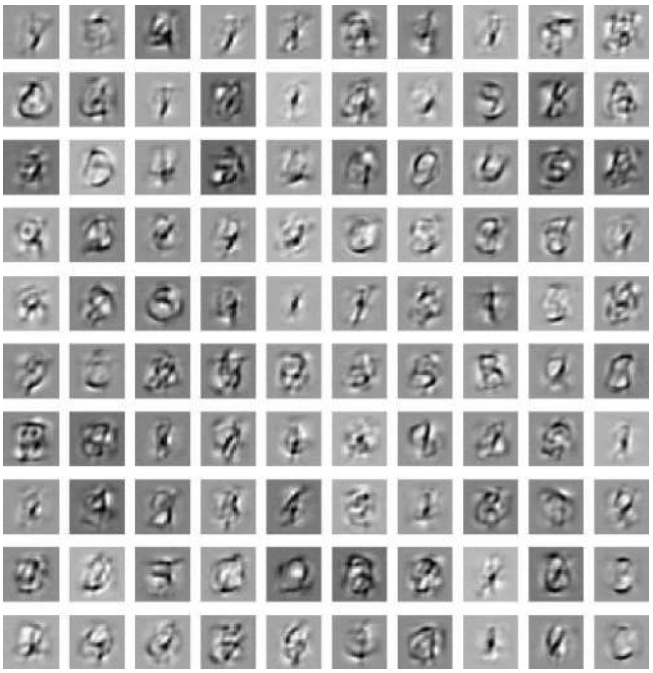


Fig. 4. Filters of the first 100 hidden units from the trained denoising autoencoder.

0 to 9. As a result, each input image is flattened into a 784-dimensional vector. To enhance the model's robustness, we apply the denoising technique proposed by Vincent et al. [2], where each pixel in a training image is independently set to zero with a 25% probability.

We first investigate the impact of multi-threading on the rate of error reduction during training. Specifically, we train a single-layer autoencoder with 500 hidden units for 15 full passes over a subset of 5,000 training samples. One training iteration involves processing all 5,000 samples using stochastic gradient descent (SGD) to update the weights. Figure 2 plots training error against elapsed time across different thread counts. Across all thread settings, error reduction is steep in the initial iterations and stabilizes around a similar value after 15 iterations. However, the use of 4 or 8 threads significantly accelerates convergence compared to single-threaded execution. This speedup is not linear due to two key limitations: (1) cache conflicts caused by concurrent reads and writes to different parts of the weight matrix, and (2) the inherently sequential nature of certain steps in backpropagation and SGD (outlined in Algorithm 1), which limits parallelism and introduces overhead.

Figure 3 presents the average time per training iteration (across all 60,000 images) as a function of thread count and the number of hidden units. With a single thread, runtime increases linearly with the number of hidden units. However, with 4 or 8 threads, the gains become sublinear due to overheads from synchronization and parallel operations. Notably, when using 8 threads with only 100 hidden units, training takes longer than single-threaded execution. Only when the hidden unit count reaches 800 does using 8 threads outperform the 4-thread configuration.

Figure 4 illustrates the filters learned after training an autoencoder with 500 hidden units on the complete set of 60,000 training samples. Each hidden unit's filter, represented as a row of the weight matrix, captures the specific input features that the neuron responds to. Since each filter is the same length as the input vector, we reshape and visualize them as 28×28 pixel images. While these filters don't exactly replicate the original digits, they do reflect patterns present in the input data. Additionally, the same figure shows reconstructed outputs from noisy test digits. Most reconstructions are clearly recognizable, indicating effective denoising and meaningful feature extraction by the autoencoder.

Finally, we evaluate a deep neural network consisting of three stacked denoising autoencoders. Each layer has 1,000 hidden units and is trained with corruption levels of 0.1, 0.2, and 0.3 respectively. Each layer undergoes 15 training iterations with a learning rate of 0.001. After unsupervised pretraining, we connect a feedforward neural network on top, consisting of 1,000 input units, 500 hidden units, and 10 output units. This network is then trained in a supervised manner using the indicator vector of the target labels, for 30 iterations with a learning rate of 0.1. The final classification accuracy achieved is 98.04%. For comparison, a Support Vector Machine (SVM) with an RBF kernel, as reported by Vincent et al. [2], achieves a slightly higher accuracy of 98.60%.

Algorithm 2 Genetic Algorithm

Initialize a population of N individuals at random.
for each generation **do**
  Evaluate each individual using the objective function and assign a fitness score.
  Generate αN new individuals ($0 < \alpha < 1$) by selecting high-fitness individuals and applying crossover and mutation.
  Replace the αN least fit individuals with the new offspring.
end for

V. Future Work

In future research, we intend to explore the use of Genetic Algorithms (GAs) for optimizing the weight matrices and bias terms of autoencoders. GAs are population-based metaheuristic optimization techniques that operate without gradient information. Inspired by natural selection, they employ operations such as mutation and crossover to iteratively improve candidate solutions until a near-optimal solution to the objective function is found [6].

Compared to Stochastic Gradient Descent (SGD), GAs offer two primary advantages in the context of training autoencoders. First, SGD often converges to local minima due to the non-convex nature of the loss landscape, whereas GAs are better suited for escaping such traps and can potentially identify global optima. Second, parallelization of SGD presents certain challenges, as demonstrated in our experiments where linear speedup was not achieved. Conversely, GAs naturally lend themselves to parallelization in two ways [7]: (a) evaluation of individuals in the population can be distributed across processors, and (b) mutation and crossover operations are element-wise and can be parallelized easily.



Fig. 5. Denoising autoencoder reconstructions: noisy inputs (odd) and outputs (even).

Algorithm 2 outlines the basic structure of a Genetic Algorithm. In our context, each individual in the population represents a set of weights and biases. The objective function is the same as the reconstruction loss described earlier, and an individual's fitness corresponds to how well it minimizes this loss.

Furthermore, we plan to assess the generalizability of our autoencoder architecture on more challenging image datasets referenced in [2], such as *bg-rand* and *bg-img-rot*, which introduce variations like background noise and image rotations.

VI. Conclusion

In this work, we developed and evaluated a deep learning framework using stacked denoising autoencoders (SDAEs) to learn robust feature representations from corrupted input data. Our approach was tested on the MNIST dataset, and we showed that the autoencoder was capable of learning meaningful internal representations that could effectively denoise and reconstruct handwritten digits. The reconstructions were qualitatively accurate, and the filters learned by the hidden layers demonstrated a clear understanding of the underlying data structure.

Furthermore, the performance of our stacked architecture was benchmarked on a classification task, where the final accuracy reached 98.04%, which is competitive with state-of-the-art methods like Support Vector Machines with RBF kernels. This highlights the effectiveness of SDAEs not just for unsupervised feature learning, but also as a pretraining mechanism for supervised learning tasks.

Our experiments also examined the computational aspects of training, particularly the impact of multi-threading on the convergence rate and iteration time of stochastic gradient descent (SGD). Although parallelization improved training speed, the speedup was sublinear due to inherent overheads and sequential components of the backpropagation algorithm. This limitation points to the need for more parallel-friendly optimization strategies.

Given these findings, one key direction for future exploration is the integration of evolutionary algorithms, such as Genetic Algorithms (GAs), as an alternative to SGD for training deep models. GAs offer potential advantages, including global search capabilities and a high degree of parallelizability, making them well-suited for distributed or high-performance computing environments. In addition, their gradient-free nature can help overcome issues with non-convex loss surfaces, which are common in deep learning models.

We also recognize the need to validate the generalizability and robustness of our model on more complex and noisy datasets. The MNIST dataset, while widely used, is relatively clean and may not reflect real-world data complexities. Thus, future experiments will include datasets with more challenging variations, such as those with background clutter, transformations, and occlusions.

In conclusion, this study affirms the viability of stacked denoising autoencoders for both representation learning and classification. It also opens up promising avenues for optimization and scalability improvem

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Fire-Fighting Robots: A Review of Trends and Technologies

Rohan S. Gardi
Department of Engineering Science
K J College of Engineering and Management Research
Pune
gardirohan251@gmail.com

Sandip C. Sahane
Department of Engineering Science
K J College of Engineering and Management Research
Pune
sandipsahane.math@gmail.com

Sanika Jagdale
Department of Engineering Science
K J College of Engineering and Management Research
Pune
jagdalesanika30@gmail.com

ABSTRACT — Fire accidents pose significant threats to life, property, and the environment, often occurring in hazardous and hard-to-reach areas. To address these challenges, a low-cost firefighting robot has been developed that autonomously detects and extinguishes fires using sensors like flame, smoke, and thermal cameras. It operates in both automatic and Bluetooth-controlled manual modes and provides live video feedback. Built with an Arduino controller, the robot is compact and effective in confined spaces. Indoor tests showed reliable performance in detecting and extinguishing small fires, highlighting its potential as a valuable tool in emergency response and disaster management.

1. INTRODUCTION

Fire accidents are one of the most dangerous and unpredictable disasters, often resulting in loss of life, serious injuries, and destruction of property. Firefighters play a crucial role in saving people and controlling fire outbreaks, but they often have to risk their lives by entering extremely hazardous environments such as burning buildings, chemical factories, and gas plants. In many situations, it becomes difficult or even impossible for humans to safely reach the fire source, especially in narrow or unstable areas. To overcome these challenges and improve the safety of fire rescue operations, the use of technology has become essential. One such solution is the development of firefighting robots — smart, unmanned systems designed to detect, approach, and extinguish fires without putting human lives at risk.

A firefighting robot is equipped with modern technologies such as flame sensors, temperature sensors, obstacle-avoiding ultrasonic sensors, and wireless communication systems. Some advanced models also use thermal imaging cameras and artificial intelligence to detect fire hotspots and navigate through smoke-filled environments. These robots can work in two modes: autonomous mode, where they perform tasks automatically based on sensor input, and manual mode, where a human operator can control the robot remotely. The compact design of the robot allows it to reach tight spaces that firefighters may not be able to access easily. Once the robot identifies the fire source, it activates a water pump or extinguisher to suppress the flames. This project focuses on building a cost-effective, efficient firefighting robot using Arduino as the main controller. The goal is to improve safety during fire emergencies and support rescue operations by reducing human involvement in high-risk situations. With continued innovation, firefighting robots can become an essential part of modern fire safety systems.

2. OBJECTIVE

The primary objectives of the firefighting robot are to accurately localize the fire within its environment and autonomously navigate while avoiding obstacles to reach the fire source. It is designed to extinguish fires effectively using suitable methods such as water or CO_2. The system enables remote monitoring and control via a user interface, camera, or wireless module, and collects real-time environmental data like temperature and gas levels for analysis. Additionally, it communicates critical information to human responders and is built to withstand harsh conditions including high temperatures, smoke, and debris.

3. LITERATURE REVIEW

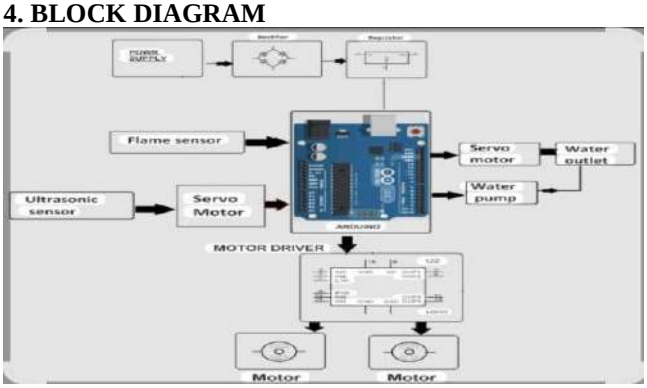
3.1 Development of Fire Fighting Robot

Fire incidents pose serious risks to life and property, especially in hazardous environments like nuclear plants and refineries. To reduce risks to human fire fighters, a compact robot named QRob has been developed. It uses ultrasonic sensors to avoid obstacles and a flame sensor to detect fire. QRob can locate a fire and stop 40 cm away from it to extinguish it. It can be remotely monitored using a camera connected to a smartphone or remote device.

3.2 Survey on Fire Fighting Robot Controlled Using Android Application

Firefighting is dangerous and often life-threatening. Robotics, powered by advancements in AI, can help reduce these risks. A fire-fighting robot has been developed that can detect and extinguish fire, controlled via an Android application. It uses sensors for fire detection and operates wirelessly. Android's open platform and built-in sensors make it ideal for controlling such robots, promoting innovation and enhancing fire safety.

4. BLOCK DIAGRAM



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ISBN: 978-93-343-2006-0

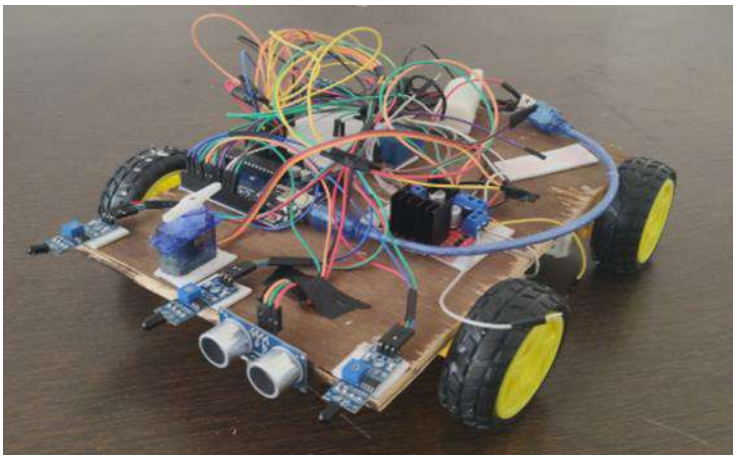
1. The block diagram shown below illustrates the working of a fire-fighting robot using an Arduino UNO as the central controller.
2. The fire sensor detects flames and sends signals to the Arduino, which processes the input and triggers necessary actions. Once fire is detected, the Arduino activates the water pump, drawing water from the container and spraying it onto the fire to extinguish it.
3. Simultaneously, the robot moves towards the fire using DC motors controlled by the L293D motor driver. A servo motor helps adjust the nozzle position for accurate water spraying. The entire system operates with a dedicated power supply, ensuring uninterrupted functionality.
4. You can either connect all the shown connections for uploading the program to check the working or you can assemble the bot completely and then proceed with
5. the connections. Both ways the connections are very simple and you should be able to get it right.
6. Based on the robotic chassis that you are using you might not be able to use the same type of container that I am using. In that case use your own creativity to set up the pumping system. However, the code will remain same**.**

5. PROGRAM



6. HARDWARE COMPONENTS AND MODEL

The hardware components of the firefighting robot include several key elements that work together to ensure efficient operation. The SG90 servo motor is a compact and lightweight device commonly used in robotics for precise angular control, offering approximately 180 degrees of rotation and accurate position feedback, which is ideal for adjusting sensor orientation or controlling small mechanical parts. The L293D motor driver module serves as an interface between the microcontroller and motors, enabling control over the direction and speed of DC and servo motors by supplying the necessary current and voltage, while protecting the microcontroller from high current loads and allowing bidirectional motor control. At the core of the system is the microcontroller, which functions as the central processing unit by coordinating sensor inputs and controlling actuators like motors and pumps through embedded software, ensuring autonomous task execution. The flame sensor is an optical device designed to detect fire by sensing specific wavelengths of light emitted by flames, crucial for accurate fire localization and triggering responses such as navigation and extinguishing. Lastly, the DC pump motor powers the pump mechanism that expels water or fire suppressant agents, playing a vital role in delivering the extinguishing medium directly to the fire



7. RESULT

The firefighting robot demonstrated effective performance in detecting and extinguishing fires within a short period. Utilizing the flame sensor, the robot accurately identified the fire source, enabling it to respond promptly and efficiently. During testing, the robot successfully detected flames from a distance of up to 1.5 meters, providing adequate coverage of its operational area. Upon fire detection, the robot initiated its extinguishing process in less than 5 seconds, reflecting its rapid reaction capability essential for minimizing fire damage. For small-scale fires, the robot was able to completely extinguish the flames within 10 to 15 seconds, showcasing its practical effectiveness in handling minor fire incidents. In a controlled testing environment, the robot achieved a 90% success rate in detecting and putting out fires, indicating its reliable functionality and robustness. Additionally, basic obstacle avoidance was implemented using infrared (IR) sensors, which allowed the robot to navigate around simple obstacles while approaching the fire source, ensuring safer and more autonomous operation. Overall, these results confirm that the robot functions as an efficient fire detection and extinguishing system in controlled scenarios, with promising potential for further improvements

in speed, accuracy, and navigation to handle more complex environments.

8. CONCLUSION

The firefighting robot is a valuable innovation designed to detect and extinguish fires in hazardous environments, reducing human risk and improving response time. It can access hard-to-reach areas and be operated remotely, ensuring safety for fire personnel. The system not only detects and suppresses fires automatically but also sends real-time alerts and live footage to authorities, enabling faster and better-coordinated emergency responses. As fire incidents increase due to various factors, such intelligent robots will play a crucial role in protecting lives and property while minimizing risks to firefighters.

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Testing of an Upgraded Aquaponic Setup for Nutrient Removal by Replacing Fish with Plant-Based Biodegradable Material

Dr. Bharat N. Mulay[1], Dr. Santosh K. Patil[2], Puneet S. Jain[3], Surekha S. Thorat[4] , Aniket R. Zolekar[5]

[1]*Department of Civil Engineering, Sandip Institute of Engineering and Management Research, Nashik, India.*

[2]*Department of Civil Engineering, K J College of Engineering and Management Research, Pune, India.*

[3, 4, 5] *Department of Civil Engineering, Sandip Institute of Engineering and Management Research, Nashik, India.*

Corresponding Author- bharat.mulay@siem.org.in

Abstract

This study involved experimentation in order to test the effects of replacing fish with biodegradable material on the removal of nutrients from the water, a small-scale aquaponic setup was set up in a laboratory. Layers of natural biomaterials, such as coconut husk, cocopeat, and coarse aggregate, were laid down in the biofilter, and four-week-old basil seedlings with four to five leaves were planted in it. Water specimens were taken from the biofilter outlet after recirculation periods of two, three, and four hours, each applied for fifteen days. The experiment continued for 45 days, separated into three separate phases of fifteen days each. The results showed that the system removed 76%, 81%, and 71% of NH3 at recirculation durations of three, four, and five hours per day, respectively. In addition, the removal of total ammonia nitrogen (TAN) was 75%, 78%, and 73% at the same recirculation durations.

Keywords: Ammonia, DO (Dissolved Oxygen), Recirculation, Aquaponic.

1. Introduction

Hydroponics and recirculating aquaculture systems are combined to create aquaponics, a modern farming technology that grows fish and edible vegetables at the same time. This kind of farming does not exclusively depend on fertilizers and outside supply of nutrients, in contrast to conventional hydroponics [1; 2]. Rather, it circulates the highly nutritious, dissolved fish waste-laden water from the fish tank through troughs filled with gravel that are planted with plants [3]. This technique uses the fish tank's nitrogen-rich water to feed soilless hydroponic systems [4]. This novel approach has the potential to reduce the high fertilizer requirements typically correlated with conventional agricultural methods by combining hydroponics with aquaculture [5]. Fish excrement is a natural fertilizer that may be used to grow and harvest food plants [3]. Nevertheless, the main obstacle restricting the adoption of these systems in developing nations is their high operating costs [6]. Notwithstanding this, aquaponic systems have the potential to be implemented in underdeveloped countries, especially since their lower operating costs might make them financially feasible [7, 8]. Water flow rate optimization and water recirculation time reduction are two efficient ways to lower operating costs and improve the viability of these systems [9]. However, studies examining how brief reductions in water recirculation and filtration affect aquaponic system water quality indicators are still in their infancy [10, 11].

The present commercial and profitable aquaponic practices are based on the core idea of recirculating and replenishing

ISBN: 978-93-343-2006-0

complete water on a regular basis to

Because of the technique, the system now costs more to develop and run. Residents in rural areas without access to water might not be able to afford such devices since they are more concerned with finding a way to feed themselves than with engaging in commerce. Such a low-cost and easily implementable system is needed to offer ample food supplies and a water reusing technology in rural portions of India [15]. Aquaculture water is presently treated utilizing the phytoremediation technology in addition to chemical and biological treatments [16–17–18]. Nonetheless, this approach may not be anticipated to work in some regions or climates due to a number of limitations [19]. Aquaponics was the subject of earlier research as a sustainable agricultural approach. Among the issues with aquaponics is the requirement for detailed and technical depth. Understanding the initial cost, power usage, regular maintenance, preserving ideal water parameters for fish and plant development, the fragility of fish, and the possibility of serious defects brought on by carelessness [19]. Blockages and the development of self-cleaning capacities are the main issues affecting aquaponic systems [20]. The lack of ability of Recirculating Aquaculture Systems (RAS) to remove generated fish waste at the tank bottom is a common cause of failure or poor performance. Fish raised through aquaponic method may not

2. Material and methods

2.1 Bioponic system setup

The main element for bio culture in the layout of the system is a reservoir that holds water of 1.2 meters in length, 1 meter in width, and 0.9 meters in height, with a volume of 1.08 cubic meters and a capacity of 1000 liters. In addition, two half-cylindrical troughs measuring 0.9 meters in length, 0.26 meters in depth, 0.55 meters in diameter, and 0.5 square meters in surface space are used as biofilter components after being cleaned and replaced with media beds. Cultivating basil plants is preferred for research

maintain the health of the system [12, 13].

satisfy market requirements because aquaponic systems find it difficult to effectively manage the accumulation of solid waste in fish tanks. The main obstacles to aquaponic adoption in areas with limited water resources are waste reduction, zero-discharge recirculation system deployment, and efficient fertilizer usage [21, 22].

Thus, the biggest drawbacks of the newest systems are keeping a healthy system and efficiently cleaning fish tanks. Numerous physico-chemical factors need to be kept an eye on and managed because water quality, plant development, and the survival of fish. Management of quality of water is a particularly delicate issue [19]. It is still early research to see if it is possible to replace fish with other foods while still being effective. If plant-based compostable organic waste biomass behave in a manner like to that of fish, it might provide essential nutrients while minimizing the build-up of waste in tanks. Research on aquaponic systems that use planted biofilters and short recirculation times but lack fish culture is scarce. A thorough examination is necessary into this system, which combines an anaerobic biomass degrading process with extra aeration to oxygenate the water and promote plant growth and filtration.

objectives. Water is moved via the water reservoir to the 10 liter frustum-shaped water recycler using an 18 watt pump running at 2200 RPM. In order to transport the filtered water to the bio culture tank—where fish have been replaced with organic matter that decomposes—two one-liter permeable plastic bottles are attached to the bio filter's bottom and connected to the output pipe. While 6 mm thick steel rods may be used and kept in the water for the duration of the process, three porous bags were hung and immersed in the water by means of strings from wooden rods that were connected to the top of the tank. Separate PVC pipes with a 20 mm diameter were used to connect the biofilter

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and cycler units to the bio culture unit (water tank). Figure 2 shows a hypothetical bioponic system, which is an half a kilogram of plant-based materials, such as grass, waste from vegetables, dried leaves, and plants that had been soaked in water. The water cycler, which was placed above the biofilter, received a vertical pumping operation from the water tank to oxygenate the water. After that, aerated water was sprayed on the biofilters to help

aquaponic system modified. The porous bags were filled with

plants absorb and get purified. With the exception of employing porous bags to create nutrients in the water rather than fish and modifying the length of time the biodegradable material was circulated, the system functioned similarly to an aquaponic system.



Figure 1 Bio-composter



Figure 2 submerged porous bio-bags



Fig.3 System with water cycler

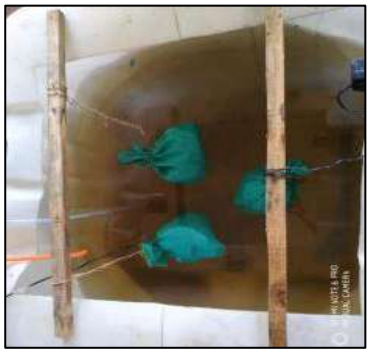


Fig. 4 Porous bags soaked in water



Fig. 5 bags with waste plant material

Four-week-old basil seedlings at the five-leaf stage were placed in the biofilter. 50% of the dry mass from biodegradable plant waste in the perforated bags was replaced while the recirculation intervals were adjusted. Water samples were extracted from the biofilter output and applied for 15 days each, at varying recirculation

durations of 3, 4, and 5 hours. The cycler's aerated water ran to the biofilter with basil plants before reaching the water tank. Samples of the effluent water leaving the biofilter unit were obtained prior to initiating the next recirculation cycle. To check for NO3, NH3, DO, and TAN, the colorimetric test kits were utilized.

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3. Results

Table 1. Temperature, pH and DO levels.

Sr. No.	Parameter	Levels (min-max)
1	Temperature (^{0}C)	22-34
2	pH	6.0-8.0
3	DO (mg/l) (before recirculation)	3- 4.5
4	DO (mg/l) (after recirculation)	5-7

As shown in table 1, the levels of pH, DO and temperature are shown. These are the vital parameters for the entire process of developing the nutrients and maintaining the balance of the system. Table 2 shows the plant growth in cm/day during the entire experimentation of 45 days. During the experiment, several water recirculation periods were used for 15 days each. Low D.O. conditions were not a concern as the perforated bags carrying the organic biodegradable stuff took the place of the fish.

Table 2. Average plant growth at different recirculation periods

Sr. No.	Q (L/min)	Plant growth (cm/d)	Recirculation Period (hr/d)
1	6.5	0.5	3
2	5.5	0.7	4
3	5.0	0.8	5

Table 3 Mean values of water quality parameters at varying recirculation periods.

Parameter	Recirculation durations (hr/d)	Influent (mg/l)	Effluent (mg/l)	Percentage removal
NH_3	3	0.082	0.033	60
	4	0.090	0.035	62
	5	0.074	0.025	67
TAN	3	1.180	0.790	33
	4	1.380	0.740	46
	5	1.780	0.740	58
NO_2	3	0.490	0.190	61
	4	0.480	0.140	70
	5	0.280	0.090	67
NO_3	3	18.00	8.00	55
	4	14.00	6.00	57

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	5	18.60	6.90	63



Figure 6 Plants in 2nd week



Figure 7 Plants in 4th week

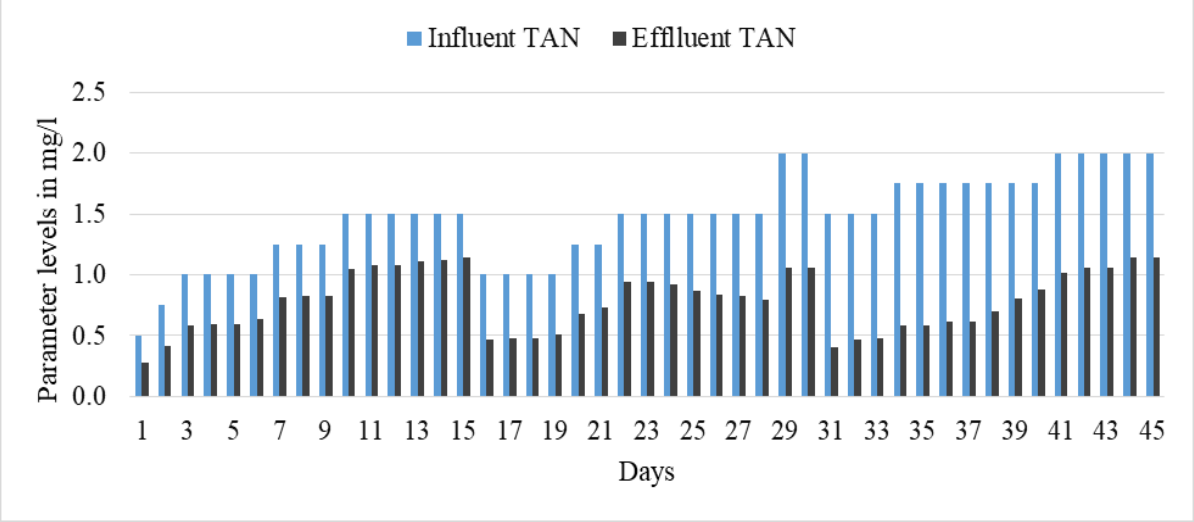


Figure 8 Plants in 6th week

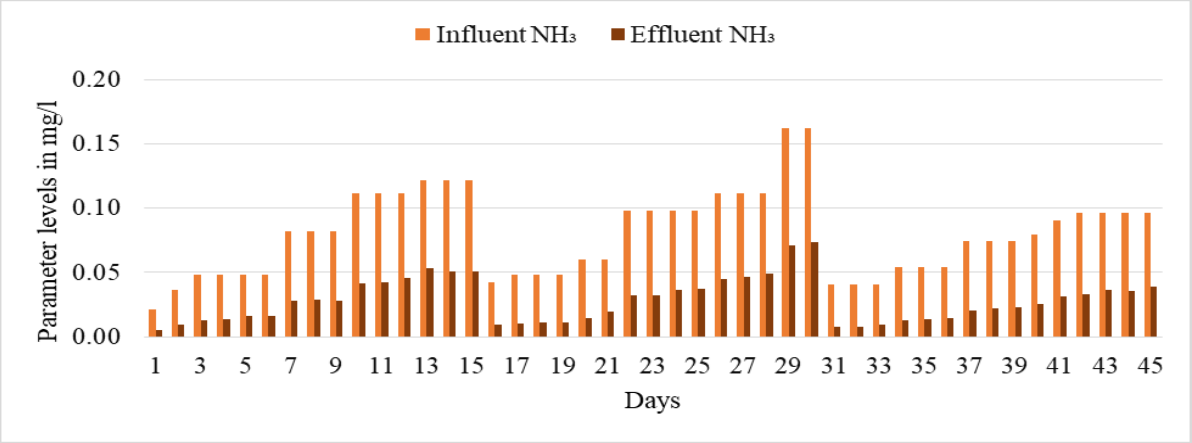
4. Discussion

The amounts of both influent and effluent NH3 and TAN are illustrated in Graph 1 and 2. Throughout the investigation, periodic periods of reduced fish activity were observed, which corresponded with decreases in dissolved oxygen (DO) levels. This resulted in a somewhat reduced food consumption, which might explain the decreased TAN levels that were seen at 3, 4, and 5 hours per day. The mean NH3 level in the effluent was determined to be 0.033, 0.035, and 0.025 mg/l, respectively.

Graph 1 Influent and effluent TAN values



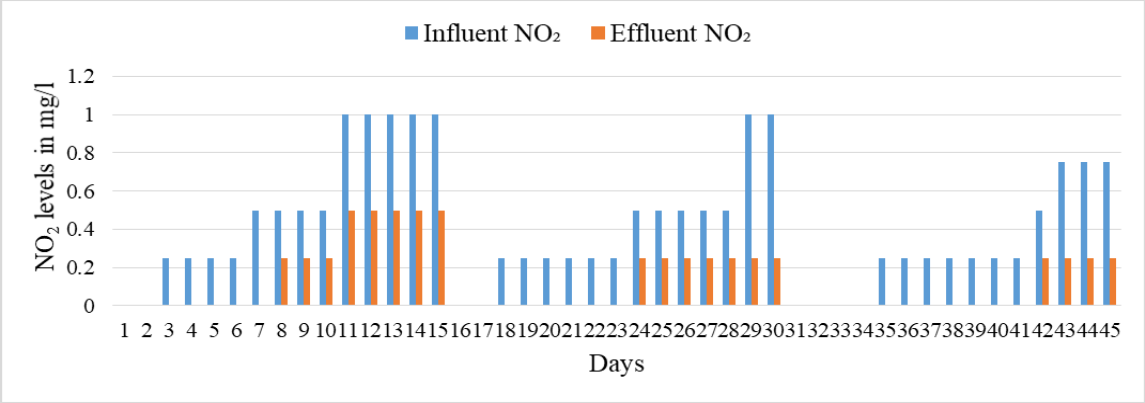
Graph 2 Influent and effluent NH_3 values



The results showed that there was no significant difference between these values, indicating that the system operated without any fluctuations or problems when the hydraulic conditions changed. At 3, 4, and 5 hours per day, the system effectively

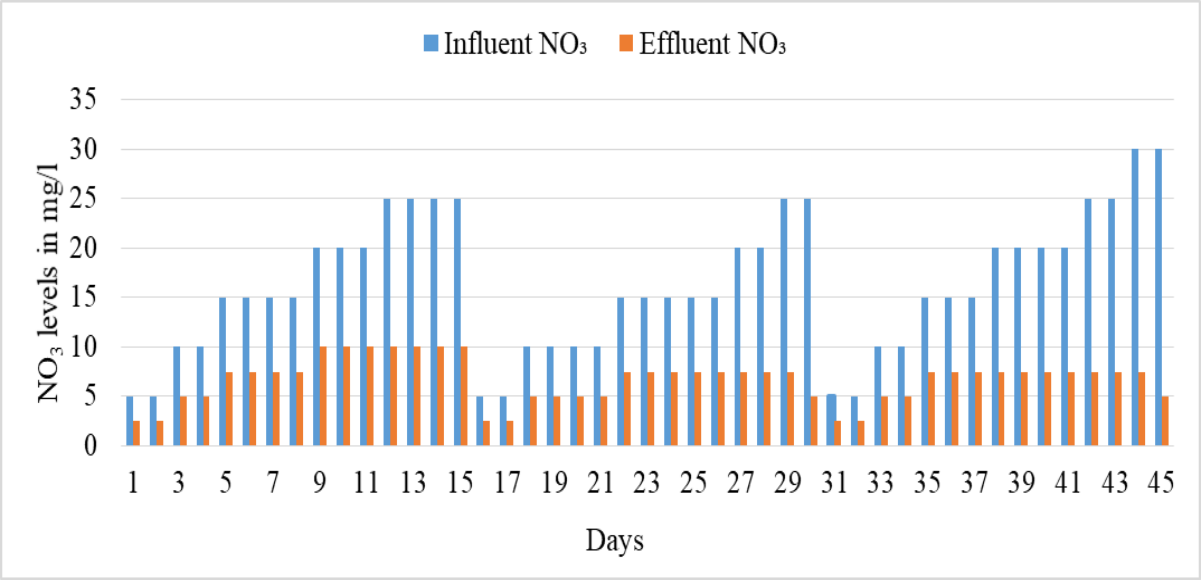
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removed NH3, reaching a maximum removal percentage of 67%. Ammonia present in water is one of the leading causes of functional problems for microorganisms [23, 24]. According to the earlier findings, 65% to 71% of the NH3 in the aquaculture water was removed. By providing enough surface area for gravel, the hydroponic trough facilitated the development of microorganisms that adhered to the associated growth mechanism and broke down the waste materials in the water. At 3 and 4 hours per day, there was no difference in the TAN levels of the fish tank water entering the biofilter (1.18 mg/l and 1.38 mg/l). In the third length cycle of four hours per day, the TAN levels were raised. There was a significant difference ($p < 0.05$) between the durations of 4 and 5 hours each day.



Graph 3 Influent and effluent NO_2 values

The graph 3 shows NO2 levels during experimentation period. Between 61 and 70 percent was the effective NO2 removal rate of the system. There was no discernible impact of flow duration on NO2 reductions. Aerobic bacteria such as Nitrosomonas and Nitrobacter transform ammonium into nitrite and nitrate forms, which is what causes the nitrification process [24-25-26-27]. Previous research has indicated that ammonium conversion to nitrite is best achieved at a pH of 6.0 to 8.5 [28, 29]. The pH range in this investigation was within this range, indicating that the system underwent appropriate nitrification. According to prior research [30], the average effluent NO2 content was found to be between 0.090 and 0.190 mg/l, which is between the range of 0.4 and 1.5 mg/l.



Graph 4 Influent and effluent NO_3 values

In graph 4, the NO3 influent and effluent values are displayed. Nitrogen accumulation occurs in aquaculture systems as a result of nitrification [27].

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The NO3 levels were lowered by 53-60% using this technique. TAN must be oxidized to NO3 during the aquaponic phase since NO3 is not hazardous to fish, even at greater concentrations of 150–300 mg/l; in systems, NO3 can range from 10 mg/l to 200 mg/l. In contrast, TAN and NO2 levels should be kept at low levels [31]. In comparison to the TAN (1.6 mg/l - 2.9 mg/l) and NO2 concentrations (0.4 mg/l - 1.1 mg/l), a tilapia-basil aquaponic system showed a relatively high concentration (54.7 mg/l) of NO3 [31]. In this experiment, the elimination of nitrates increased proportionately with longer recirculation times.

5. CONCLUSIONS

1. Water doesn't require to be changed for lengthy periods of time, compared to an aquaponic setup. There were no appreciable pH variations, hence this system could be maintained without professional observation.

2. NH4 does not contaminate fish. But it often becomes nitrites when temperature and pH change. Chemically speaking, ammonium and ammonia are connected by the following equation: NH4+ + OH- NH3 + H2O At temperatures higher than 32°C and pH values higher than 9, the reaction is pushed to the left. The process of turning the NH4+ back into NH3 starts. As a result, there was no longer any chance of NH4 conversion back to the dangerous NH3, which at higher quantities can kill fish or have a detrimental effect on their health, just as it can in an aquaponic system, according to the study's findings on pH and temperature maintenance.

3. Considering this system was fish-free, there was no need to worry about dissolved oxygen levels dropping or the possibility of a hypoxic state.

4. The biomass produced by the system from plant waste functioned as a reliable source of nutrients.

5. The nutrients were appropriately combined with water and the combination was oxygenated in a water cycler that was adequately aerated and did not require any extra mechanical aeration.

6. The bioponic system's solids settling issue due to fish excrement was essentially resolved by the hanging perforated bags, which supplied leachate and allowed a little amount of suspended particles to settle along with some algae development at the bottom of the tank.

6. LIMITATIONS

The leachate formation process cannot be manually monitored or controlled in these systems. It results in an uneven leachate development and unpredictable nutrient synthesis within the leachate. The leachate released from bio bags has to be thoroughly investigated utilizing some modern, state-of-the-art equipment, and such spectrophotometers. Aeration is required to keep the tank water from acquiring an unpleasant smell after a few days. Correctly replenishing the biomass in the bags is crucial, and knowing when to do so takes expertise.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgement

The author would like to thank the Environmental engineering laboratory of the Civil engineering department of Sandip Foundation’s Sandip Institute of Engineering and Management, Nashik, Maharashtra, India for proving necessary experimental facility.

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ISBN: 978-93-343-2006-0

Pushover Analysis of an Existing Structure

Prathamesh S. Wanjale Pmwanjale9197@gmail.com

ABSTRACT

In the era of rapid urbanization and infrastructure development, maintaining the safety and functionality of aging structures is a critical responsibility of structural engineers. Over time, buildings may deteriorate due to environmental effects, overloading, or design limitations. Structural Health Monitoring (SHM) plays a vital role in assessing the condition of such structures and determining whether they require retrofitting or demolition. Pushover Analysis, a non-linear static method, serves as an effective tool for evaluating the seismic performance of existing buildings.This study highlights the significance of SHM and demonstrates how Pushover Analysis using software like ETABS can be used to predict structural responses under seismic loads. The method provides insights into weak zones, plastic hinge formations, and overall structural capacity, helping engineers make informed decisions about the rehabilitation or removal of unsafe buildings. However, despite technological advancements, demolition methods often remain non-engineered and lack systematic analysis, leading to unsafe practices.To bridge this gap, this report also emphasizes the need for integrating engineering-based analytical tools like ETABS into demolition and retrofitting decision-making processes. Furthermore, it references the Applied Element Method (AEM) used in specialized software such as Extreme Loading for Structures, which combines Finite Element and Discrete Element Methods to simulate collapse behavior more accurately.The effective implementation of SHM and advanced analysis techniques is essential not only for extending the life of structures but also for ensuring public safety, minimizing property damage, and guiding sustainable urban development.

KEYWORDS

Pushover Analysis, Seismic Evaluation, ETABS, Existing Structure, Nonlinear Static Analysis, Plastic Hinge, Performance Point.

INTRODUCTION

As global infrastructure continues to grow and age, the responsibility of maintaining its safety and functionality falls heavily on the shoulders of structural engineers. With time, buildings and other structures experience deterioration due to aging materials, environmental exposure, overuse, and changing load demands. This natural aging process poses serious challenges to structural integrity and public safety, making **Structural Health Monitoring (SHM)** a vital engineering practice.

Structural engineers play a pivotal role in SHM by assessing the condition of aging structures, identifying signs of distress or potential failure, and recommending appropriate interventions such as retrofitting, strengthening, or controlled demolition. Their responsibilities extend from on-site inspections to advanced computational modeling that simulates real-world conditions and responses.

Pushover Analysis, a nonlinear static method, is one of the key analytical tools used by structural engineers to evaluate how structures behave under seismic or lateral loading. This method helps visualize progressive collapse mechanisms, pinpoint weak zones, and estimate failure capacities. When implemented using advanced software like **ETABS** and **STAAD**, pushover analysis allows engineers to model aging structures, apply incremental loads, and predict their performance against future earthquakes or stress conditions.

The structural engineer's role does not end at analysis. It includes data interpretation, decision-making on whether a structure can be rehabilitated or must be demolished, and the design of retrofit strategies. Furthermore, engineers ensure that public safety, cost-efficiency, and environmental sustainability are all considered in the final recommendations.

This paper focuses on how pushover analysis, when integrated with modern engineering software, empowers structural engineers to monitor, analyze, and extend the life of aging infrastructure. It also highlights the increasing importance of transitioning from conventional visual inspections to more scientific and simulation-based approaches for safer cities and smarter engineering decisions.

THEORETICAL CONTENT (STRUCTURAL EVALUATION/ ANALYSIS BY PUSH OVER)

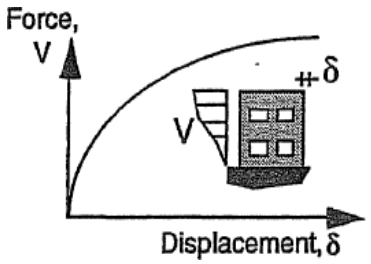
Evaluation is complex process, which has to take not only the design check of structure but also the deterioration of the material and damage cause to the structure, if any.

Determination Performance of existing Structure:

Capacity

This nonlinear procedure is the generation of the "pushover" or capacity curve. This represents the lateral displacement as a function of the force applied to the structure. This process is independent of the method used to calculate the Demand and provides valuable insight for the

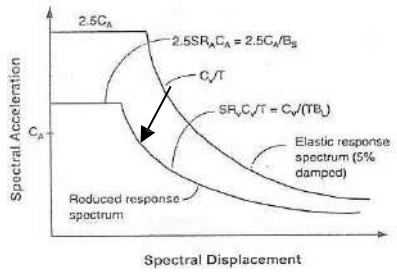
Capacity curve



Demand

Ground motions set of lateral displacements as a design condition (IS Code Response Spectrum). For a given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the structure.

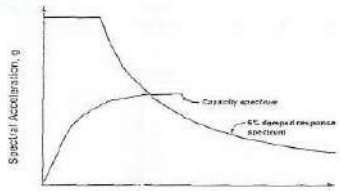
Demand Spectra



Performance

Once capacity curve and demand displacement are defined, a performance check can be done. Using the Performance Point the global response of the structure and individual component deformations are compared to limits in light of the specific performance goals for the structure.

Performance Point



Performance of structure is measured by the level of structural and/or Non-structural damage expected from the probable loading. Damage is expressed in terms of post yield, inelastic deformation limits for various structural components and elements found in concrete structure.

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Main objective of performance evaluation is to place the structure into one of the following performance levels:

a) Immediate Occupancy Performance Level:

Structural Performance Level, Immediate Occupancy, means the post loading state in which only very limited structural damage has occurred. The basic vertical and lateral-force-resisting systems of the building retain nearly all of their pre-loading strength and stiffness. The risk of life-threatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

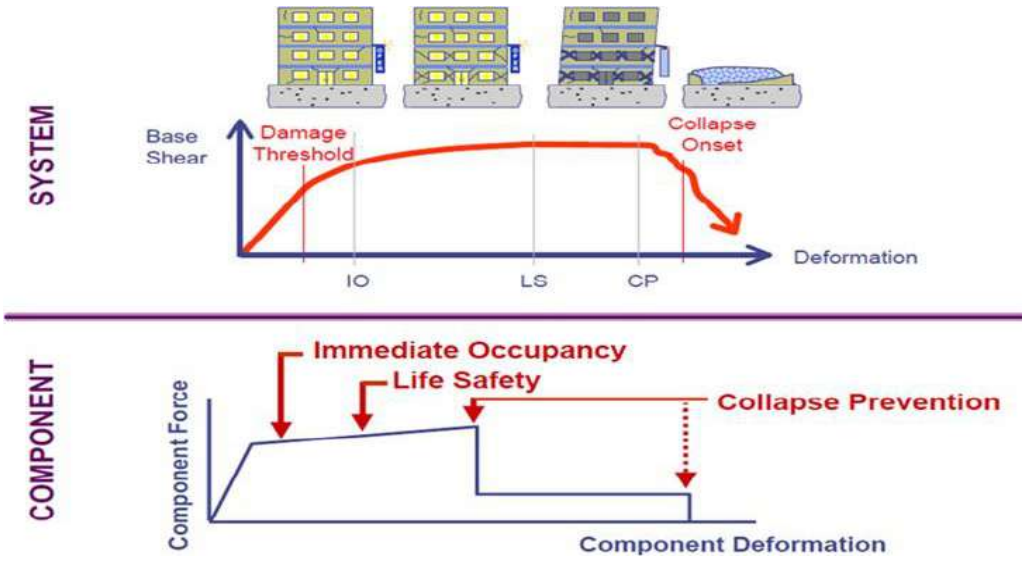


Fig. 1: Various performance levels

b) Life Safety Performance Level:

Structural Performance Level, Life Safety, means the post-loading damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. Some structural elements and components are severely damaged, but this has not resulted in large falling debris hazards, either within or outside the structure.

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c) Collapse Prevention Performance Level:

Structural Performance Level, Collapse Prevention, means the structure is on the verge of experiencing partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral force-resisting system. However, all significant components of the gravity load-resisting system must continue to carry their gravity load demands. Significant risk of injury due to falling hazards from structural debris may exist. The structure may not be technically practical to repair and is not safe for re-occupancy.

METHODOLOGY

The following methodology outlines the step-by-step process for conducting **Pushover Analysis** to evaluate the structural health of aging buildings using **ETABS/STAAD**, along with references to relevant **IS Codes**

1. **Selection of Structure**

   An aging reinforced concrete building is selected, showing signs of structural degradation due to age, environmental effects, or overloading. Original design drawings and usage history are collected to support modeling.

2. **Data Collection and Preprocessing**

   - Visual inspection and Non-Destructive Testing (NDT) are conducted to assess the current condition.
   - Material properties such as compressive strength of concrete and yield strength of steel are obtained, either from historical data or field testing.

3. **Structural Modeling in ETABS**

   The selected structure is modeled using accurate geometrical and material data:

   - Concrete and steel grades as per IS 456:2000.
   - Structural elements modeled with appropriate cross-sectional dimensions.
   - Rigid diaphragm assigned for floor slabs.

4. **Application of Gravity and Lateral Loads**

   - Dead load and live load combinations are applied.
   - Seismic loads are calculated based on the building location (zone factor, importance factor, etc.).

- Pushover loads are defined as monotonically increasing lateral loads at each story level to simulate earthquake-induced lateral forces.

5. **Pushover Analysis Setup**
   - Nonlinear hinge properties are assigned to beams and columns as per FEMA 356 or default hinge models in ETABS.
   - Lateral load patterns (e.g., uniform, triangular) are selected based on the fundamental mode shape.
   - Control nodes are assigned to monitor displacement at the roof level.
6. **Execution of Pushover Analysis**
   - The pushover analysis is run, and the structure is subjected to gradually increasing lateral load.
   - Hinges begin to form at member ends as the structure undergoes nonlinear deformation.
   - The load-displacement curve (capacity curve) is generated, showing base shear versus roof displacement.
7. **Performance Evaluation**
   - The performance point is identified using the Capacity Spectrum Method or ATC-40 approach.
   - Structural performance levels are interpreted (Immediate Occupancy, Life Safety, and Collapse Prevention).
   - The plastic hinge formation pattern is studied to identify weak members and failure mechanisms.
8. **Result Interpretation and Recommendations.**
   - Based on the analysis, the building's ability to withstand future seismic events is evaluated.
   - If the performance falls below acceptable levels, retrofitting strategies such as jacketing, shear wall addition, or base isolation may be suggested

ISBN: 978-93-343-2006-0

REAL-TIME PUSH-OVER ANALYSIS USING ETABS: A CASE STUDY OF AN EXISTING OVER HEAD WATER TANK LOCATED AT BAGDOGRA



A. Water Tank Design Consideration

1. Overhead Water Tank of height = 18.75m
2. No. of staging = 4
3. No. of Column = 12 nos (320x320) up to height 18.75m from GR. LVL.
4. Area of Water Tank = 9.66m x 6.44m.
5. Water Tank Beams Size (280mm x 280mm)

B. Geometrical Properties:

Area Section properties:

Section	Material	Area Type	Type	Thickness (m)	Bend thickness (m)	Cover (m)	Rebar
S1-200 Bottom Slab	M15	Shell	Shell-Thin	0.200	0.200	0.02	HYSD 415
S2-150 Top slab	M15	Shell	Shell-Thin	0.150	0.150	0.02	HYSD 415
S-200 Vertical Wall	M15	Shell	Shell-Thin	0.200	0.200	0.02	HYSD 415

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S-320 Vertical Wall	M15	Shell	Shell-Thin	0.320	0.320	0.02	HYSD 415

Frame Section properties:

Section	Material	Shape	t3 (m)	t2 (m)	Cover (m)	Rebar
Column 320 x 320	M15	Rectangular	0.32	0.32	0.040	HYSD 415
Beam Size 280x280	M15	Rectangular	0.28	0.28	0.030	HYSD 415

C. Material Properties:

Sr. No.	Material	Fc (KN/m^2)	ES(N/mm^2)
1	M15	15000	19364.91

Sr. No.	Material	Fy (KN/m^2)	Fu (KN/m^2)	EffFy (KN/m^2)	EffFu (KN/m^2)
1	HYSD 415	415000	485000	456500	533500

D. Load & Combinations:

1. **Dead Load (DL): -** The self-weight of all the beams, column, slabs and walls are considered for the self-weight of the structure.
2. **Water Load (SDL): -** The Water/super dead load is the load of the non-structural member of the tank and it also includes the floor finishes and water load on bottom slab of the tank and pressure on the side walls of the tank.

   Super-Dead Load applied on bottom slab of tank = **24 kN/m^2**

   Super-Dead Load applied on bottom slab of tank = 0.1 at the top of wall and linearly increased to **14kN/m^2** at the bottom of wall.
3. **Live Load (LL): -** Load due to movement of people for inspection or regular maintenance is considered. A live load of the water tank and **1.5kN/m2** is considered at the top slab of water tank.
4. **Earthquake Load (EQ): -** The Bagdogra, West Bengal, India region lies under earthquake zone-IV as per IS-1893-2016, hence zone factor of 0.24 is considered, an Importance factor of

ISBN: 978-93-343-2006-0

1.2 is considered, response reduction factor of 5 and the natural period is program calculated. The soil is considered as soft soil as per the soil test report provided.

5. **Wind Load (WL): -** As per IS-875 Part III 2015 the Bagdogra, West Bengal, region has a basic wind speed of 47m/s. The risk coefficient factor k1 is considered as 1, the terrain category is considered as Category-3, terrain height factor k2 is program calculated as per height of the structure.

6. WSM Criteria	**7. LSM Criteria**
a) (DL+SDL)	**a)** 1.5 (DL+SDL)
b) (DL+SDL+LL)	**b)** 1.5 (DL+SDL+LL)
c) (DL+SDL+0.8*LL±0.8*WLX)	**c)** 1.2[DL+SDL+LL±(WLX)]
d) (DL+SDL+0.8*LL±0.8*EQX)	**d)** 1.2[DL+SDL+LL±(EQX)]
e) (DL±WLX)	**e)** 1.5[DL+SDL±(WLX)]
f) (DL±EQX)	**f)** 1.5[DL+SDL±(EQX)]
	g) 0.9DL+0.9SDL±1.5(WLX)
	h) 0.9DL+0.9SDL±1.5(EQX)

E. Model & Loading Detail

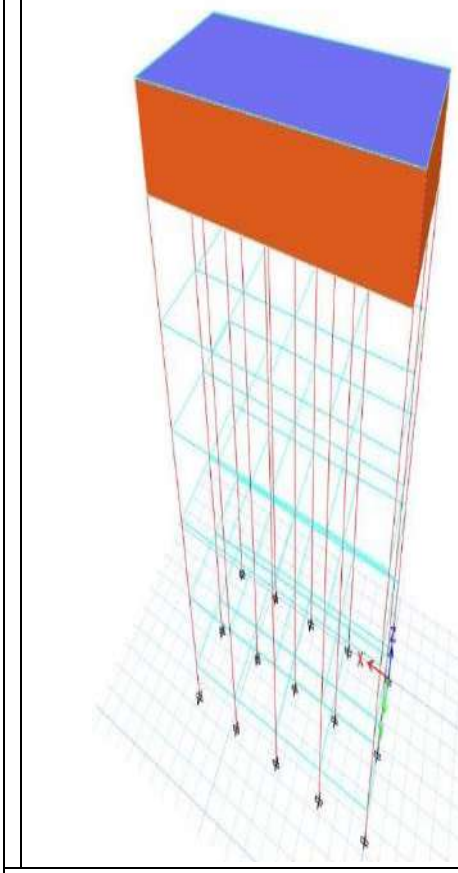


Fig1. 3D View of structure

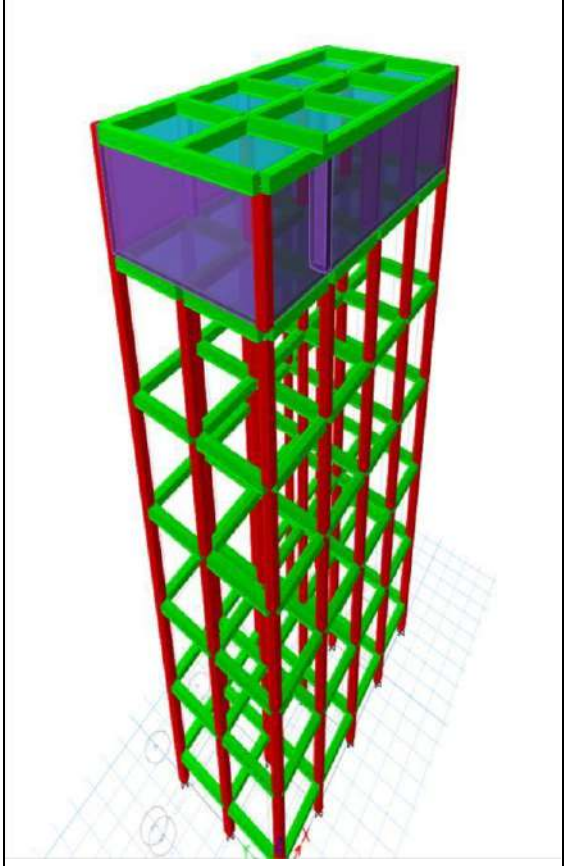


Fig1. Render View of Water Tank

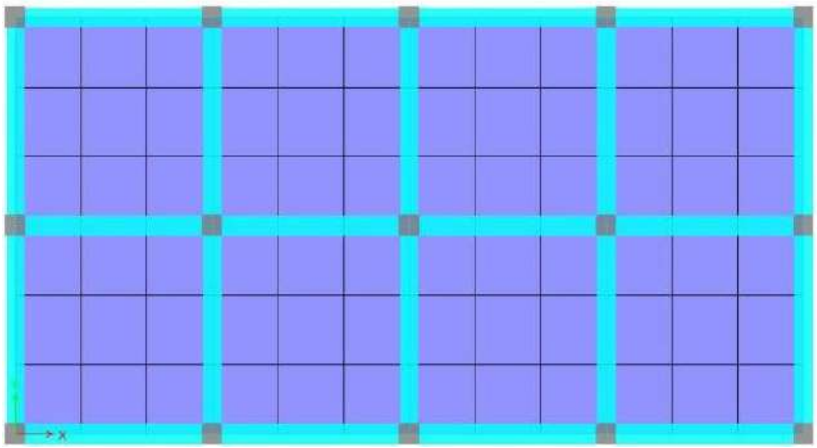


Fig. 3: Framing Plan of Water Tank Bottom slab

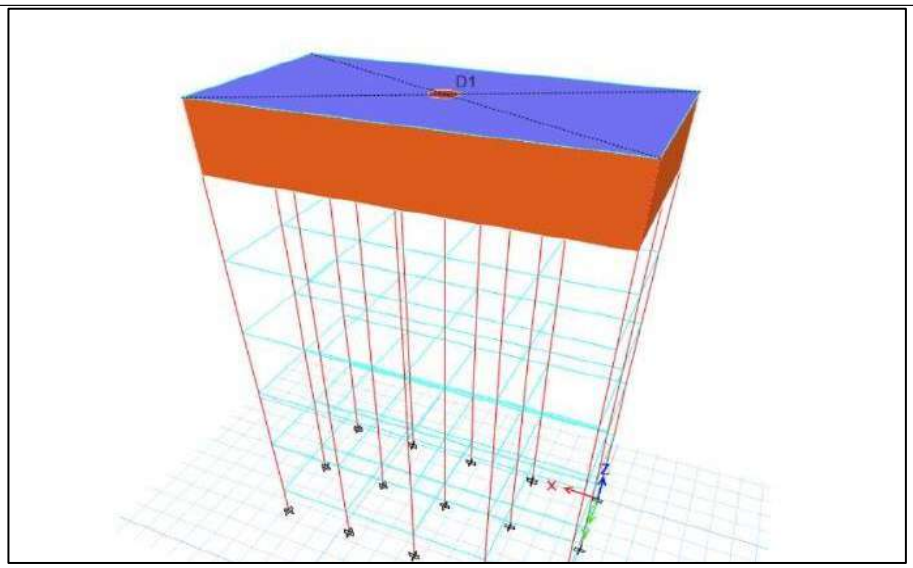
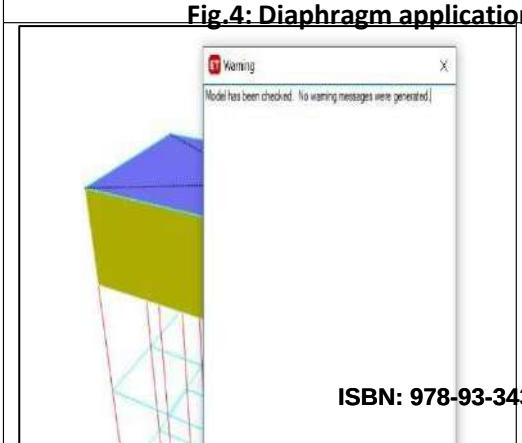


Fig.4: Diaphragm application on floor in 3D View.



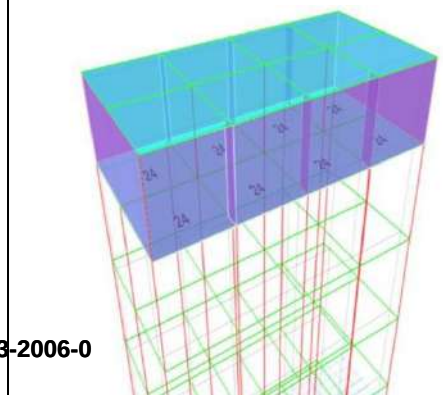


Fig.4: Model Checking Message.

Fig 5. Water pressure applied on slab.

F. Summary of Design Result:

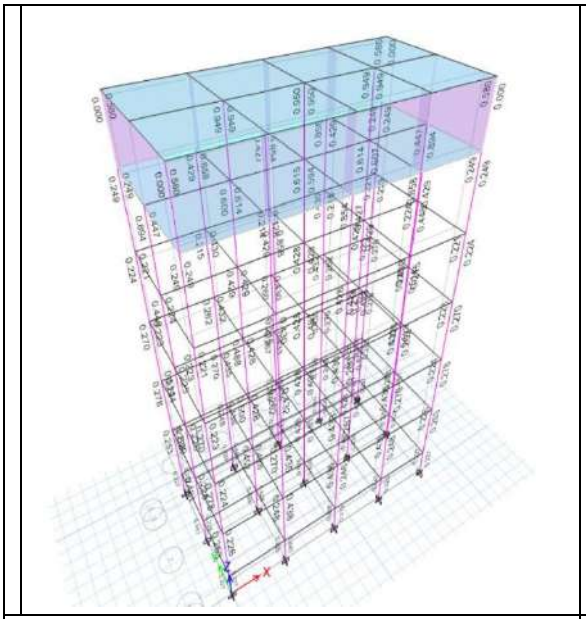


Fig.13: Beam /Column Ratio

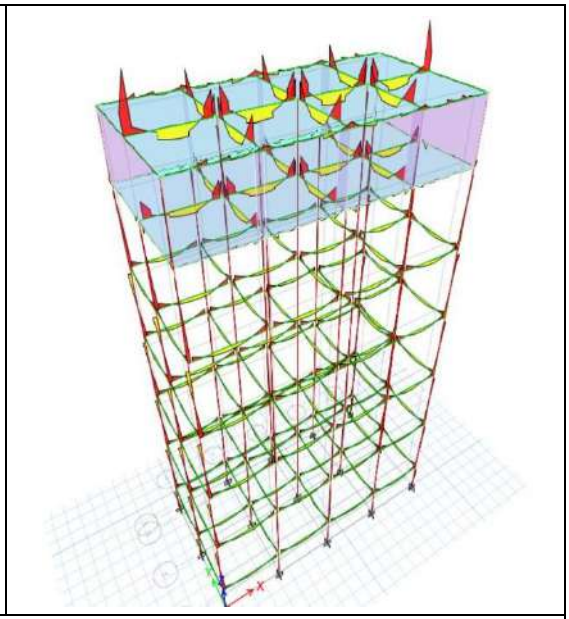


Fig.14: Assigned BMD on floor of structure.

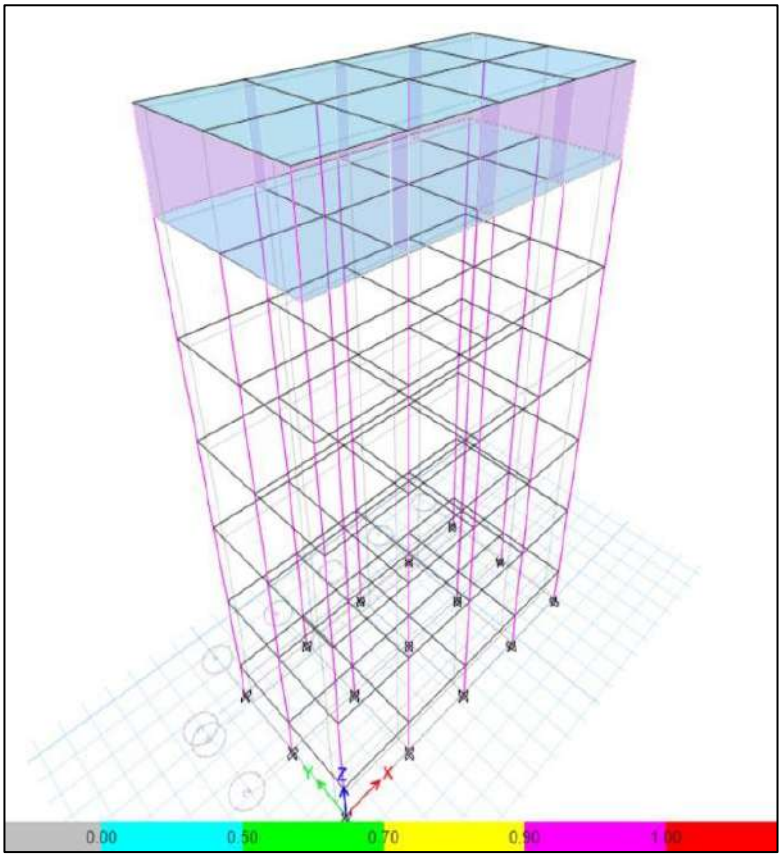


Fig.15: P.M.M. Ratio Diagram

CONCLUSION

Structural analysis performed on an existing structure, incorporating material properties obtained from Non-Destructive Testing (NDT) and applying current loading conditions, reveals that the structural condition can be categorized as structurally unfit/unsafe for the existing design loads. In addition, this structure is located in Earthquake Zone-IV, which falls under the High Damage Risk Zone as per IS 1893 (Part 1):2016, indicating a high probability of significant damage during seismic events.

Detailed analysis through pushover analysis using ETABS/STAAD shows inadequate lateral load resistance and widespread formation of plastic hinges in critical members such as columns and beams, signaling an impending structural failure during major seismic activity. The deterioration observed may be due to factors such as material aging, corrosion of reinforcement, poor construction practices, and absence of ductile detailing as prescribed in IS 13920:2016.

Therefore, the structure is deemed unfit for continued occupancy or use without intervention. It is strongly recommended that major retrofitting and structural strengthening measures be undertaken, including jacketing of structural members like columns, beam & slab, or other advanced techniques. Alternatively, if retrofitting is economically or technically unfeasible, controlled demolition may be considered. The decision must be based on a detailed cost-benefit analysis, ensuring life safety and compliance with present-day structural and seismic design standards.

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An Effective Framework in Data Clustering with Specific Applications to Product/Service Recommendations: A Hybrid Approach

Mr. SAKSHI SIVA RAMAKRISHNA[1], and Dr. T ANURADHA[2]

[1] Department of CSE, ACHARYA NAGARJUNA UNIVERSITY, GUNTUR, INDIA

ramakrishna_sakshi@yahoo.co.in

[2] Department of CSBS, RVRJC College of Engineering, GUNTUR, INDIA

a_talasila@yahoo.com

Abstract

Data serves as a cornerstone throughout the business lifecycle, from initial operations to high-level strategic planning. In today's digital business environment, where competition in digital marketing is relentless, analyzing transactional data has become essential. This paper introduces a robust hybrid framework that synergizes data clustering methods with recommendation system strategies to enhance the relevance and effectiveness of product and service recommendations. The framework leverages KMeans and DBSCAN clustering algorithms alongside Principal Component Analysis (PCA) for dimensionality reduction. These techniques are applied to a content-enriched representation of movies sourced from the MovieLens 100k dataset. To overcome challenges such as cold-start problems and data sparsity, the model integrates both content-based and collaborative filtering approaches, using cosine similarity as a metric. Experimental results, including Silhouette coefficient analysis and qualitative assessments, reveal that the proposed method not only achieves well-formed clusters but also delivers more accurate and diverse recommendations. The framework proves to be scalable and adaptable across various application domains.

Keywords: Clustering, Principal Component Analysis (PCA), KMeans, DBSCAN, Recommendation Systems, Collaborative Filtering, MovieLens.

Introduction

Recommendation systems are central to the success of modern digital platforms, driving user engagement and satisfaction in domains such as e-commerce, streaming services, online education, and social media by helping users navigate vast volumes of content to find relevant products, services, or information. As digital ecosystems grow in complexity and scale, the demand for accurate, diverse, and personalized recommendations continues to rise [1]. However, traditional recommendation systems face persistent challenges, including the cold-start problem, sparsity of user-item interaction data, scalability, and the ability to provide explainable outputs [2].To address these issues, researchers have increasingly turned to hybrid models that combine multiple recommendation techniques, such as collaborative filtering, content-based filtering, matrix factorization, and clustering. Hybridization offers a promising avenue for balancing the strengths and limitations of individual methods, resulting in improved prediction accuracy and user satisfaction [3]. Recent advances also highlight the use of clustering algorithms to pre-process data, group similar users or items, and reduce computational complexity in large-scale recommender systems [4].

Moreover, techniques such as dimensionality reduction (e.g., PCA, autoencoders) are often employed to compress high-dimensional interaction matrices into more manageable forms without sacrificing informative structure, allowing models to better capture latent relationships [5]. Deep learning

approaches and graph-based models have also emerged to deal with non-linear and complex dependencies in user behavior, further enhancing personalization in recommendation systems [6].

Considering these developments, this paper proposes a hybrid clustering-based recommendation framework that combines the strengths of KMeans and DBSCAN for user-item segmentation, PCA for dimensionality reduction, and a fusion of collaborative and content-based filtering using cosine similarity. Unlike conventional approaches, this framework explicitly addresses sparsity and cold-start challenges while improving recommendation accuracy and diversity. Evaluation on the MovieLens 100k dataset demonstrates the scalability and robustness of the proposed method in real-world recommendation scenarios.

1.1 Organization of the Paper

The paper is organized into the following divisions. The following section reviews the related work in clustering and recommender systems. The third section states the problems and outlines the objectives. Section 4 details the proposed model and methodology. Section 5 discusses the experimental results. The last section concludes with the study and suggests future directions.

2 Literature Review

The evolution of recommender systems has transitioned from simple heuristic algorithms to sophisticated hybrid approaches capable of handling complex, sparse, and large-scale datasets. Foundational strategies like collaborative filtering and content-based filtering have provided the basis for personalized recommendations but often suffer from issues such as sparsity, scalability, and limited generalization [7].
Clustering techniques have gained prominence as a means of structuring high-dimensional user-item interaction data. Algorithms like KMeans and DBSCAN enable systems to identify user or item subgroups with similar behaviors, thus enhancing both computational efficiency and recommendation quality [8]. These unsupervised learning methods not only reduce the search space but also offer a pathway to improved personalization through micro-segmentation. Hybrid systems have become particularly effective in overcoming limitations such as cold-start problems and data sparsity. For instance, Ricci et al. and Jannach et al. emphasized that combining multiple recommendation strategies (e.g., collaborative filtering with content-based approaches) produces more accurate and user-centric outputs by leveraging complementary strengths [9]. A significant advancement in this context is the use of matrix factorization, which identifies latent features by decomposing the user-item matrix, though it still faces challenges in sparse data settings.

An important contribution by Rajeswari and Sumathi introduced a KMeans-based hybrid filtering system that improves personalization by clustering users before applying collaborative filtering. Their model addresses cold-start and sparsity challenges by exploiting demographic and behavioral similarities [10]. Another impactful study by Siva Rama Krishna and Anuradha proposed a graph-based hybrid approach for sparse transactional data. Their method applies to the HITS algorithm to derive hub and authority weights and uses these scores in a weighted imputation mechanism for missing values. When compared to Singular Value Decomposition (SVD), this method achieved significantly lower RMSE scores, indicating its potential in highly sparse datasets [11]. Recent literature also explores the integration of deep learning into recommendation models. Autoencoders, attention mechanisms, and graph neural networks (GNNs) have been applied to learn complex, non-linear relationships in user-item data. These models can capture temporal dynamics and context-aware behavior, further enriching recommendation outcomes [12][13]. Explainability and fairness have emerged as important secondary objectives in recommender system design. Techniques such as SHAP (SHapley Additive exPlanations) and adversarial training are increasingly used to ensure model

transparency, trust of the user, and balanced treatment across user groups or clusters[14][15]. Taken together, the literature points toward a clear trend: next-generation recommender systems will increasingly rely on hybrid architectures that combine clustering, matrix factorization, graph theory, and deep learning to deliver scalable, accurate, and user-aligned recommendations across varied domains.

3 Problem Statement and Objectives

Traditional recommendation systems face several issues such as:
- Cold-start problem: limited data on new users or items.
- Data sparsity: insufficient user-item interactions.
- Limited personalization: failure to adapt to individual user preferences.

To address these, the study sets out the following objectives:
- To implement a hybrid clustering framework combining KMeans and DBSCAN.
- To enhance recommendation quality using a combination of content and collaborative filtering.
- To evaluate the clustering structure and recommendation outcomes using real-world movie data.

4 Proposed Model

Phase 1: Data Collection and Feature Extraction

We use the MovieLens 100k dataset containing 100,000 ratings from 943 users on 1,682 movies. Features include movie genres (19 binary-encoded fields) and average user ratings. These are combined to form a content feature vector for each movie.

Phase 2: Preprocessing and Dimensionality Reduction

Features are standardized using z-score normalization. Principal Component Analysis (PCA) reduces the dimensionality to two principal components to facilitate clustering and visualization.

Phase 3: Clustering with KMeans and DBSCAN

KMeans clustering is applied to partition movies into k groups. DBSCAN is used to identify dense subgroups and outliers. Cluster validity is assessed using Silhouette scores. Both clustering algorithms capture different structural aspects of the data.

Phase 4: Hybrid Recommendation Engine

Using collaborative filtering, a user-movie rating matrix is constructed. Cosine similarity is used to compute movie-to-movie similarities. For a given input movie, top-N similar movies are retrieved. Recommendations are further refined by filtering based on cluster membership to ensure both relevance and diversity.

Phase 5: Evaluation and Visualization

Clusters are visualized in 2D using PCA projections. Silhouette scores are reported for both KMeans and DBSCAN. Recommendations are qualitatively assessed to verify alignment with user preferences and clustering context.

5 Experimental Results

The proposed model is implemented and tested with MovieLens 100k dataset. Comparisons are made to test the proposed model. The Silhouette score is a commonly used metric in unsupervised learning to assess the effectiveness of clustering outcomes. It quantifies how well each data point fits within its assigned cluster relative to other clusters, offering insight into both intra-cluster cohesion and inter-cluster separation. Scores range from -1 to 1, where higher values signify more clearly separated and well-formed clusters.

Table 1: Comparison of Clustering Performance (Silhouette Scores)

Clustering Algorithm	Silhouette Score
KMeans (k=5)	0.32
DBSCAN	0.24

Table 1 compares the clustering performance of KMeans and DBSCAN based on Silhouette scores. The KMeans algorithm performs better in terms of cohesion and separation of movie clusters, indicating more well-defined groups for recommendation.

Evaluation is conducted on the MovieLens 100k dataset. KMeans with k=5 yielded a Silhouette score of 0.32, while DBSCAN achieved 0.24. Sample recommendations for popular titles (e.g., Star Wars) show improved relevance and variety when using the hybrid method compared to collaborative filtering alone.

Table 2: Top-5 Hybrid Recommendations for *Star Wars*

Movie Title	Cluster ID
Empire Strikes Back	**1**
Return of the Jedi	**1**
Raiders of the Lost Ark	**1**
Indiana Jones and the Last Crusade	**1**
Back to the Future	**1**

Table 2 shows the top-5 hybrid recommendations for Star Wars, filtered based on cosine similarity and cluster ID. These results suggest that the hybrid system effectively retrieves movies that are both thematically and statistically aligned with the input title.

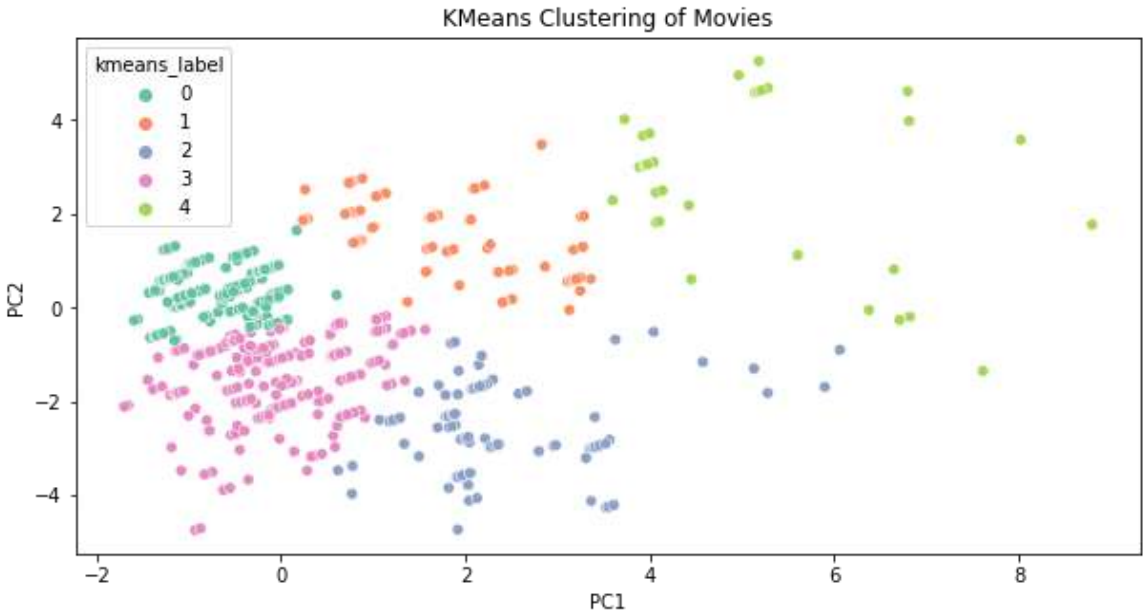


Fig. 1 PCA Projection of Movie Clusters Identified by KMeans (k=5)

The above figure shows a scatter plot of movies clustered using KMeans. Each point represents a movie from the MovieLens dataset, with high-dimensional features reduced to two principal components using PCA. The different colors indicate different clusters (0–4). The plot reveals meaningful grouping structures, validating the effectiveness of clustering as a basis for personalized recommendation.

Recommendations for: Star Wars (1977)

	title	rating
126	Godfather, The (1972)	4.283293
173	Raiders of the Lost Ark (1981)	4.252381
171	Empire Strikes Back, The (1980)	4.204360
180	Return of the Jedi (1983)	4.007890
0	Toy Story (1995)	3.878319

Fig. 2. Recommendations for Star Wars movie

Figure 2 presents the top-5 movie recommendations for *Star Wars (1977)* generated using the hybrid recommendation framework. These results reflect the system's ability to identify high-quality and thematically similar movies by combining clustering and cosine-based similarity. The presence of sequels and related action-adventure films like *Empire Strikes Back* and *Raiders of the Lost Ark* demonstrates the content and genre alignment. *The Godfather* and *Toy Story*, though distinct in narrative, appear due to shared audience appreciation patterns captured via collaborative signals. This confirms the hybrid model's capacity to integrate both feature-based similarity and user behavior trends.

Conclusion

This paper presents a novel hybrid framework for clustering and recommendation that effectively combines content and collaborative signals. The integration of KMeans, DBSCAN, PCA, and cosine similarity yields a robust system suitable for various recommendation scenarios. Future work includes incorporating temporal dynamics, neural collaborative models, and deployment on real-time platforms.

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Application of Heat Removal In automobiles Using Al_2O_3 Nano Particles

Siddharth Suman
Assistant Professor
Mechanical Engineering Department
K J College of Engineering & Management Research
Pune, India
siddharthsumansingh@gmail.com

Mahesh R. Pawar
Assistant Professor
Mechanical Engineering Department
Yashoda Mahadeo College of Engineering
Pune, India
mrpawwar686@gmail.com

Ravindra Y. Daspute
Assistant Professor
Mechanical Engineering Department
Dr. D. Y. Patil College of Engineering & Innovation
Pune, India
dasputeravindra@gmail.com

Vidyadhar S Dixit
Assistant Professor
Mechanical Engineering Department
K J College of Engineering & Management Research
Pune, India
d.vidyadhar.13@gmail.com

***Abstract*— The Heat Exchanger serves as a critical component in modern industries, especially during times of resource scarcity and intense market competition. This project focuses on conducting a thermal performance analysis of a heat exchanger utilizing Nano-Fluid, a blend of Nano particles and water as the base fluid. The study involves varying the nano-fluid composition to optimize heat transfer rates and overall heat transfer coefficient in an engine radiator pipe through experimental analysis. By evaluating factors such as heat exchanger effectiveness, the project aims to ascertain the impact of Nanofluids on enhancing radiator performance, determining the optimal percentage of Nano particles in the coolant mixture for achieving maximum heat exchange efficiency.**

***Keywords*— Nano fluids, Heat Exchanger, Radiator, Efficiency.**

I. INTRODUCTION

Researchers have long been focused on enhancing heat transfer in industrial and everyday devices to boost performance and efficiency. Traditional methods like free and forced convection, and extended surfaces have been employed in the past to achieve higher heat transfer rates. In the modern era, the exploration of new techniques has led to the emergence of nanofluids, which are fluids containing nanoparticles ranging from 10 nm to 100 nm suspended in a base fluid. Radiators play a crucial role in various applications, including industrial machinery and automobiles. With the automotive sector striving to enhance efficiency and performance, the use of nanofluids in car radiators has gained attention. While nanofluids have been extensively studied in heat exchangers, limited research has been conducted on their application in car radiators. Studies suggest that nanofluids can lead to a 15%-40% enhancement in heat transfer efficiency due to the significantly higher thermal conductivity of solid particles compared to traditional base fluids. The movement of nanoparticles in nanofluids improves energy exchange processes, resulting in unexpected enhancements in heat transfer coefficients. Nano fluids, first proposed in 1995, offer a novel approach to heat transfer by dispersing highly thermally conductive solid particles in low-conductivity fluids. This innovation has the potential to revolutionize heat exchange performance in various industrial sectors, offering a promising solution to the limitations of conventional heat transfer fluids.

I. SYSTEM DESIGN

A. Radiator

A radiator functions as a heat exchanger, transferring heat from hot coolant to the air blown through it by a fan. Aluminum radiators, prevalent in modern cars, consist of thin aluminum fins brazed to flattened aluminum tubes. Coolant flows through numerous parallel tubes, with fins facilitating heat transfer to the air passing through. Turbulators, inserted in some tubes, enhance fluid turbulence to ensure efficient cooling. By maintaining fluid temperature near the tubes, heat extraction is optimized. Radiators typically feature transmission coolers within their tanks, where oil exchanges heat with the coolant instead of the air.

B. Pipe in pipe heat exchanger

In this project, a thermal performance analysis of a pipe-in-pipe heat exchanger was conducted by varying the composition of nanofluids used, comprising a mixture of [specific components] and Glycol. Experimental tests were performed on the heat exchanger with variations in the volume fraction of the coolant. The results included data on heat transfer rates, overall heat transfer coefficient, and the maximum heat obtained by the pipe-in-pipe heat exchanger. The equipment facilitates the transfer of energy from a hot fluid to a cold fluid efficiently, aiming for maximum performance at minimal investment and operational costs. Heat transfer in such systems typically involves convection on each fluid side and conduction through the separating wall. The historical development of aluminium heat exchangers, particularly in the automotive industry, saw significant advancements with the introduction of vacuum brazing techniques and the Nocolok brazing process by ALCAN, leading to increased usage in automobile air conditioning systems and other applications due to improved performance from highly corrosion-resistant alloys.

C. Electric Water Heater

Electric heaters are commonly used for heating water, which is a heat transfer process that involves using an energy source to raise the temperature of the water. This is essential for various domestic activities such as cooking, cleaning, bathing, and space heating. In industrial settings, hot water that is heated

ISBN: 978-93-343-2006-0

to steam serves numerous purposes. Devices that ensure a continuous supply of hot water are known as hot water heaters.

D. Fan

The fan, commonly known as forced convection in heat transfer processes, plays a crucial role in facilitating the transfer of heat from a radiator. This heat exchanger is frequently utilized in refrigeration and air conditioning units, as well as in the cooling systems of internal combustion engine automobiles. Typically rectangular or square in shape, the fan's circular area can lead to the formation of low-velocity zones or high-temperature regions in the corners. Studies have shown that the power consumed by the fan amounts to 2-5% of the total power generated by the engine. This additional airflow provided by the radiator fan is essential for preventing the engine from overheating, particularly during idle or slow-speed operation. Conversely, at higher vehicle speeds, the forward motion of the vehicle naturally directs sufficient air through the radiator for effective cooling. The fan itself can be either mechanical or electric in nature.

E. Rota Meter

The rotameter is an essential device for measuring the volumetric flow rate of fluid in a closed tube. As a variable area meter, it allows the sectional area the fluid travels through to vary, which in turn causes a measurable effect on the flow rate. This makes it a valuable tool for accurately monitoring fluid flow in various industrial and scientific applications.

F. Temperature Indicator

The temperature indicator is a device used to display temperature readings through a sensing probe. It features an LCD display and operates on two button batteries.

G. Tank

In our project, we utilize two tanks for storing cold water and nano fluid. The tank for the engine has a capacity of 10L and dimensions of 250x250mm, while the heat exchanger tank has a capacity of 7L. Both tanks are constructed from mild steel plane sheet metal.

H. Pump

In our project, we utilized two pumps to efficiently move water or nano fluid from one point to another. One pump was installed in the engine tank, while the other was placed in the heat exchanger tank. These devices play a crucial role in ensuring the smooth flow and circulation of fluids within the system, ultimately contributing to the overall performance and functionality of the project.

I. Pipes (pvc)

PVC pipe is commonly utilized for fluid transportation due to its durability and versatility. PVC, short for polyvinyl chloride, is a synthetic thermoplastic material produced through the polymerization of vinyl chloride. These pipes are typically available in 20-foot lengths, making them suitable for a variety of applications where fluid transfer is necessary.

J. Nano-Particles

Nanofluid is a specialized fluid where nanoparticles are dispersed in a water-based solution. These engineered colloidal suspensions typically incorporate metals, carbides, oxides, and carbon nanotubes. Nanofluids exhibit unique properties that make them valuable in a wide range of applications such as heat management in vehicles, engine cooling, pharmaceuticals, and heat exchangers. They offer high convective heat transfer coefficients and thermal conductivity, leading to significant enhancements in heat transfer efficiency. Research indicates that nanofluids can improve heat transfer by 15 to 40%, offering potential benefits such as reducing the size and weight of automotive radiators without compromising performance. This innovation can lead to improved fuel efficiency and reduced drag coefficients in vehicles, highlighting the promising future of nanofluids in various industries.

1) Type of Nano-fluids

Nano-fluid is a solid-liquid composite material which consists of 1-100nm with size of Nano particles of nano-fibers which will be added to the base fluid in order to obtain the thermal conductivity. There were two type material that can be used to prepare the nanofluid which is: (1) metallic solid and (2) nonmetallic solid.

2) Preparations of Nanofluids

The preparation of nanofluids is a crucial initial stage in experimental research aimed at enhancing thermal conductivity through the incorporation of nanophase particles. Nanofluids are more than just a mixture of liquid and solid; they require specific characteristics such as uniform suspension, stability, durability, minimal particle agglomeration, and no alteration of the fluid's chemical composition. Adjusting pH, utilizing surface activators or dispersants, and employing ultrasonic vibration are effective techniques for achieving these goals. By modifying the surface properties of particles and preventing cluster formation, stable suspensions can be obtained. Two main techniques for producing nanofluids are single-step and two-step methods.

3) Properties of Al_2O_3

Al_2O_3 stands out as a prominent nanoparticle within the realm of nanotechnology. Its utilization in radiator applications, particularly in the form of Al_2O_3 nanofluids, serves to enhance heat transfer rates. The decision to incorporate Al_2O_3 in radiators is primarily driven by its superior heat dissipation capabilities coupled with its cost-effectiveness. While other nanoparticles may offer heightened heat transfer efficiencies, they often come at a premium cost. The preparation of Aluminium Oxide nanofluids involves dispersing nanopowders directly into a water-based fluid and subjecting them to sonication for the required duration. Notably, Al_2O_3 nanofluids exhibit unique attributes that render them promising for various heat transfer applications, including high thermal conductivity, low viscosity, elevated convective heat transfer coefficients, and a substantial surface area per unit volume.

II. CAD MODAL

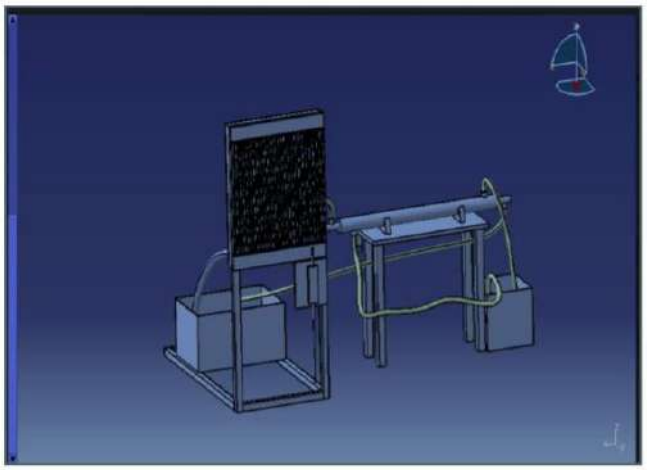


Fig. 1 A Cad Modal

III. EXPERIMENTAL TESTING

A. *Working:*

In a typical heating setup, water is heated by a heater and circulated by a pump. The temperature of the water is monitored by a sensor, with heat transfer occurring between the system and its surroundings through natural convection. When the radiator fan is activated, forced convection increases the heat transfer rate, aided by the fins of the radiator.

The coolant flows through tubes in a parallel arrangement within the radiator, with fins conducting heat from the tubes to the air passing through. Turbulators within the tubes increase fluid turbulence, ensuring efficient heat transfer. Without turbulence, only the fluid directly in contact with the tubes would be cooled, leading to less effective heat transfer.

By creating turbulence, all the fluid mixes together, maintaining a higher temperature at the tube surface for increased heat extraction. Observations and calculations are carried out on the air and water temperatures at the inlet and outlet points of the system to optimize heat transfer efficiency.

B. *Procedure for Al_2O_3 Nanofluid,*

Ensuring the proper and leak-proof connections of hoses is crucial for the efficient functioning of a radiator system. To begin the maintenance process, open the radiator cap and carefully pour a mixture of clean water and ethylene glycol in a 60:40 ratio. This step is essential for maintaining the cooling properties of the system.

For the preparation of nanofluid, take 500 ml of water and add 25 mg of Al2O3 Nano particles. Stir the solution thoroughly and place it under UV light in a dark room for 45 minutes. Once the nanofluid is ready, pour the solution into the radiator, ensuring a smooth and even distribution.

After filling the radiator, close the cap securely and connect the radiator, pump, and heater to a power supply. Switch on the power for the pump and heater, and open the knob of the rotameter to achieve a flow rate of 10 liters per minute.

Operate the pump and heater for 15 to 20 minutes until the temperature reaches 60°C or higher. Subsequently, switch on the supply to the radiator, which will activate the radiator fan. Adjust the flow rate to 10 lpm and take readings at two-minute intervals for flow rates up to 8 lpm.

Monitor the inlet and outlet temperatures of the radiator using a thermocouple and record the data. Additionally, measure the outlet temperature of the air from the radiator to assess the cooling efficiency of the system.

Following these steps diligently will help maintain the optimal performance of the radiator system and ensure effective cooling of the engine.

IV. *RESULTS*

TABLE I. OBSERVATION TABLE OF WATER

Mass flow rate	T1	T2	T3	T4	T5	T6	t
6	55	49.0	32.4	46.1	31.2	34.4	2
6	53.4	48.6	32.4	46.2	33.9	36.2	4
6	52.6	48.3	32.4	46.3	35.8	37.6	6
5	55	50	32.4	48.4	37.4	39.1	2
5	54.6	49.7	32.4	49.7	38.8	40.2	4
5	54.2	49.6	32.4	49.9	40.2	41.2	6

TABLE II. OBSERVATION TABLE OF AL2O3 NANO FLUID

Mass flow rate	T1	T2	T3	T4	T5	T6	t
6	55.0	48.0	33	44.2	34.9	35	2
6	52.3	47.7	33	44	36.5	37	4
6	51.5	47.6	33	43.9	37.8	38	6
5	55.0	49.5	33	44.9	39.0	39	2
5	53.9	49.0	33	45.7	40.0	40	4
5	53.4	48.0	33	47.6	40.9	40.9	6

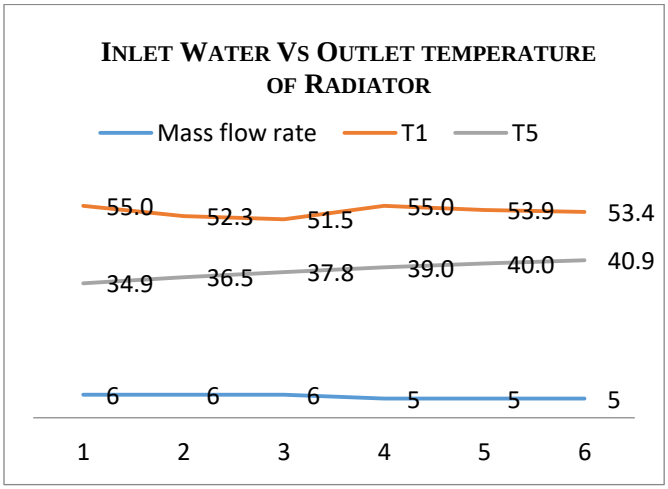


Fig. 2 A Graph For Water AS COOLING Medium For Inlet Vs Outlet temperature of Radiator

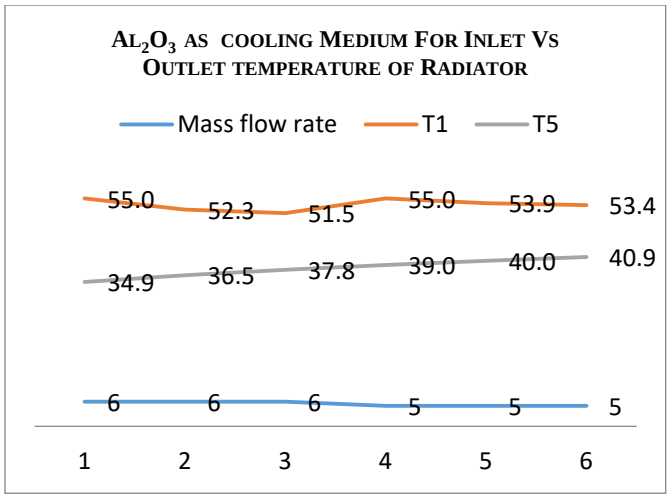


Fig. 3 A Graph of Al2O3 as cooling Medium For Inlet Vs Outlet temperature of Radiator

IV. CONCLUSIONS

The results obtained from the analysis of the data reveal several key conclusions. Firstly, a decrease in mass flow rate correlates with an increase in the temperature difference between the inlet and outlet temperatures of the coolant. Notably, the nanofluid exhibits superior temperature rejection in the graph. Secondly, as time in minutes increases, the temperature difference between the inlet and outlet temperatures of the coolant also rises, with the nanofluid displaying better temperature rejection. Thirdly, a decrease in mass flow rate leads to an increase in the average heat transfer rate of the coolant, with the nanofluid outperforming water and water + ethylene glycol in terms of average heat transfer rate. Additionally, the effectiveness of the coolant increases with a decrease in mass flow rate, with the nanofluid demonstrating superior effectiveness compared to water and water + ethylene glycol. Moreover, as time in minutes increases, the average heat transfer rate of the coolant also rises, with the nanofluid showing superior performance compared to the other coolants. These findings suggest that nanofluids exhibit enhanced heat transfer capabilities and hold promise for various applications requiring efficient heat transfer.

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Single Axis Solar Tracking Technique

Nihal Singh[1], Shriyash Shriname[2], Hema S. Koli[3]

[1,2,3]Engineering Science Chemistry Department, K J College of Engineering and Management Research,
Affiliated to Savitribai Phule Pune University
Pune- 411048, India

Abstract- A solar tracking system is an innovative solution designed to maximize the efficiency of solar energy collection. The system ensures that solar panels maintain an optimal alignment with the sun throughout the day, significantly increasing energy output compared to stationary panels. This project involves designing and implementing a dual-axis or single-axis solar tracking mechanism controlled by sensors and a microcontroller. Light-dependent resistors (LDRs) detect the sun's position, and the system adjusts the panels using motorized actuators to track the sun's movement from east to west and, in the case of dual-axis trackers, north to south. The system aims to optimize energy generation for residential, commercial, or industrial applications, contributing to renewable energy adoption and reducing dependency on fossil fuels. The project focuses on achieving an efficient, cost-effective, and reliable design while addressing environmental sustainability goals.

Keywords: *photovoltaic cells, single axis, Light-dependent resistors*

1. INTRODUCTION

The shift from conventional fossil-based resources several solar power resources are available in like geothermal energy, wind energy, bio-energy as well as solar power. Solar energy is among the most significant attempting to solve the issue of worldwide heating in addition to is a source of fresh energy. It may also assist in provided that an alternative so sensational fossil-based energy resources in addition to as a cost-effective source of energy besides. Consumption is actually tined enclosed by photovoltaic and thermal energy, making use of solar panels as well as solar collectors, respectively. There will be numerous applications given that photovoltaic thermal sporting goods. At low-temperature ranges, space conditioning and domestic hot water by-product tend to be the overall most typical use at medium temperature ranges, solar temperature reduction, desalinization furthermore postindustrial process high temperature tend to purpose which can deed alternative energy. at high-temperature stages, concentrating solar power plants are going to be sensational programs that catch the overall most attention of worldwide. furthermore, for very high-temperature ranges up to 1000 °c, processes specified hydrogen production in addition to methanol-reforming can use sun irradiation [1]. Accompanied by all of the anticipated res, solar energy (SPV) systems experience has taken major toleration in addition to investment funds wondering it’s around the world potential in addition to its totipotent to set off-world power very little time. So, within the coming years, SPV techniques will experience the highest participation in energy production among all of the res. moreover, the SPV module is really a dc source, something that often sets off powerful dc whose amplitude is dependent on the availability containing daytime sunlight as well as the temperature at standard test condition (STC)

consisting of 25°c along with Solar Constant of 1 kw/m^2 [2]. Significantly, the SPV module indicates the overall unidirectional characteristic. Hence, the power output of the SPV module is usually withstanding broadens along with atmospheric temperature along with room temperature. Also, the SPV generator indicates only one MPPT under full exposure to sunlight.

On this context, the main objective consisting of utilizing the MPPT tracking method is to exactly track and distinguish the overall global MPPT, as well as thereby gathering the overall maximum power. Additionally, MPPT techniques are compared in order to as an organized set of rules that is normally needed in order to operate on the system with efficiency. This signified, multiple MPPT tracking algorithms have already been published in the scientific literature, which

is, actually, the heterogeneous ways in order to match the source and load impedances [3]. The correct geographical orientation of such devices would possibly raise the light intensity of the incident solar radiation flux, and that depends upon azimuth and inclination angle.

Photovoltaic Technology:

Solar cells are the best-known technique for producing electrical power through Silicon Cells swaddle in photovoltaic modules to elucidate the photovoltaic solar panel more easily, photons from sunlight energies electrons in an upper state of energy and coming to the lower state to release one electron so that creating electricity [4]. The term photovoltaic defines the general unbiased working condition of a photodiode in which current through the appliance is due to the transduced light energy [5]. Solar cells generate direct current electricity from light, which can be used to recharge a battery for electric devices.

Solar Module:

In the field of photovoltaic, a photovoltaic module or photovoltaic panel is a packaged interconnected assembly of photovoltaic cells, also known as solar cells. An installation of photovoltaic modules or panels is known as a photovoltaic array. Photovoltaic cells typically require protection from the environment. For cost and practicality reasons a number of cells are connected electrically and packaged in a photovoltaic module, while a collection of these modules that are mechanically fastened together, wired, and designed to be a field-installable unit, sometimes with a glass covering and a frame and backing made of metal, plastic or fiberglass, are

known as a photovoltaic panel or simply solar panel. The foremost application of photovoltaics was to power satellite as well as spacecraft, but nowadays the majority of solar modules are going to be used for grid-connected power generation [6]. Therefore, the inverter is needed to transform the dc to ac. there's a less significant marketplace for off-grid power for inaccessible outbuildings, wayside difficulty in communication, meteorological, as well as cathodic protection are needed to be in pipelines.

2. Methodology/Working

Components used for single-axis solar tracking system are as follows-

1. Microcontroller (e.g., Arduino, PIC)
2. LDR sensors for sunlight detection
3. Servo or stepper motors for panel movement
4. Motor driver circuits
5. Solar panel
6. Power supply unit

LDR sensors detect the intensity of sunlight in different directions. The microcontroller processes the sensor data to identify the sun's position. Based on the input, the motor adjusts the solar panel's position to align with the sun, ensuring maximum sunlight capture. In dual-axis trackers, both azimuth (east-west) and elevation (north-south) angles are controlled.

Applications: Residential and commercial solar power systems. Industrial-scale solar farms. Portable solar-powered devices. Off-grid solar installations in remote areas.

3. Working principle:

A solar tracker is a device for aligning a day lighting reflector, solar photovoltaic panel or concentrating solar reflector or lens toward the sun. The sun's position in the sky varies with the seasons (elevation) even with the time of day as the sun moves across the sky. Solar-powered devices function best when every time pointed at the sun, so a solar tracker will hike the effectively of devices over any confirmed position, at the cost of extra system complexity. There are several kinds of solar trackers, of different charges, quality, and performance. Some best-known type of solar tracker is the heliostat, a movable mirror which reflects the moving sun to a fixed position, but several other techniques will be used as well. The efficiency of the solar tracker depends upon the application. concentrators, in particular in solar cell processes, require an intensity of exactness to ensure that fact that saturated sunlight is directed exactly to the device, that is at (or near) the focal point of the reflector [7]. Usually, concentrator techniques won't work without tracking, so at slightest single-axis tracking is necessary. Sizeable power plants or high-temperature resources research facilities using multiple ground-mounted mirrors along with an absorbent spot need with high accuracy similar to that used for solar telescopes.

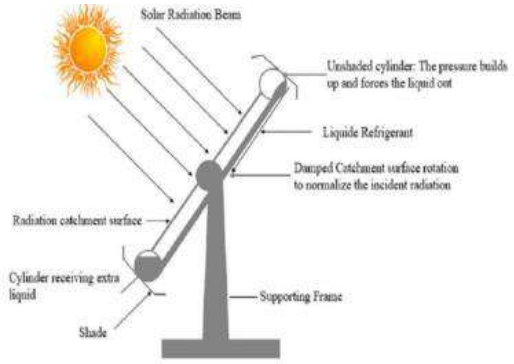


Fig. 1 Basic design of solar tracker

Sun Path, Azimuth & Altitude Angle:

The change of position of moving sun varies at different time and season to season due to earth's continuous and periodic rotation and revolution. As a result, it has become necessary to locate the orientation of sun for a particular moment. The locations are placed on a special type of chart named Sun Path Diagram. A Sun Path Diagram shows the azimuth angle, elevation angle, sun paths throughout the years, sunrise and sunset time etc.



Fig. 2 Single axis solar tracking system

ISBN: 978-93-343-2006-0

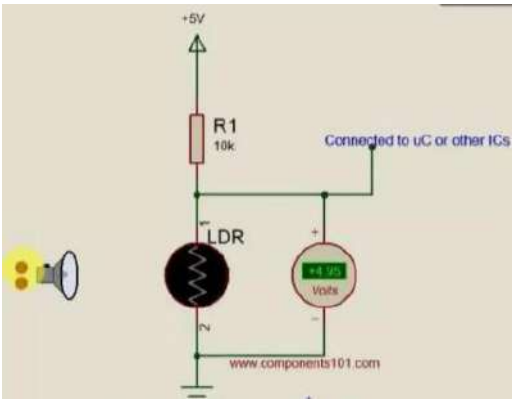


Fig. 3 Circuit diagram

4. Future Scope

- Integration with IoT for remote monitoring and control.
- Implementation of machine learning algorithms to predict sun position in adverse weather conditions.
- Use of advanced sensors for increased accuracy.
- Scalability for large-scale solar farms.

5. Conclusion

The solar tracking system demonstrates a practical approach to enhancing the efficiency of solar panels by continuously aligning them with the sun's movement. By implementing this system, we can significantly boost energy production, promote renewable energy adoption, and contribute to environmental sustainability.

Assessing the viability of a solar tracking system involves a thorough examination of various factors that contribute to the cost-benefit analysis and the return on investment (ROI). First, initial costs must be carefully considered, comparing fixed-tilt systems with tracking systems and accounting for additional expenses related to foundation, installation, and ongoing maintenance. Tracking systems, due to their intricate designs and moving parts, typically incur higher initial expenses. Another critical consideration is the expected increase in energy output. This involves comparing the tracking system's anticipated energy yield to that of a fixed-tilt system, taking into account the specific solar irradiation at the site and the tracking system's efficiency in capturing sunlight throughout the day.

Ongoing maintenance expenses are a key factor, as moving parts in tracking systems may require more frequent maintenance compared to the relatively simpler fixed-tilt systems. This consideration is crucial for evaluating the overall reliability and long-term costs associated with the solar tracking system. The lifespan of the system and the warranty offered by the manufacturer also play a significant role. Longer warranties can instil greater confidence in the investment, providing assurance regarding the tracking system's durability and performance over time.

Additionally, it is crucial to explore financing options in order to ease upfront costs and enhance the overall ROI of the solar energy project. Lastly, a detailed ROI analysis is essential. This involves a comprehensive evaluation of the system's cost, anticipated energy savings, potential earnings from excess energy production through net metering, and any applicable incentives or rebates. A shorter return period indicates a more financially lucrative investment.

In conclusion, selecting a solar tracking system requires a meticulous assessment of site conditions, technology, local incentives, and a diligent cost-benefit analysis. This comprehensive approach will ensure the implementation of the most efficient and financially viable solution for a solar energy project.

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Intelligent Transport Monitoring System Using Raspberry Pi

Prajakta Lavand
Department of E&TC
KJCOEMR, Pune
Plavand2011@gmail.com

Vaishnavi Kamthe
Department of E&TC
KJCOEMR, PUNE
kamthevaishnavi96@gmail.com

Anushka Navale
Department of E&TC
KJCOEMR, PUNE
navaleanushka19@gmail.com

Prof. Shilpa Kale
Department of E&TC
KJCOEMR, Pune
Shilpakale,kjcoemr@kjei.edu.in

Abstract- An innovative and ultramodern device for shadowing and covering the transporting vehicle in order to assure the security of humans, passengers, or kiddies. The suggested approach notifies the applicable authorities right down of the position and filmland of the machine' innards in the event of an exigency, similar as an accident, breakdown, or fire. Pi cameras are used to take filmland, while GPS modules are used to determine the position. There's a fear switch. Parents or guardians will get an dispatch alert. When an exigency takes place, the fear switch is active. In each situation, an dispatch including filmland of the vehicle' inside is encouraged to the separate authority and parents. Fire detector enforced in the given system which acts as a fire sensor. If the Fire is detected also fire detector will be active and incontinently buzzer will be on.

Index Terms- Buzzer, Camera, Fire detector, GPS module, fear switch, jeer Pi, Wi- Fi

INTRODUCTION

The most crucial issue in the current, advanced world is safety. Women, children, or other passengers may not be safe. We hear or see a lot of news on our campus, such as a female being raped, students going missing, etc. We put this method in place to address this issue. In recent years, we have seen or read about school buses being involved in accidents, negligent drivers, children going missing, and other hazards. The recommended strategy lowers the likelihood of dangers by concentrating on tracking and monitoring the school bus. Automatic vehicle tracking and monitoring is provided by the proposed solution, which benefits local travelers, school buses, their owners, and the safety of the children and passengers. A panic switch is also included [1].

Keys are used in case someone slips or is stopped in traffic, and a panic switch is utilized in an emergency. When those specific buttons are touched, an image of the inside of the car and the coordinates of the location will be sent, along with a message to the parents and guardians or school officials. for tracking the vehicle utilizing GPS and the Raspberry-Pi's clever features.
For using GPS and the smart features of the Raspberry-Pi to track the car. The idea of tracking the car might be strengthened by its current location. The vehicle may be tracked using GPS and its database is updated using the Raspberry-Pis. The GSM module helps to monitor and update the process by providing the parents and relevant authority with the most recent vehicle information, which they may view on a smartphone. This gives the smartphone a real-time location display of the car. Customers will therefore be able to see a moving car continually on their cellphones at any time and determine how long it will take for the vehicle to arrive at its destination [2].

DESIGN

System Objectives:

a. Real-time Data Acquisition and Processing: In order to make timely judgments, it is necessary to develop a system that can effectively handle data from several sensors and input devices in real-time.

b. Predictable Event Detection and Response: To implement reliable systems for detecting events such as intrusion attempts, panic switch activations, and fires, and to ensure prompt and appropriate responses to these situations..

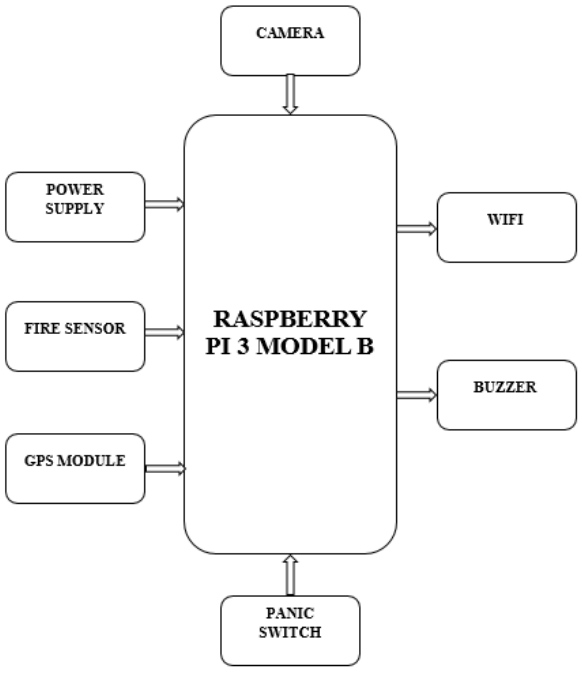


Fig. 1 System Block Diagram

METHODOLOGY

A Raspberry Pi, an infrared flame sensor, a GPS module, a buzzer, and wifi for connectivity are vital components of the system. It continually gathers sensor data, interprets the atmosphere around the car, and then automatically delivers the data. The Raspberry Pi begins the operating system that controls system functionality. The fire sensor monitors the nearby environment for any signs of fire. If it detects a change that exceeds a preset threshold, it alerts the Raspberry Pi. After continuously receiving the location of the car, the GPS module transmits the coordinates to the Raspberry Pi. The pi camera records the environment and captures live images and movies. The system then enters a phase of continuous monitoring, during which the fire sensor continuously evaluates the environment for signs of fire or extreme heat. Any changes that surpass a preset threshold are reported to the Raspberry Pi. The GPS module, which continuously receives signals from GPS satellites to determine the system's position, provides the location coordinates to the Raspberry Pi.

To warn anyone around, the Raspberry Pi triggers the buzzer to make a loud noise. After connecting to an already setup network via the WiFi module, it notifies a specified recipient of the alert, including GPS coordinates and any photos or videos that were taken.When someone detects a fire or wants to manually sound an emergency alarm, they can press the panic switch, which will send a signal to the Raspberry Pi. The Pi camera transmits data to the Raspberry Pi for processing or storage after capturing images or videos. The Raspberry Pi receives a signal from the fire sensor, decodes it, and sounds an alarm if it detects a developing fire. The Raspberry Pi activates the buzzer to emit a loud sound in order to alert people nearby. The WiFi module connects to an existing network and sends an alert to a designated recipient, providing GPS coordinates and any captured images or videos. The panic switch can be used to manually trigger an emergency alert or detect a fire. This will send a signal to the Raspberry Pi. The Raspberry Pi initiates the same alerting processes as in the fire detection scenario. The system can either continue to monitor the situation after giving the warning or continually monitor instructions before shutting down. The system relies on data coming from sensors and input devices to the Raspberry Pi, which employs preset logic to control communication channels and output devices. The system requires a stable Wi-Fi connection, a reliable power source, and secure communication channels in order to function correctly.

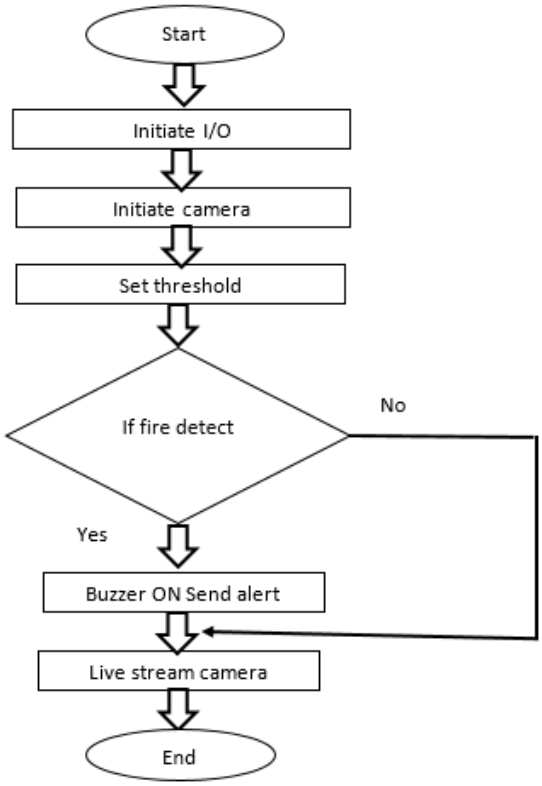


Fig. 2 System Flowchart

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RESULT

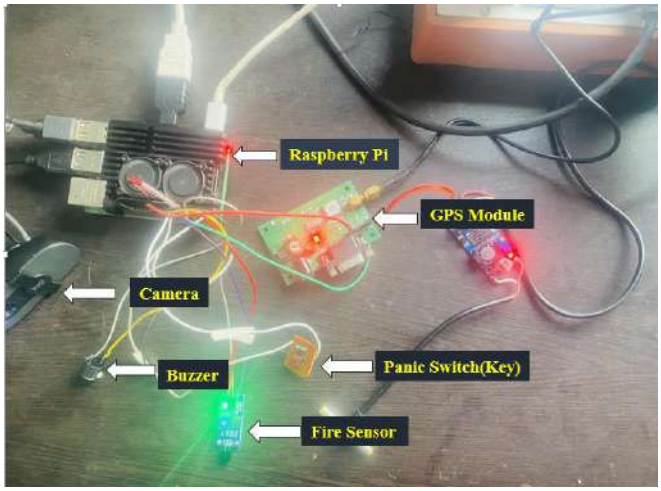


Fig.3 System Hardware Components

SYSTEM TESTING RESUTS

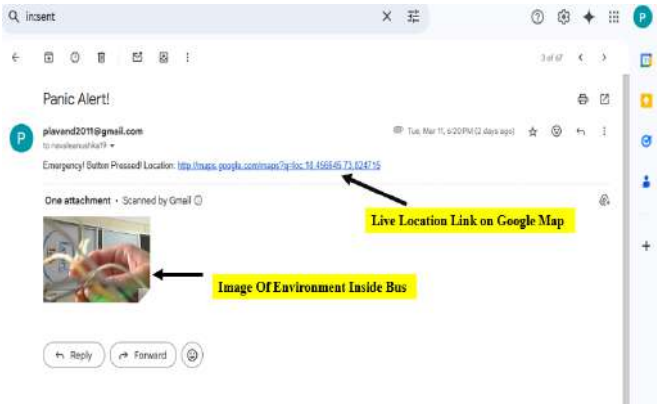


Fig. 4 Mail of Image and Live Location

The hardware elements needed for the system's implementation are shown in Figure 3. According to the block diagram, every component is related to the others. Figure 4 shows the entire image of the mail that was delivered to the appropriate authorities by the vehicle sender. An image of the inside space is included, along with a link to a Google map. The precise position will be identified in real time.
Figure 5 below displays the live location's satellite view. You can obtain it by clicking on the link that was sent to you via email. Parents or the appropriate authority will be able to determine the exact location of the bus's stall by monitoring its real-time position.



Fig. 5 Live Location on Google Map

CONCLUSION

The raspberry pi based intelligent transport monitoring system gives more advantages like safety, user experience. The Raspberry Pi is easy to use because it functions like a small computer that kept all information. In order to achieve the targeted outcomes, structured modeling is supposed to be used in the project's design. The methods used by various technologies for performing vehicle monitoring more specifically, passenger safety vary. The suggested system aims to offer a safe and secure solution in addition to playing a significant part in real-time monitoring. Images of the interior of the school bus and van, as well as the emergency location, are included with the email notice.

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Comparative Structural Analysis of Minor Bridges Using MIDAS Software: A Case Study on PSC I and Box Girders

Saptarshi Gorale1 and Dr. Pujari A. B.2

[1] K.J. College of Engineering and Management Research. Tal-Haveli, Dist-Pune.

Mail ID:icitet.kjcoemr@kjei.edu.in

Abstract. Bridges are vital infrastructures that facilitate transport, economic development, and societal connectivity. The evolution of engineering tools has enabled precise analysis and design of these structures. This thesis explores the application of MIDAS software in analyzing minor bridges and presents a comparative study between Prestressed Concrete I (PSC I) Girders and Box Girders. The objective is to assess structural efficiency, durability, cost-effectiveness, and construction feasibility to guide optimized girder selection in future bridge projects.

Keywords: MIDAS software, efficiency

1. INTRODUCTION

Bridges stand as remarkable feats of engineering, connecting distant shores, spanning formidable rivers, and overcoming natural obstacles with graceful efficiency. Each bridge tells a story of ingenuity, innovation, and meticulous planning, reflecting the collaborative efforts of architects, structural engineers, and construction teams. As symbols of progress and connectivity, major bridges capture the imagination and inspire awe with their monumental presence and technical sophistication.

In this chapter, we embark on a journey of exploration into the realm of major bridge analysis. By examining key aspects such as structural design, material selection, construction techniques, and performance evaluation, we aim to unravel the intricacies of these engineering marvels and understand the factors that contribute to their functionality, resilience, and longevity.

Bridges, as critical components of transportation infrastructure, demand meticulous analysis to ensure their safety, functionality, and longevity. With the advent of sophisticated engineering software, such as MIDAS, engineers can conduct comprehensive analyses that simulate real-world conditions, assess structural performance, and optimize design parameters with unprecedented accuracy and efficiency. This chapter serves as an introduction to the application of MIDAS software in the analysis of bridges, exploring its capabilities, methodologies, and benefits in the realm of bridge engineering.

Bridges are vital infrastructural elements connecting regions, facilitating transportation, and fostering economic growth. Their design, construction, and maintenance require meticulous analysis and planning to ensure safety, durability, and cost-effectiveness. The advancement of technology has revolutionized the process of bridge analysis, offering sophisticated software tools to simulate, model, and optimize various aspects of bridge engineering.

1.1 Understanding Structural Design:

At the heart of every major bridge lies a carefully crafted structural design that balances aesthetic considerations with functional requirements and safety standards. Structural engineers employ advanced modeling techniques and computational tools to optimize the geometry, configuration, and load-bearing capacity of bridge components,

ISBN: 978-93-343-2006-0

ensuring structural integrity and stability under various loading conditions.

1.2 Material Selection and Innovation:

The choice of materials plays a crucial role in determining the performance and durability of a major bridge. Traditional materials such as concrete, steel, and timber offer proven reliability and strength, while modern innovations such as composite materials and high-performance alloys push the boundaries of structural efficiency and sustainability. By leveraging cutting-edge materials and construction techniques, engineers can achieve lighter, more resilient bridge structures that withstand the test of time and environmental challenges.

1.3 Construction Techniques and Challenges:

The construction of major bridges is a complex endeavor that requires meticulous planning, precision engineering, and skilled craftsmanship. From the erection of massive steel trusses to the casting of towering concrete piers, each stage of construction presents unique challenges and logistical hurdles. Construction teams must navigate site constraints, environmental considerations, and safety regulations while maintaining strict quality control and project timelines.

1.4 Performance Evaluation and Maintenance:

Once completed, major bridges undergo rigorous performance evaluation to ensure compliance with design specifications and safety standards. Structural health monitoring systems, including sensors, gauges, and inspection protocols, enable engineers to detect potential defects, assess structural integrity, and implement timely maintenance interventions. By proactively addressing maintenance needs and infrastructure vulnerabilities, bridge owners can extend the service life of major bridges and safeguard public safety.

1.5 Understanding MIDAS Software:

MIDAS, an acronym for "Modeling, Integrated, Design, and Analysis Software," stands as a versatile platform that empowers engineers to simulate, analyze, and design complex structural systems, including bridges, with precision and reliability. Built upon advanced finite element analysis (FEA) techniques, MIDAS offers a wide array of tools and modules tailored to the unique challenges of bridge engineering, encompassing linear and nonlinear analyses, dynamic response simulations, and optimization algorithms.

1.6 Key Features and Capabilities:

MIDAS software boasts a rich set of features and capabilities designed to streamline the bridge analysis process and enhance engineering decision-making. From geometric modeling and mesh generation to load simulation and performance evaluation, MIDAS provides engineers with intuitive interfaces and powerful solvers that facilitate the exploration of various design alternatives and the assessment of structural behavior under diverse loading scenarios.

1.7 Methodologies for Bridge Analysis:

In the realm of bridge analysis, MIDAS software supports a range of methodologies and analysis techniques to address different aspects of bridge performance. Engineers can conduct static analyses to evaluate structural stability and load-carrying capacity, dynamic analyses to assess response under seismic or wind loads, and nonlinear analyses to account for material behavior and geometric nonlinearities. Moreover, MIDAS offers specialized modules for bridge-specific analyses, such as moving load simulations, prestressed concrete design, and fatigue life assessment.

1.8 Benefits of Using MIDAS Software:

The adoption of MIDAS software confers numerous benefits to bridge engineers and project stakeholders. By leveraging advanced computational capabilities and integrated workflows, engineers can expedite the analysis process, reduce manual errors, and optimize design parameters to meet performance objectives and regulatory

requirements. Additionally, MIDAS facilitates collaboration among multidisciplinary teams, enabling seamless data exchange and decision support throughout the project lifecycle.

1.9 A Comparative Analysis of PSC I Girder and Box Girder

In the realm of structural engineering, the choice between different bridge girder types plays a pivotal role in determining the efficiency, safety, and cost-effectiveness of a bridge design. Among the various options available, Prestressed Concrete I (PSC I) girders and Box girders stand out as two prominent choices, each with its unique set of characteristics and

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advantages. This chapter aims to delve into a comparative analysis of these two types of girders, shedding light on their structural features, construction methods, benefits, and limitations.

1.10 Structural Features:

PSC I Girder:

PSC I girders, also known as I-beams, are characterized by their slender, elongated shape resembling the letter "I" in cross-section. These girders are typically cast using prestressed concrete, wherein high-strength steel tendons are placed inside the concrete and tensioned prior to the application of loads. This prestressing imparts enhanced strength and load-bearing capacity to the girder, allowing for longer spans with reduced deflection.

Box Girder:

In contrast, Box girders feature a hollow, rectangular cross-section, resembling a box. They are often constructed using reinforced concrete or steel, providing a closed-section configuration that offers excellent torsional stiffness and resistance to bending moments. Box girders are particularly favored for their superior structural efficiency and aesthetic appeal, making them a popular choice for modern bridge designs.

1.11 Construction Methods:

PSC I Girder:

The construction of PSC I girders typically involves casting concrete in a preformed mold, incorporating prestressing tendons as required. The curing process ensures the development of strength and durability in the girder, allowing for efficient handling and transportation to the construction site. Installation involves lifting and placing the girders onto the bridge supports, followed by the placement of deck slabs to complete the bridge superstructure.

Box Girder:

Construction of Box girders often entails the assembly of prefabricated segments or casting of concrete in situ within formwork to create the desired box-shaped structure. The use of prefabricated segments can expedite the construction process, while in situ casting offers greater flexibility in accommodating complex geometries and structural requirements. Once assembled, the box girder segments are connected and post-tensioned to ensure structural integrity and continuity.

1.12 Benefits and Limitations:

PSC I Girder:

Cost-Effectiveness: PSC I girders are relatively economical to produce and transport, making them a cost-effective choice for medium-span bridges.

Versatility: They can be adapted to various bridge configurations and loading conditions, offering versatility in design.

Maintenance: PSC I girders typically require minimal maintenance due to their durable construction and inherent resistance to corrosion.

However, PSC I girders may have limitations in terms of span length and torsional resistance, which could restrict their applicability in certain bridge designs, particularly those requiring longer spans or high torsional stability.

Box Girder:

Structural Efficiency: Box girders offer superior structural efficiency, particularly for long-span bridges, due to their closed-section configuration and high torsional stiffness.

Aesthetic Appeal: The sleek, modern appearance of box girders lends itself well to architectural integration and aesthetic enhancement of bridge structures.

Longevity: With proper design and construction, box girders exhibit excellent durability and long-term performance, requiring minimal maintenance over their service life.

Despite their structural advantages, box girders may pose challenges in terms of fabrication complexity, transportation, and construction logistics, particularly for large-scale projects with intricate geometries.

In conclusion, both PSC I girders and Box girders offer distinct advantages and considerations in bridge design and construction. The choice between these two types of girders depends on various factors such as span length, loading requirements, construction constraints, and aesthetic preferences. By conducting a comprehensive comparative analysis, engineers can

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make informed decisions to select the most suitable girder type for a given bridge project, ensuring optimal performance, durability, and cost-effectiveness.

1.2 Problem Statement

In the realm of bridge engineering, the accurate analysis of structural behavior is paramount. Traditional methods, while effective, often entail extensive time and resources. The advent of software such as MIDAS provides engineers with powerful tools to streamline the analysis process, offering detailed insights into the behavior of major/Minor bridges under various conditions.

1.3 Aim of the Study

The primary aim of this project is to conduct a comprehensive analysis of a major bridge using MIDAS software. By leveraging the capabilities of MIDAS, this study seeks to:

Evaluate the structural integrity of the bridge under different loading scenarios.

Assess the dynamic response of the bridge to environmental factors such as wind, seismic activity, and traffic loads.

Optimize the design parameters to enhance structural performance while adhering to safety standards and cost considerations.

Provide insights into potential maintenance requirements and longevity of the bridge structure.

Validate the efficacy of MIDAS software in accurately modeling and analyzing complex bridge structures.

1.4 Objectives of the Study

To achieve the aforementioned aim, the following objectives will be pursued:

Literature Review: Conduct a comprehensive review of existing literature on bridge analysis methodologies, software tools, and case studies to establish a theoretical framework for the study.

Selection of Bridge: Identify a suitable major bridge for analysis based on factors such as size, complexity, and availability of relevant data.

Data Acquisition: Gather necessary data including structural drawings, material properties, environmental conditions, and historical performance records of the selected bridge.

Model Development: Utilize MIDAS software to develop a detailed finite element model of the bridge, incorporating geometric, material, and loading parameters.

Static Analysis: Perform static analysis to evaluate the structural response of the bridge under dead loads, live loads, and other static forces.

Dynamic Analysis: Conduct dynamic analysis to assess the bridge's behavior under dynamic loading conditions such as seismic events, wind gusts, and vehicular traffic.

Optimization: Utilize optimization algorithms within MIDAS to optimize the design parameters such as cross- section dimensions, reinforcement layout, and support configurations.

Sensitivity Analysis: Perform sensitivity analysis to identify critical parameters influencing the structural performance and resilience of the bridge.

Evaluation and Validation: Evaluate the results of the analysis against established design codes, standards, and empirical data. Validate the accuracy and reliability of MIDAS software in predicting the behavior of the bridge.

Recommendations: Provide recommendations for potential design enhancements, maintenance strategies, and future research directions based on the findings of the study.

1.5 Scope and Limitations

It is important to acknowledge the scope and limitations of this study. While MIDAS software offers advanced capabilities for bridge analysis, it is not without constraints. Limitations may include computational complexity, simplifications in modeling assumptions, and uncertainties in input parameters. Additionally, the study will focus on a single minor bridge, limiting the generalizability of the findings to other bridge structures. However, by addressing these limitations and maintaining transparency in methodology, this study aims to contribute valuable insights into the application of MIDAS software in the analysis of minor bridges.

2. HISTORY

ISBN: 978-93-343-2006-0

The following chapter shall introduce the reader to past, present, and future in bridge engineering. The history of engineering is as old as mankind itself, and it is without doubt that technical progress and the rise of human society are deeply interwoven. Bridges have often played an essential role in technical advancement within Civil Engineering.

The development of important types of bridges and the changing use of materials and techniques of construction throughout history will be dealt with in the first part of this chapter. Notably, manifold legends and anecdotes are connected with the bridges of former eras. Studying the history of a bridge from its construction throughout its life will always also reveal a fascinating picture of the particular historical and cultural background.

The second part of this chapter introduces the main challenges that the current generation of bridge engineers and following generations will face. Three important areas of interest are identified. These are improvements in design, construction, maintenance, and rehabilitation of a bridge, application of high-performance materials, and creative structural concepts. As technology advances, many new ways of innovation thus open for the bridge engineer.

2.1 HISTORY OF BRIDGE CONSTRUCTION

The bridges described in the following sections are examples of their kind. A vast amount of literally thousands of bridges built requires choosing a few exemplary ones to show the main developments in bridge construction throughout the centuries. Any book examining bridges in a historical context will make its own choice, and studying these works can be of great value for understanding of the legacy of bridge engineering. The subdivision into certain periods in time shall provide a framework for the reader's orientation in the continuous process of history as it unfolds

2.1.1 Ancient structures

It will never be known who built the first actual bridge structure. Our knowledge of past days fades the further we look back into time. We can but assume that man, in his search for food and shelter from the elements and with his given curiosity, began exploring his natural environment. Crossing creeks and crevices with technical means thus was a matter of survival and progress, and bridges belong to the oldest structures ever built. The earliest bridges will have consisted of the natural materials available, namely wood and stone, and simple handmade ropes. In fact, there is only a handful of surviving structures that might even be considered prehistoric, e.g. the so-called Clapper bridges in the southern part of England, as Brown (1993) notes.

2.1.1.1 Ancient Structural principles

The earliest cultures already used a variety of structural principles. The simplest form of a bridge, a beam supported at its two ends, may have been the predecessor of any other kind of bridges; perhaps turned into reality through use of a tree that was cut down or some flat stone plates used as lintels. Arches and cantilevers can be constructed of smaller pieces of material, held together by the compressive force of their own gravity or by ropes. These developments made larger spans possible as the superstructure would not have to be transported to the site in one complete piece anymore.

Probably the oldest stone arch bridge can be found crossing the River Meles with a single span at Smyrna in Turkey and dates back to the ninth century BC (Barker and Puckett 1997). Even suspension bridges are no new inventions of modern times but have already been in use for hundreds of years. Early examples are mentioned from many different places, such as India and the Himalaya, China, and from an expedition to Belgian Congo in the early years of this century (Brown 1993). Native tribes in Mexico,

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Peru, and other parts of South America, as Troitsky (1994) reports, also used them. He also mentions that cantilevering bridges were in use in China and also in ancient Greece as early as 1100 BC. Podolny and Muller (1982) give information on cantilevering bridges in Asia and mention that reports on wooden cantilevers from as early as the fourth century AD have survived.

2.1.1.2 Trial and error

In some cases, authors of books or book chapters on the history of bridges use terms such as primitive, probably as opposed to the modern state-of-the-art engineering achievements. It is spoken of a lack of proper understanding, and of empirical methods. From today's point of view it is easy to come to such a judgement, but one should be careful not to diminish the outstanding achievements of the early builders. In our technical

age with a well-developed infrastructure, computer communication, and heavy equipment readily available it is easy to forget about the real circumstances under which these structures were built. Since mathematics and the natural sciences had yet even begun being developed it is not astonishing that no engineering calculations and material testing as adhering to our modern understanding were performed. But a feeling for structures and materials was present in the minds of these ancient master builders. With this and much trial and error they built beautiful structures so solid and well engineered that many have survived the centuries until our days.

2.1.1.3 The Earliest Beginnings

Earliest cultures to use bridges according to our current knowledge were the Sumarians in Mesopotamia and the Egyptians, who used corbelled stone arches for the vaults of tombs (Brown 1993).

In the fifth century BC the Greek historian Herodotus, who lived from about 490 to 425 BC (Brown 1993), wrote the history of the ancient world. His report on the city of Babylon includes a description of the achievements of Queen Nitocris, who had embankments and a bridge with stone masonry piers and a timber deck built at the River Euphrates. This bridge is believed to have been built in about 780 BC (Troitsky 1994) and was built as described in the following (Greene 1987, p118). "

> *... and as near as possible to the middle of the city she built a bridge with the stones she had dug, binding the stones together with iron and lead. On this bridge she stretched, each morning, square hewn planks on which the people of Babylon could cross. By night the planks were withdrawn, so that the inhabitants might not keep crossing at night and steal from one another."*

Herodotus' report does not tell about the construction of this bridge and leaves much room for imagination on how the bridge might actually have looked like. His second report on a bridge, however, gives a more detailed view. A floating pontoon bridge was used by Persian King Xerxes to cross the Hellespont with his large army in the year 480 BC (Brown 1993). Herodotus describes the bridge in detail (Greene 1987, pp482f):

> *"It is seven stades* (a stade was about 660 feet) *from Abydos to the land opposite. [...] This is how they built the bridge: they set together both penteconters and triremes, three hundred and sixty to bear the bridge on the side nearest the Euxine and three hundred and fourteen for the other bridge, all at an oblique angle to the Pontus but parallel with the current of the Hellespont. This was done to lighten the strain on the cables. [...] When the strait*

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was bridged, they sawed logs of wood, making them equal to the width of the floating raft, and set these logs on the stretched cables, and then, having laid them together alongside, they fastened them together again at the top. Having done this, they strewed brushwood over it, and, having laid the brushwood in order, they carried earth on the top of that; they stamped down the earth and then put up a barrier on either side…"

If one considers Herodotus' account to be accurate the bridge must have been a fairly impressive structure and without any equivalent at its time. Especially the description of how the pontoons were anchored indicates a well developed understanding of structural principles. Use of bridges for military needs was not uncommon in ancient times. Gaius Iulius Caesar (100 - 44 BC) is amongst the authors who left us very clear records of early bridges. In his *De Bello Gallico*, written in 51 or 50 BC, he mentions several bridges that he had his troops build during his conquest, e.g. across the Saône, and in the fourth book he describes the famous timber bridge built across the Rhine in 55 BC. This type of bridge was actually rebuilt a second time later during his conquest. His description of the structure is to such detail that several attempts were made to

reconstruct it, and it shows the level of knowledge to which the engineering profession had grown by that time (Wiseman and Wiseman 1990, pp78-80):

"Two piles a foot and a half thick, slightly pointed at their lower ends and of lengths dictated by the varying depth of the river, were fastened together two feet apart. We used tackle to lower these into the river, where they were fixed in the bed and driven home by pile drivers, not vertically, as piles usually are, but obliquely, leaning in the direction on the current.
Opposite these, 40 feet lower down the river, two more piles were fixed, joined together in the same way, though this time against the force of the current. These two pairs were then joined by a beam two feet wide, whose ends fitted exactly into the spaces between the two piles of each pair. The pairs were kept apart from each other by means of braces that secured each pile to the end of the beam. So the piles were kept apart, and held fast in the opposite direction, the structure being so strong and the laws of physics such that the greater the force of the current, the more tightly were the timbers held in place.

A series of these piles and beams was put in position and connected by lengths of timber set across them, with poles and bundles of sticks laid on top. The structure was strong, but additional piles were driven in obliquely on the downstream side of the bridge; these were joined with the main structure and acted as buttresses to take the force of the current. Other piles too were fixed a little way upstream from the bridge so that if the natives sent down tree trunks or boats to demolish it, these barriers would lessen their impact and prevent the bridge being damaged.

Ten days after the collection of the timber was begun, the work was completed and the army led across."

Troitsky (1994) reports on an even older Roman timber bridge, the Pons Sublicius. It is the oldest Roman bridge whose name is known, named after the Latin word for wooden piles. This bridge was built in about 620 BC by King Ancus Marcius and spanned the River Tiber (Adkins and Adkins 1994).

The brief record of timber bridges given in this section would not be complete without mentioning Appolodorus' bridge across the Danube. It was built in about 104 AD under Emperor Trajan (O'Connor 1993). Its magnitude – the length must have been more than a kilometer – and the unique structure of timber arches makes it special among the Roman bridges of which we have record.

2.1.1.4 Timber Bridges

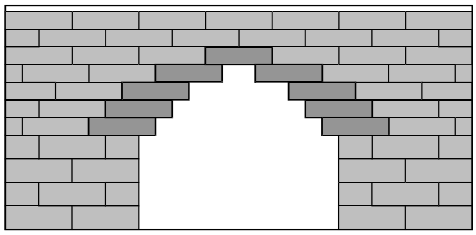
Timber bridges and timber superstructures on stone

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piers will probably have been prevailing in many parts of the Roman Empire at that time. Wood was a cheap construction material and abundantly available on the European continent. Furthermore it can be readily cut to shape and transported with much less effort than stone. The Romans already knew nails as means of connecting timber. Even the principle of wooden trusses was already known, as reliefs on both the Trajan's Column in Rome (AD 113) and the Column of Marcus Aurelius (AD 193) clearly show truss-type railings of military bridges (O'Connor 1993). However, there is no historic evidence that the Romans actually used the truss as a structural element in their bridges. Truss systems may have actually been used for the wooden falsework that was used for erection of stone masonry arches.

2.1.1.5 Stone Bridges

Apart from timber bridges, stone masonry arch structures are examples of the outstanding skills of the ancient Romans. The Roman stone arches where built on wooden falsework or centering which could be reused for the next arch once one had been completed. The semicircular spans rested on strong piers on foundations dug deeply into the riverbed. Brown (1993) points out that due to the width of these piers between the solid abutments the overall cross section of the river was reduced, thus increasing the speed of the current. To deal with this problem the Romans built pointed cutwaters at the piers. A very comprehensive study on Roman arches can be found in O'Connor (1993).

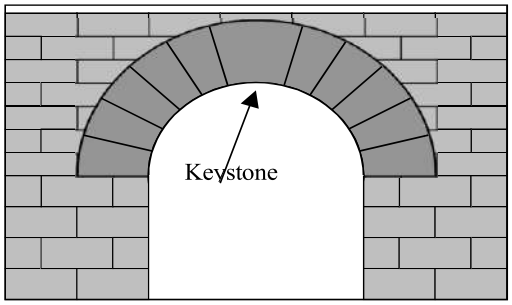


The arches used were voussoir arches, which are put together of tapered stones with a keystone that closes the arch. Compressive forces from the dead load and the weight of traffic on the bridge hold the stones together even without use of any mortar. Corbelled arches, on the other hand, consist of stones put on top of each other in a cantilevering manner until they two halves finally meet in the middle. This principle was already known prior to Roman times and was used in vaulted tombs throughout the Old World. Both different arch types are shown in Figure 2-1.

Figure 2-1: Corbelled Arch and Voussoir Arch

2.1.1.6 Aqueducts and Viaducts

The Roman infrastructure system was very well developed. It served both military and civil uses by providing an extensive network of roads. Aqueducts and viaducts of the Roman era can still be found scattered over the former Roman Empire, primarily in Italy, France, and Spain. Some Roman bridges or their remainders are also located in England, Africa and Asia Minor (O'Connor 1993).



Probably the best-known Roman aqueduct is the Pont du Gard near Nîmes in Southern France, which is shown in Figure 2-2. Built by Marcus Vipsanius Agrippa (64 - 12 BC) in about 19 BC, this structure was part of an aqueduct carrying water over more than 40 km (Liebenberg 1992). The crossing of the River Gard has an impressive height of 47.4 m

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above the river, consisting of three levels of semicircular arches that support the covered channel on top. The spans of the two lower levels are up to 22.4 m wide. All of its stone masonry was built without use of mortar except for the topmost level. A more recent addition to the Pont du Gard built in 1747 provides a walkway next to the bottom arch level that is an exact copy of the Roman architecture (Leonhardt 1982). Another well-known aqueduct can be found at Segovia in Spain.

Figure 2-2: The Pont du Gard, Nîmes, France (taken from Brown 1993, p18)

Sextus Iulius Frontius (c. 35 - 104 AD) wrote *De Aquis Urbis Romae* on the history and technology of the Roman aqueducts (O'Connor 1993). Aqueducts were used to provide thermae, baths, and public fountains with water; few residential buildings had an own connection. However though, the amount of water available for every citizen is estimated to have equaled or even exceeded today's standards for water supply systems. Adkins and Adkins (1994) speak of half a million to a million cubic meters of water that were provided through Rome's aqueducts per day.



Located in Spain is a bridge that attracts interest because of its scale and the magnificent setting. The Puente de Alcántara crosses the River Tagus at Caceres close to the border to Portugal with six elegant masonry arches as shown in Figure 2-3. Again, these arches were built without the use of mortar. The name of the bridge contains some redundancy, since it is derived from an old Arabic term for 'bridge'. The two main arches with a gate on the roadway are higher than the Pont du Gard and remain the longest Roman arches, both spanning 30 m (Brown 1993). The name of the Roman engineer who built this masterpiece in 98 AD under Emperor Trajan is known. Caius Iulius Lacer's tomb is found nearby, and the gate with the famous

inscription *Pontem perpetui mansuram in saecula mundi* (I leave a bridge forever in the centuries of the world) has survived the centuries (Gies 1963, p16).

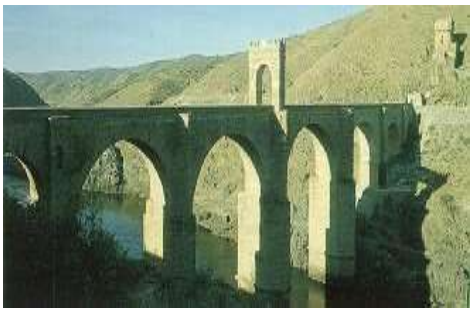


Figure 2-3: The Puente de Alcántara, Caceres, Spain (taken from Brown 1993, p25)

2.1.1.7 Religious Symbolism

An interesting fact in the context of early bridge building is religious symbolism. Higher positions in Roman hierarchy often involved both spiritual and practical tasks, such as control of the markets and storage facilities, or the building activities. O'Connor (1993, p2) tells that bridge building supervision "was placed in the care of the high priest, who received the title *pontifex*, commonly translated as 'bridge builder', from the Latin *pons*

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(bridge) and *facere* (to make or build)." This title, *pontifex maximus*, was passed on to later Roman emperors and through early Christian bishops even to the present Pope. In this context O'Connor (1993, p3) offers the explanation that this important title symbolized the "bridge from God to man…"

2.1.1.8 Contributions of Ancient Bridge Building

In conclusion, the main bridge construction principles were already known and used to some extent in ancient times. Due to lack of surviving timber structures one can only rely on historical reports and depictions of these. Prevailing structures in ancient times were the semicircular stone arch bridges, many of which have survived until the present day. Roman builders left a legacy of impressive structures in all parts of former Roman Empire. Arch structures were intelligently used both for heavy traffic and elaborate water supply systems; temporary timber structures also served military purposes. These systems were developed to the full extent that was technically possible and were not to be surpassed in mastery until many centuries later.

Engineering knowledge was already documented systematically by authors such as Vitruvius, whose work influenced the builders of later centuries considerably. Great builders and artists, such as Bramante, Michelangelo, and Palladio were careful students of his works.

2.2 Bioengineering

An interesting and promising approach that has only been little been developed is the use of bioengineering in construction. The main point of this approach is the examination of principles in natural structures, especially

in the living environment. Applications of bioengineering knowledge are found in the aerospace industry, which has implemented e.g. specially textured foils on the surface of airplanes to decrease air resistance. A similar approach is possible for construction engineering. The variety of natural structures is worth being examined further under an engineering point of view. Research need not be limited to bridge construction, other areas will also be influenced, e.g. building technology may explore new means of heating and insulation, the construction materials industry may find new means in utilization of biologically produced or modified polymers, and the like. The following examples shall merely give an impression of structures and concepts that nature has developed:

Cobwebs,

which form

strong but

extremely

light

networks;

Grass and

corn, which

incorporate

both

strength

and

flexibility;

Tress and shrubs, composed of strong wood fibers tower their environment;

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Crystals, which have an enormous strength through their regular inner composition and also show interesting electrochemical effects;

Bee honeycombs, whose regular geometrical structure makes them stiff and light;

Bones, which have an interior matrix network adapted to the flow of forces; Thermal insulation, which allows animals to inhabit roughest climates.

3. LITERATURE REVIEW

1. **Kishan Gautam" A Review on Various Methods used in the Analysis of Bridge Decks" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol. 9 Issue 06, June-2020** Harrop J. introduced the strip method for designing skew slabs, where reinforcement is often placed parallel to the slab edges instead of in an orthogonal layout. Equilibrium moment fields are considered, and the strip method simplifies the design process for reinforced concrete slabs, ensuring adequate load capacity. Different researchers extended this method to analyze various structures, such as stiffened sector plates and curved plates on elastic foundations. They also studied the dynamic behavior of curved bridges under different loading conditions, including the effects of skew angles and solar radiation. Various analytical and numerical methods were employed to assess the structural performance and optimize design parameters.

2. **Bharat Jeswani" Analysis and Design of Bridge Components using Staad Pro" International Research Journal of Engineering and Technology (IRJET)Volume: 07 Issue: 06 | June 2020** Mahantesh. S.Kamatagi (Sep 2015): Conducted a comparative study on the design of longitudinal girder of T-Beam Bridge. Found that IRC 112-2011 provides an economical design compared to IRC 21-2000. Abrar Ahmed (July 2017): Compared T-beam and Box Girder designs. Found that T-Beam Girder is more economical for spans up to 25m, while Box Girder is suitable for spans greater than 25m. Anushia K Ajay (June 2017): Conducted a parametric study on T-Beam Bridge design, focusing on the economical depth of longitudinal girder for different spans. David A.M. Jawad (2010): Studied the dynamic behavior of T-Beam Bridge decks due to heavy vehicles. Referenced historical research and recommended dynamic allowances for traffic loading. P.Veerabhadra Rao (Aug 2017): Compared the analysis of simply supported RC T-beam Bridge using different methods. Found that IRS loadings resulted in significantly higher loads compared to IRC loadings.

3. **Aashish Nema "Analysis of Structure and Design of Steel Bridge Using Staad Pro Software" International Journal for Research in Applied Science & Engineering Technology (IJRASET) ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538 Volume 11 Issue III Mar 2023** Chao Jiang: Investigated the fatigue life of fillet welds in steel bridge towers considering corrosion effects. Found that corrosion greatly reduced fatigue life but still met code requirements due to low tensile stress. Chenxing Cui: Studied shear behavior of stud connectors in steel bridge decks with ballastless tracks, using push-out tests and finite element analysis. Found that double-layer concrete slabs and group effects reduced shear performance of studs. Oskar Skoglund: Examined fatigue strength of four structural detail solutions for steel bridges through

ISBN: 978-93-343-2006-0

numerical simulations, proposing a new detail that improved fatigue strength by over 25%. Itunumi Savage: Conducted seismic analysis and base isolation retrofit design for a steel truss vertical lift bridge, finding base isolation effective for seismic retrofit. Xin Shi: Investigated seismic performance of self-centering hollow-core FRP-concrete-steel bridge columns, finding adequate self-centering and energy dissipation capacities. D. Martínez-Muñoz: Optimized composite bridge design using discrete swarm intelligence algorithms for cost and CO2 emissions reduction. Yangfan Shen: Studied vortex-induced vibration of a steel arch bridge tower, finding aerodynamic measures and eddy current dampers effective in mitigating VIV. Tomasz Maleska: Explored the effect of soil cover depth on seismic response in large-span thin-walled corrugated steel plate bridges, finding significant impact of soil cover depth on bridge response. Kai Liu: Developed a method using induction heating to remove asphalt pavement from steel bridge decks, analyzing temperature distribution for optimal removal timing. K. Chu: Examined fatigue behavior of joint-free bridges with steel and GFRP-reinforced ECC link slabs, finding GFRP-reinforced ECC link slabs exhibited superior performance. Bin Qiang: Investigated mechanical properties of bridge-steel weldments at elevated temperatures, finding significant degradation in mechanical properties at high temperatures. Hua Zhao: Designed and experimentally studied a steel-concrete composite box girder for a cable-stayed bridge, providing recommendations for design and construction. Biao Wei: Developed equal strength mild steel tenons as displacement restraining devices for long-span railway arch bridges, finding them effective in reducing bridge response to earthquakes. Miroslav Škaloud: Proposed simple formulae for designing webs of steel bridges subjected to repeated loading, aiming to simplify design analysis. Yazan M. Alshawabkeh: Investigated lateral buckling capacity of steel H-piles supporting integral abutment bridges, developing an empirical formula for calculating lateral buckling capacity.

4. **H. M. SHIN1a, H. M. LEE 2b, S. J. OH3 and J. H. CHEN 3 "Analysis and Design of Reinforced Concrete Bridge Column Based on BIM" Procedia Engineering 14 (2011) 2160–2163** The study introduces Project Life-cycle Management (PLM) and Construction Product Lifecycle Management (CPLM) systems, adapting them for civil structure design. It focuses on developing a parametric modeling approach for RC bridge columns, aiming to enhance competitiveness. Utilizing 3D object models, the study emphasizes the integration of design characteristics into the structural analysis process. Key aspects include:

   Product Breakdown System (PBS): Utilizing part models at the lowest level to create whole models, enabling efficient communication and data exchange among project participants throughout the structure's life-cycle.

   Model Library: Emphasizing the reuse of existing models to improve productivity and eliminate inefficiencies in producing new models for each project.

   Parameter Determination for FEA Modeling: Establishing design parameters for 3D object models to facilitate Finite Element Analysis (FEA), including longitudinal reinforcement, hoop steel ratios, thickness, width of pier and footing, and joint conditions.

   The study proposes a BIM-based analysis and design process to overcome the drawbacks of classical design methods, aiming to reduce errors and increase efficiency. It involves the classification of 3D- information models based on diverse information categories such as drawing, material, load, and design

   code information. Modules for computing loads and libraries of design codes are developed to support the analysis and design process. Overall, the study seeks to streamline civil structure design through the integration of parametric modeling and BIM-based approaches.

5. **Dr. Mahesh Suresh Endait1 , Prof. Virendrakumar B. Patil 2 , Mr. Ravindra Narendra Patil3 "BRIDGE STRUCTURAL STABILITY ANALYSIS**

ISBN: 978-93-343-2006-0

USING MODAL ANALYSIS" Eur. Chem. Bull. 2023, 12 (S3), 1055 – 1065 The document discusses various aspects related to bridge design, including historical background, literature survey on bridge structure deterioration identification, and research objectives focusing on the vibration properties of different bridge materials. The methodology section outlines the structural stability analysis using modal analysis, employing ANSYS simulation to assess natural frequencies and mode shapes. Results and discussions include findings on deformation and mass participation factors for concrete, silicone rubber, and neoprene rubber bridge decks across different frequency modes.

6. **Mohd Junaid Mohd Zubair1 , Prof. Arvind B. Vawale2 , Prof. Nitin S. Vaidkar3 Prof. Dr. Pradeep Sudhakar Bhalage4 "ANALYSIS & DESIGN GIRDER BRIDGE BY USING CSI BRIDGE" INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT] ISSN No.: 2394-3696, Website: ijiert.org, Held on 15th and 16th June 2020**
The reviewed papers discuss various aspects of bridge design and analysis, including load testing, comparison of design codes, use of software like CSi Bridge and Staad Pro, and exploration of different girder types and materials. Overall, the studies aim to optimize bridge designs for safety, efficiency, and economy. Future research should focus on advancing technoeconomical solutions, encouraging innovative designs, and enhancing multidimensional sections for public structures.

7. **Muhammad Ashraf. S[1], Aneetta Varghese[2], Anna Mariam Saji[3], Aswin Hanuraj. R´, Maneesh T Manojμ "DESIGN AND ANALYSIS OF CHAMAKKAVU BRIDGE" International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 07 Issue: 07 | July 2020** This project aims to design a safe, elegant, and cost-effective bridge over the Achankovil River to replace the old bridge, which is crucial for the community's connectivity. The new bridge, serving both pedestrians and vehicles, will alleviate the difficulties faced by 5596 families and visitors to the Chamakkavu temple due to the absence of the old bridge. The proposed design involves a prestressed T beam bridge using RCC materials and considering IRC class AA loading. STAAD Pro V8i software is utilized for accurate and efficient design compared to manual methods. The project draws insights from literature emphasizing the importance of bridges in urban development and disaster relief. The new bridge aims to address traffic congestion, improve access to essential services, and withstand natural disasters more effectively than its predecessor.

8. **Prof. Sandip B Dhepale1, Prof. Prasad R Gayake2 "Design and Analysis of Highway Bridge based on their Material and its Comparative Study of Life Cycle and Cost Analysis" International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 07 Issue: 06 | June 2020** This study focuses on the importance of sustainable development in the bridge industry, emphasizing economic and environmental impacts. It compares conventional concrete bridge decks with alternative engineered cementitious composite link slab designs, demonstrating that the latter results in lower life-cycle costs and reduced environmental impacts. Additionally, it examines the cost comparison between prestressed concrete (PC) bridges and steel bridges. The research highlights the significance of lifecycle modeling in decision-making, considering factors beyond initial costs. Key aspects such as life- cycle cost, IRC Class loading, and design software (STAADPRO) are discussed. The literature survey explores various studies on bridge design, maintenance, and sustainability, providing valuable insights into modern bridge engineering practices. The research methodology outlines the life cycle cost analysis process and the use of STAAD Pro software for bridge design, considering factors like material properties, loading conditions, and design standards. Overall, the

ISBN: 978-93-343-2006-0

study aims to contribute to informed decision-making in bridge design and maintenance, integrating economic, environmental, and engineering considerations.

9. **Mohd Junaid Mohd Zubair1 , Prof. Arvind B. Vawale2 , Prof. Nitin S. Vaidkar3 Prof. Dr. Pradeep Sudhakar Bhalage4 "ANALYSIS & DESIGN GIRDER BRIDGE BY USING CSI BRIDGE" INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT] ISSN No.: 2394-3696**, Website: ijiert.org, Held on 15th and 16th June 2020 The reviewed literature explores various aspects of bridge design and analysis, emphasizing the importance of selecting appropriate codes and methodologies for ensuring safety and cost-effectiveness. Different studies compare designs based on codes like AASHTO and IRC, analyzing factors such as structural behavior, loading conditions, and material usage. Methods such as finite element analysis and software like CSi Bridge are employed to evaluate bridge performance under different loading scenarios. Results indicate that certain design approaches, such as prestressed concrete box girders, may offer better stability, economy, and structural efficiency. Overall, the research highlights the significance of meticulous design, considering factors like bending moments, shear forces, deflection, and load distribution. By comparing various design standards and methodologies, engineers can make informed decisions to create safer, more economical, and structurally sound bridges.

10. **Qasim Zaheer1, Tan Yonggang1, and Furqan Qamar2, * "bridge structure's optimization and it's development over time" Int. J. Simul. Multidisci. Des. Optim. 13, 5 (2022) © Q. Zaheer et al., Published by EDP Sciences, 2022 https://doi.org/10.1051/smdo/2021039** The study reviewed 156 papers on structural optimization for bridges published between 1970 and 2021, finding an increasing trend in research output, particularly in well-funded countries. While cost reduction remains a common goal, recent years have seen a rise in multi-objective optimization and enhancing structural performance. The study suggests establishing precise weighting standards for optimization goals, improving mathematical quantifications, and developing benchmarking systems tailored to different optimization challenges. Metaheuristic algorithms are noted for their limited applicability, leading to a call for more focused research on classifying optimization problems and creating benchmarking systems to enhance optimization algorithms' effectiveness across various problem types. The authors acknowledge no competing interests and express gratitude to Dalian University of Technology, China, for supporting their research.

4. Research Methodology

4.1 Introduction

This chapter outlines the research methodology employed in the analysis of major bridges using Midas software. It encompasses the procedures, techniques, and tools utilized to conduct the study effectively. The methodology is crucial as it dictates the reliability and validity of the research findings.

4.2 Research Design

The research design for this project adopts a quantitative approach, focusing on numerical data and analysis. It involves the utilization of Midas software for structural analysis, considering its capabilities in simulating complex bridge structures accurately. The design incorporates both primary and secondary data sources to ensure comprehensive analysis.

4.3 Data Collection

4.3.1 Primary Data: Primary data collection involves obtaining information directly from the source. In this study, primary data is

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acquired through field surveys, including site inspections and measurements of the bridge's physical parameters. Additionally, data regarding material properties, traffic loads, and environmental conditions are collected through sensors and instruments.

4.3.2 Secondary Data: Secondary data is gathered from existing literature, research papers, technical documents, and online databases. This includes information on previous bridge analyses, design standards, material specifications, and case studies. Secondary data provides valuable insights and references for comparison and validation purposes.

4.4 Structural Analysis with Midas Software

Midas software is employed for structural analysis due to its advanced features and capabilities in simulating complex bridge structures. The analysis process involves the following steps:

1. Model Development: A detailed 3D finite element model of the bridge is created using Midas software. The model includes geometric, material, and loading data obtained from primary and secondary sources.

2. Material Properties: Material properties such as concrete, steel, and other structural elements are defined within the software based on laboratory testing and design specifications.

3. Load Application: Traffic loads, including vehicular live loads, dead loads, and environmental loads, are applied to the bridge model according to design standards and field measurements.

4. Analysis Settings: Analysis parameters such as boundary conditions, element types, mesh density, and analysis methods are configured within the software to ensure accurate simulation results.

5. Analysis Execution: The bridge model is analyzed under various loading conditions using Midas software. Structural responses such as deflections, stresses, strains, and dynamic behavior are evaluated to assess the bridge's performance.

6. Result Interpretation: Analysis results are interpreted to identify critical sections, structural vulnerabilities, and areas for improvement. Comparisons are made with design standards, codes, and previous studies to validate the findings.

4.5 Validation and Verification

The validity and accuracy of the analysis results are ensured through validation and verification processes. Validation involves comparing the simulated responses with field measurements and experimental data to confirm the model's predictive capabilities. Verification entails checking the software's accuracy by benchmarking against analytical solutions and established theoretical models.

4.6 Ethical Considerations

Ethical considerations, including confidentiality, integrity, and accountability, are upheld throughout the research process. Data confidentiality is maintained, and proper permissions are obtained for accessing proprietary information or sensitive data. Additionally, ethical guidelines and professional standards are adhered to in conducting the research.

4.7 Limitations

Despite rigorous methodology, certain limitations may affect the research outcomes. These include constraints in data availability, simplifications in modeling assumptions, uncertainties in input parameters, and limitations of the software itself. Awareness of these limitations is essential for interpreting the findings accurately.

5. Future Scope

As bridge engineering continues to evolve, driven by technological advancements, changing societal needs, and environmental

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considerations, the future holds promising avenues for innovation and improvement. This chapter explores the potential future directions and emerging trends in bridge engineering, focusing on areas of design, materials, construction techniques, and sustainability.

5.1 Advancements in Design:

Future bridge designs are likely to integrate cutting-edge computational tools and methodologies, enabling engineers to optimize structural performance while incorporating novel architectural elements. Parametric design approaches, augmented reality, and generative design algorithms will empower designers to explore a wide range of design alternatives and efficiently address complex geometries and functional requirements. Moreover, advancements in digital twin technology will enable real-time monitoring and predictive maintenance of bridge infrastructure, enhancing safety and longevity.

5.2 Evolution of Materials:

The future of bridge construction will witness the adoption of innovative materials and sustainable practices to address environmental concerns and enhance structural performance. High-performance composites, self-healing concrete, and advanced nanomaterials will offer improved durability, corrosion resistance, and structural efficiency, paving the way for lightweight and resilient bridge structures. Additionally, the integration of renewable and recycled materials will contribute to reducing the carbon footprint of bridge construction and promoting circular economy principles.

5.3 Sustainable Construction Techniques:

With a growing emphasis on sustainability and resilience, future bridge construction techniques will prioritize eco-friendly practices and resource-efficient processes. Prefabrication and modular construction methods will minimize material wastage and construction time while maximizing quality control and safety on-site. Furthermore, the adoption of robotic construction technologies, 3D printing, and autonomous construction vehicles will revolutionize the way bridges are built, enabling precise execution and customization of complex structural elements.

5.4 Smart and Resilient Infrastructure:

The future of bridge engineering will embrace the concept of smart and resilient infrastructure, integrating sensors, Internet of Things (IoT) devices, and artificial intelligence to enhance operational efficiency and structural performance. Smart monitoring systems will enable real-time data collection and analysis, allowing for proactive maintenance interventions and adaptive response to changing environmental conditions. Additionally, the implementation of resilient design principles, such as multi-hazard risk assessment and climate adaptation strategies, will ensure the long-term viability of bridge infrastructure in the face of natural disasters and climate change.

5.5 Integration of Green Technologies:

In line with global efforts to mitigate climate change and reduce greenhouse gas emissions, future bridges will incorporate green technologies and renewable energy sources to achieve carbon neutrality and energy efficiency. Solar panels, wind turbines, and kinetic energy harvesting systems will be seamlessly integrated into bridge structures to generate clean energy and contribute to sustainable urban development. Moreover, green roofs, vertical gardens, and permeable pavements will enhance biodiversity and mitigate the urban heat island effect, creating healthier and more livable environments around bridge corridors.

6. Conclusion

In conclusion, the exploration of bridges as monumental feats of engineering reveals not only their physical structures but also the intricate interplay between history, innovation, and future challenges within the realm of civil engineering.

ISBN: 978-93-343-2006-0

Through an in-depth analysis of major bridge components, from structural design to material selection, construction techniques to performance evaluation, a comprehensive understanding of the complexities involved in bridge engineering emerges. Bridges symbolize progress and connectivity, embodying the collaborative efforts of architects, engineers, and construction teams who strive to overcome natural obstacles and connect distant shores with grace and efficiency.

The introduction of sophisticated engineering software, such as MIDAS, has revolutionized the way bridges are analyzed and designed. By leveraging advanced computational capabilities, engineers can simulate real-world conditions, optimize design parameters, and ensure structural integrity and safety with unprecedented accuracy and efficiency.

Moreover, the comparative analysis of bridge girder types highlights the importance of thoughtful design considerations in achieving optimal performance, durability, and cost-effectiveness. Whether opting for PSC I girders or Box girders, engineers must carefully weigh factors such as span length, loading requirements, and construction constraints to make informed decisions that meet project objectives and regulatory standards.

Looking towards the future, the history of bridge engineering serves as a testament to human ingenuity and technological advancement. As we continue to innovate, challenges in design, construction, maintenance, and the application of high-performance materials will shape the landscape of bridge engineering for generations to come. Creative structural concepts and advancements in technology offer new opportunities for bridge engineers to push the boundaries of what is possible, ensuring the continued evolution of bridge design and construction.

In essence, the study of bridges transcends mere structural analysis; it embodies the spirit of human endeavor, innovation, and collaboration, weaving together past achievements, present challenges, and future aspirations in a timeless tapestry of engineering excellence. As bridges continue to stand as symbols of progress and connectivity, they remind us of our capacity to overcome obstacles and forge pathways to a brighter future.

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ISBN: 978-93-343-2006-0

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ISBN: 978-93-343-2006-0

Role of Materials in Enhancing the Performance of Biosensors

Dr. Prajakta N. Deshmukh
Department of Engineering Science
KJCOEMR, Pune
prajaktadeshmukh.kjcoemr@kjei.edu.in

Dr. Mahendra R. Panssare
Department of Engineering Science
KJCOEMR, Pune
mahendrapansare.kjcoemr@kjei.edu.in

Dr. Vivek B. Korde
Department of Engineering Science
KJCOEMR, Pune
vivekkorde.kjcoemr@kjei.edu.in

Abstract
Biosensors are analytical devices designed to detect specific biological analyses through a combination of a biological recognition element and a physicochemical transducer. The efficiency, sensitivity, and specificity of biosensors are highly dependent on the materials used in their construction. This paper reviews the various classes of materials employed in biosensor development, including transducer materials, biological recognition elements, immobilization materials, nanomaterials, and substrate materials. Special emphasis is placed on how these materials contribute to the functionality and performance of biosensors, particularly in terms of sensitivity, stability, and selectivity.

1. Introduction

Biosensors have become essential tools in numerous domains including medical diagnostics, environmental monitoring, food safety, and biotechnology. At the core of biosensor function lies the interaction between a biological recognition element and a transducer, which converts the biological event into a measurable signal. The choice of materials for each component is critical in determining the sensor's performance characteristics such as sensitivity, selectivity, and stability. Recent advancements in nanotechnology and material science have opened new avenues for enhancing biosensor efficiency and broadening their applications.

2. Transducer Materials

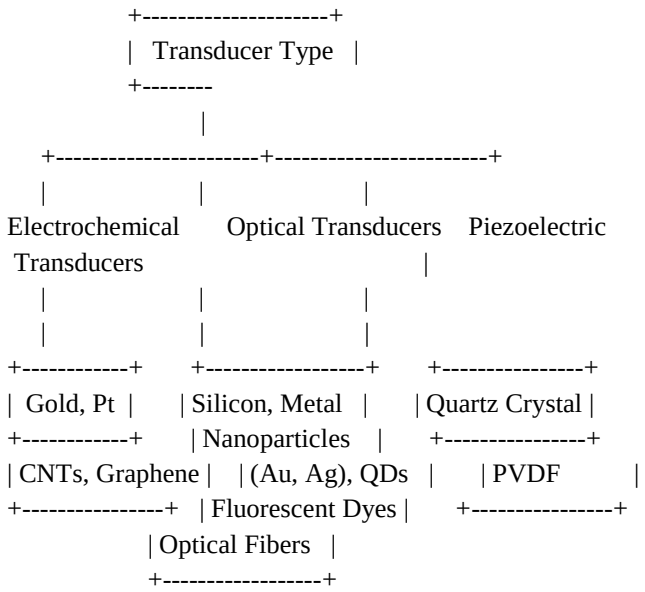
The transducer in a biosensor is responsible for converting the biochemical interaction into a readable signal, and the materials used directly impact the efficiency of this conversion.

Electrochemical Transducers: Metals such as gold and platinum are commonly used for their excellent conductivity, biocompatibility, and stability. Carbon-based nanomaterials like carbon nanotubes (CNTs) and graphene provide high surface area and electrical conductivity, enhancing signal transduction.

Conducting Polymers: Materials such as polyaniline (PANI) are popular due to their tunable electrical properties and ease of chemical modification.

Optical Transducers: These utilize materials like silicon for waveguides and metal nanoparticles (e.g., gold, silver) for surface plasmon resonance (SPR). Fluorescent dyes, quantum dots, and optical fibers further enhance optical detection capabilities.

Piezoelectric Transducers: Materials such as quartz crystal and polyvinylidene fluoride (PVDF) are used for mass-sensitive measurements, making them suitable for real-time detection applications.



ISBN: 978-93-343-2006-0

Conducting Polymers (used across types):
- Polyaniline (PANI)

3.Biological Recognition Elements The selectivity of a biosensor is primarily governed by the biological recognition element employed. The **biological recognition element** (or bioreceptor) is the key component that determines a biosensor's **selectivity** and **specificity**. It works by selectively interacting with (binding to) the specific **target analyte** (the substance you want to detect) while ideally ignoring all other molecules in the sample. This specific binding event is what the sensor's transducer then converts into a measurable signal.

Enzymes:
Enzymes like glucose oxidase catalyze specific biochemical reactions, allowing for highly selective analyte detection.
Antibodies:
These proteins bind specifically to antigens and are widely used for the detection of biomolecules.
Nucleic Acids and Aptamers: These offer high specificity and are especially useful in detecting genetic material or small target molecules.
Cells and Cellular Components: These enable detection of complex biological processes and can be used in whole-cell biosensors for environmental or pharmaceutical applications.

4.Immobilization Materials Effective immobilization of biological molecules is essential to maintain biosensor performance. The **immobilization material** (or matrix) acts as the bridge between the biological recognition element (e.g., enzyme, antibody, DNA) and the electronic or optical **transducer**. Its properties directly and significantly influence the final performance of the biosensor.

Role of Immobilization Materials in Biosensor Performance

Effective immobilization is essential to meet several critical performance requirements:

- Maintain Bioreceptor Activity: The material must provide a biocompatible microenvironment that preserves the 3D structure and biological activity of the delicate biological molecule. Harsh chemical or physical environments can lead to denaturation and a loss of function.
- Enhance Stability and Shelf-Life: It must securely anchor the biological molecule to the transducer surface, preventing leaching (desorption) and allowing the biosensor to be stored and used repeatedly over an extended period. This improves reusability and storage stability.
- Improve Sensitivity: High-surface-area materials can load a larger amount of the bioreceptor, which can lead to a stronger signal upon analyte binding, thus increasing sensitivity and lowering the limit of detection.
- Facilitate Signal Transduction: For electrochemical biosensors, the material can sometimes assist in or mediate the electron transfer between the biological reaction site and the electrode surface, leading to a faster and more efficient signal.
- Control Specificity: The matrix can act as a selective barrier (e.g., controlling pore size) to prevent large interfering molecules from reaching the transducer surface, indirectly enhancing the sensor's specificity.

Polymers:
Polyethylene glycol and similar polymers are commonly used to reduce non-specific binding and maintain biomolecule functionality.
Silica and Self-Assembled Monolayers(SAMs): These materials provide stable platforms for immobilizing recognition elements, contributing to sensor repeatability and stability.

5.Nanomaterials in Biosensors Nanotechnology has significantly enhanced biosensor capabilities. Nanotechnology, specifically the use of nanomaterials, has profoundly enhanced biosensor capabilities by improving nearly every key performance metric. Nanomaterials are utilized as advanced immobilization platforms, signal enhancers, or even as the core transducer material itself, offering superior performance compared to traditional bulk materials.

Key Enhancements from Nanomaterials:

The superior performance of nano-enhanced biosensors stems from the unique properties nanomaterials exhibit at the 1–100 nm scale:

1. Increased Sensitivity and Lower Detection Limits
2. Enhanced Signal Transduction and Electron Transfer
3. Improved Biocompatibility and Stability

Nanoparticles(Gold,Silver):
These are used to increase surface area and signal amplification.

Carbon Nanotubes and Graphene: These materials improve electronic properties and sensitivity due to their excellent conductivity and high surface-to-volume ratios.

Quantum Dots: With tunable fluorescence properties, quantum dots are highly effective in optical biosensing platforms.

6.Substrate Materials Substrate materials serve as the structural base for biosensors. Substrate materials in biosensors help as the structural base and often the transducer platform where the critical bio recognition event takes place. The choice of substrate is fundamental to a biosensor's performance, stability, and manufacturability.

Glass and Silicon: These materials offer excellent mechanical and optical properties, making them suitable for a wide range of applications.

Flexible Polymers(e.g.,PDMS): Used in the development of wearable and flexible biosensors, these materials provide mechanical adaptability and transparency.

7.Conclusion

The choice of materials in biosensor design is crucial in determining performance parameters such as sensitivity, selectivity, and longevity. Advances in material science, especially with nanomaterials and hybrid structures, continue to push the boundaries of biosensor capabilities. Future developments are expected to yield more robust, sensitive, and versatile biosensors with applications spanning healthcare, environmental safety, and industrial monitoring.

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Experimental Investigations on a Light Weight Material for Vehicle Frontal Bumper

Mr. SHIVAJI T. DUDHBHATE [(1)]

Department of Mechanical Engineering,

K J College of Engineering and Management Research, Pune

Savitribai Phule Pune University, Pune, Maharashtra.

shivajidudhabhate.kjcoemr@kjei.edu.in

Abstract-

Glass fibre reinforcement has been a recent trend and effective method for enhancing strength characteristic of metals, plastics, joints etc. at a very low competitive cost. Aluminum is a light weight metal with less strength characteristic as compared to other metals. Comparative analysis is made between aluminum and glass fibre reinforced aluminum specimen for studying strength properties. The specimen is made up of aluminium having a square cross section. The plate thickness is varied from 1mm, 2mm & 3mm. Glass fibre reinforcement is done on these specimens. A nonlinear material approach is used for simulation. Experimental analysis will be done with help of three-point bending test. Force plots are used for comparing both models. FEA and experimental results will be validated by comparative analysis. Result and conclusion will be stated after the comparative analysis between FEA & Experimental testing.

I. INTRODUCTION

World is now focused on the rapid developments in the various fields such as aerospace, space, automotive, electronics, and defence, infrastructure developments & power generation. Automotive sector has emerged as booster to the economy of nations over worldwide. As automotive manufactures are looking to bring light weight and fuel-efficient vehicles in market. So there is continual research on reducing the cost of vehicle by utilizing the light weight composites which can give similar mechanical characteristics as compared to metals parts used in automobile.

Current research work focuses on use of aluminum and glass fiber composite to be utilized in manufacturing of bumpers of automobiles. It is anticipated that this aluminum glass fiber composite can absorb the lateral or transverse loading occurred during accidents or deliberately happened incidents. In this work 3-point bending approach is used to analyze the performance of composite material and compared with the aluminum Specimen. FEA method is used for modelling and simulation. Also the FEA results are validated with experimental results. Aluminium - glass fibre reinforced plastics (GFRP) sandwich panels are hybrid laminates consisting of GFRP bonded with thin aluminum sheets on either side. Such sandwich materials are increasingly used in airplane and automobile structures. Laminates with varying aluminium thickness fractions, fibre volume fractions and orientation in the layers of GFRP were fabricated by hand layup method and evaluated for their impact performance by conducting drop weight tests under low velocity impacts. The impact energy required for initiating a crack in the outer aluminium layer as well as the energy required for perforation was recorded. The impact load-time history was also recorded to understand the failure behaviour. The damage depth and the damage area were measured to evaluate the impact resistance. Optical photography and scanning electron micro graphs were taken to visualize the crack and the damage zone. The bidirectional cross-ply hybrid laminate (CPHL) has been found to exhibit better impact performance and damage resistance than the unidirectional hybrid laminate (UDHL). Increase in aluminium thickness fraction (Altf) and fiber volume fraction (Vf) resulted in an increase in the impact energy required for cracking and perforation. On an overall basis, the sandwich panels exhibited better impact performance than the monolithic aluminium.

A. METHODOLOGY

1. 3D CAD Model Generation.
   - Getting input data on dimensions of aluminium specimen.
   - Creating 3D model in CATIA.
2. Determination of load.
3. Testing
   - Testing specimen on UTM machine.
4. Fabrication, Experimental Validation and Result Analysis.

II THEORY

In this topic, some important points have been discussed which are useful in the testing of light weight material for vehicle frontal bumper.

B. Types of Car Bumpers:-

1] Plastic Bumper-

ISBN: 978-93-343-2006-0

Most modern cars use a reinforced thermoplastic bumper, as they are cheap to manufacture, easy to fit and absorb more energy during a crash. A majority of car bumpers are custom made for a specific model, so if you are looking to replace a cracked bumper with a similar one, you would have to buy from a specialist dealer. However, many companies now offer alternative designs in thermoplastic, with a range of fittings designed for different models.

2] Body Kit Bumper-

Modified cars often now have a full body kit rather than just a front and rear bumper. These kits act as a skirt around the entire body of the car and improve performance by reducing the amount of air flowing underneath the car and so reducing drag. Due to each car's specifications, these have to be specially purchased and can be made from thermoplastic, like a standard bumper, or even out of carbon fibre.

3] Carbon Fibre Bumper-

Carbon fibre body work is normally the thing of super-cars, but many car companies, and specialist modifiers, are starting to use it for replacement body part on everyday cars. This is because it is very light and is safe during a crash. It is, however, a lot more expensive than normal thermoplastic.

4] Steel Bumper-

Originally plated steel was used for the entire body of a car, including the bumper. This material worked well, as it was very strong in a crash, but it was very heavy and dented performance. As car engine design has improved, steel bumpers have pretty much disappeared for anything except classic cars. Replacing one involves a lot of searching for scrap cars or having one specially made. Improving passenger car damage ability and repair ability has been an important RCAR topic since the Council was established in 1972. In order to prevent unnecessary damage to the structure of passenger cars in low speed crashes, a 15 km/h, 40 % overlap test was implemented in the 1980s and revised again in 2006 (the impact angle was changed from 0° to 10° and the rear impact moving barrier weight was increased from 1000 to 1400kg). This test is referred to as the RCAR Structural Test. Car manufacturers design their vehicles to perform well in this RCAR structural test but some have fitted vehicles with countermeasures that do not exhibit good crash behaviours in real world crashes. In some cases, manufacturers have eliminated the bumper beam and replaced them with localized countermeasures, such as crush cans, to manage the test. Such sub-optimised designs are in most cases not robust and often lead to expensive damage in car-to-car crashes. Insurance claims data indicate that rear bumpers are often under-ridden by a striking vehicle due to bumper system instability or vertical dive of vehicles during braking. In these cases, it is desirable to have bumper systems that have sufficient vertical

Overlap to maintain engagement. To this end, bumpers should ideally be mounted at slightly different heights front and rear but has sufficient height to maintain engagement over a wide range of circumstances.

C. Material Properties

Properties of material that are used in light weight bumper are listed below.

1. Aluminium
    - Light Weight
    - Corrosion Resistance
    - Thermal Conductivity
2. Glass Fiber
    - High Tensile Strenght
    - Durability
    - Dimensional Stability

III. MODELING OF CAR BUMPER

Computer-aided design (CAD) is the use of computer system (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term CADD (for Computer Aided Design and Drafting) is also used.

D. Type

There are several different types of CAD, each requiring the operator to think differently about how to use them and design their virtual components in a different manner for each.

There are many producers of the lower-end 2D systems, including a number of free and open-source programs. These provide an approach to the drawing process without all the fuss over scale and placement on the drawing sheet that accompanied hand drafting since these can be adjusted as required during the creation of the final draft.

3D wireframe is basically an extension of 2D drafting (not often used today). Each line has to be manually inserted into the drawing. The final product has no mass properties associated with it and cannot have features directly added to it, such as holes. The operator approaches these in a similar fashion to the 2D systems, although many 3D systems allow using the wireframe model to make the final engineering drawing views.

3D “dumb” solids are created in a way analogous to manipulations of real-world objects (not often used today). Basic three-dimensional geometric forms (prisms, cylinders, spheres, and so on) have solid volumes added or subtracted from them as if assembling or cutting real-world objects. Two-dimensional projected views can easily be generated from the models. Basic 3D solids don’t usually include tools to easily allow motion of components, set limits to their motion, or identify interference between components.

There are two types of 3D Solid Modelling -

1. Parametric modelling allows the operator to use what is referred to as "design intent". The objects and features created are modifiable. Any future modifications can be made by changing how the original part was created. If a feature was intended to be located from the centre of the part, the operator should locate it from the centre of the model. The feature could be located using any geometric object already available in the part, but this random

placement would defeat the design intent. If the operator designs the part as it functions the parametric model is able to make changes to the part while maintaining geometric and functional relationships.

2. Direct or Explicit modelling provide the ability to edit geometry without a history tree. With direct modelling, once a sketch is used to create geometry the sketch is incorporated into the new geometry and the designer just modifies the geometry without needing the original sketch. As with parametric modelling, direct modelling has the ability to include relationships between selected geometry (e.g., tangency, concentricity).

Top end systems offer the capabilities to incorporate more organic, aesthetics and ergonomic features into designs. Freeform surface modeling is often combined with solids to allow the designer to create products that fit the human form and visual requirements as well as they interface with the machine.

E. Manufacturing of Car Bumper

Following operations were while fabricate the project

1) Cutting: -

This operation is performed to cut the material as our required size. The machine used for this operation is power chop saw. A power chop saw, also known as a drop saw, is a power tool used to make a quick, accurate crosscut in a workpiece at a selected angle. Common uses include framing operations and the cutting of molding. Most chop saws are relatively small and portable, with common blade sizes ranging from eight to twelve inches. The chop saw makes cuts by pulling a spinning circular saw blade down onto a workpiece in a short, controlled motion. The workpiece is typically held against a fence, which provides a precise cutting angle between the plane of the blade and the plane of the longest workpiece edge. In standard position, this angle is fixed at 90°. A primary distinguishing feature of the miter saw is the miter index that allows the angle of the blade to be changed relative to the fence. While most miter saws enable precise one-degree incremental changes to the miter index, many also provide "stops" that allow the miter index to be quickly set to common angles (such as 15°, 22.5°, 30°, and 45°). The time required for this operation is 50 minutes.



Fig. Cutting

2) Finishing: -

This operation is performed to finish the edges with grinder using grinding wheel. The machine used for this operation is hand grinder. An angle grinder, also known as a side grinder or disc grinder, is a handheld power tool used for cutting, grinding and polishing. Angle grinders can be powered by an electric motor, petrol engine or compressed air. The motor drives a geared head at a right-angle on which is mounted an abrasive disc or a thinner cut-off disc, either of which can be replaced when worn. Angle grinders typically have an adjustable guard and a side-handle for two-handed operation. Certain angle grinders, depending on their speed range, can be use*d* as sanders, employing a sanding disc with a backing pad or disc. The backing system is typically made of hard plastic, phenolic resin, or medium-hard rubber depending on the amount of flexibility desired. The time required for this operation is 20 minutes.

3) Hand Lapping:-

In hand lapping process first we slect the aluminium plate and clean it by cloth or paper. then we take the epoxy resin which is a hardener . we pour the epoxy resin on plate and make the proper thickness of epoxy then we take sheet of glass fiber as a dimension of plate and lapped by hand with the help of roller. After lapping we put in open place for dry .we create 3 plate for different thickness i.e 1mm, 2mm, 3mm.



Fig. Lapping

4) Polishing: -

This operation is performed to polish the welded joints with hand grinder using grinding wheel. The machine used for this operation is hand grinder. With refinement, grinding becomes polishing, either in preparing metal surfaces for subsequent buffing or in the actual preparation of a surface finish, such as a No. 4 polish in which the grit lines are clearly visible. Generally speaking, those operations which serve mainly to remove metal rapidly are considered as grinding, while those in which the emphasis is centered on attaining smoothness are classified as polishing. Grinding employs the coarser grits as a rule while most polishing operations are conducted with grits of 80 and finer. If polishing is required, start with as fine a grit as possible to reduce finishing steps. There is a wide range of grinding and polishing tools on the market and advice is available from ASSDA members to assist in particular applications. Polishing operations are conducted with the abrasive mounted either on made-up shaped wheels or belts which provide a resilient backing.

F. Experimental Analysis

The UTM (Instron 1342) is a servo hydraulic fluid-controlled machine, consists of a two column dynamically rated load frame with the capacity of load up to 100kN (dynamic), hydraulic power pack (flow rate 45 litre/minute) and 8800 Fast Track 8800 Controller test control systems is stand alone, fully digital, single axis controller with an inbuilt operating panel and display. The controller is fully portable and specifically designed for materials testing requirement. This controller has position, load and strain control capability. The software available with the machine are: (a) Merlin Testing Software for Tensile Test (b) da/dN Fatigue Crack Propagation Test. (c) Kic Fracture Toughness Test. (d) Jic Fracture Toughness Test.

The three-point bending tests were conducted on a universal testing machine. The load−displacement curves were obtained from the experiments. Figure 19 shows the schematic diagram for the three-point bending tests. The peak load F could be obtained from the three-point bending tests ,and the bending strength R was calculated using Eq. (1).

$$R = \frac{3Fl}{2bh^2} \qquad (1)$$

where l is the size of the span, b and h are the width and thickness of the specimen, respectively, and F is the peak load during the test.

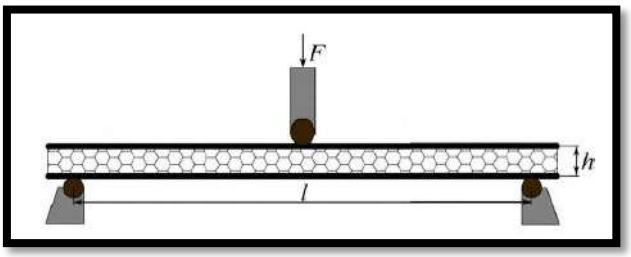


Fig. Schematic of 3-point bending test.

1) Testing of 1mm Plate on UTM-



Fig. Setup of 1mm plate on UTM

2) Testing of 2mm plate on UTM-



Fig. Setup of 2mm plate on UTM

3) Testing of 3mm plate on UTM-



Fig. Setup of 3mm plate on UTM

H. *Experimental Result*

1) The results obtained after the Experimental testing are as Follows

Properties	**1mm Plate**	**2mm Plate**	**3mm Plate**
Total Deformation(mm)	46.1	45	11.3
Peak Load (N)	994.7	1071.14	2768.5

From the Analysis & experimental testing results, it is clear that the total deformation value is almost equal. So, the results are validated.

ISBN: 978-93-343-2006-0

2) Result of Graphs

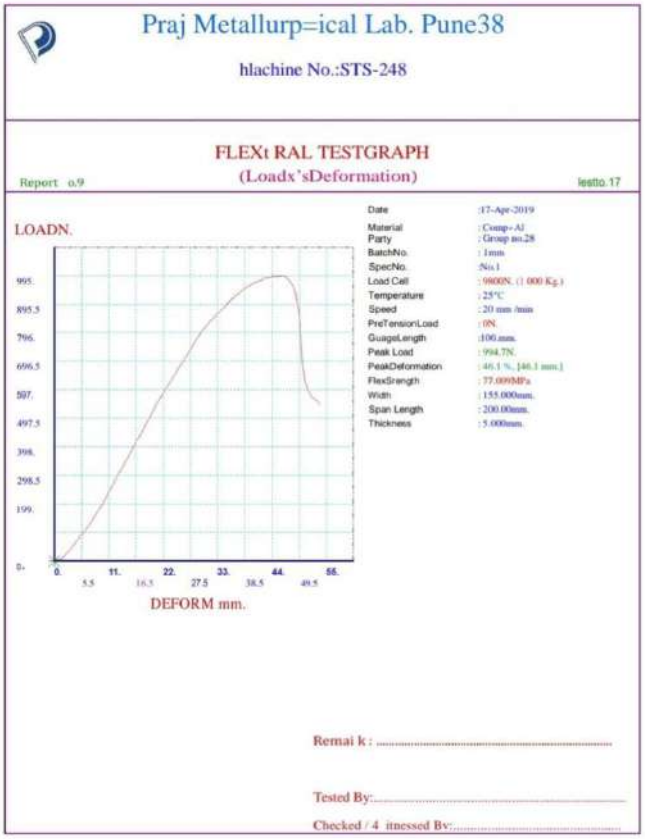


Fig. Load-Deformation Graph (1mm)

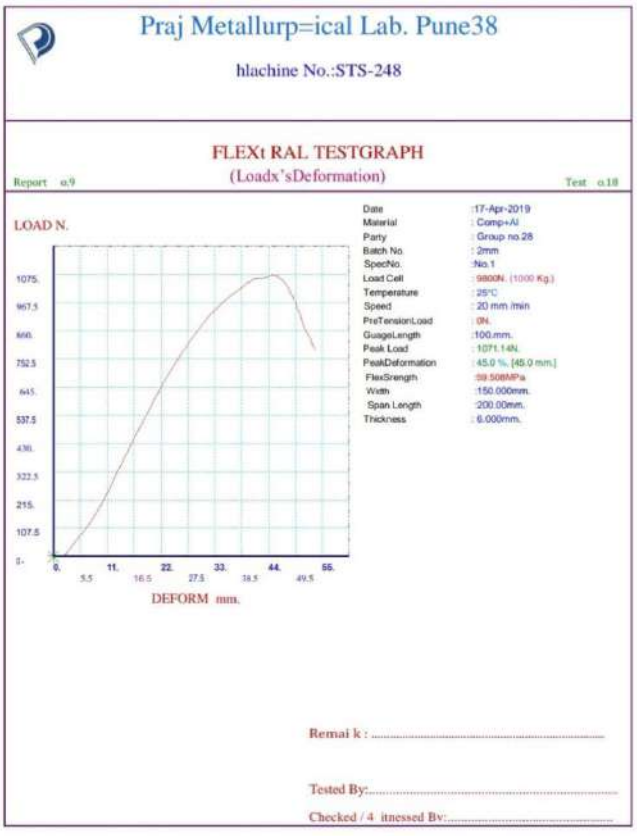


Fig. Load-Deformation Graph (2mm)

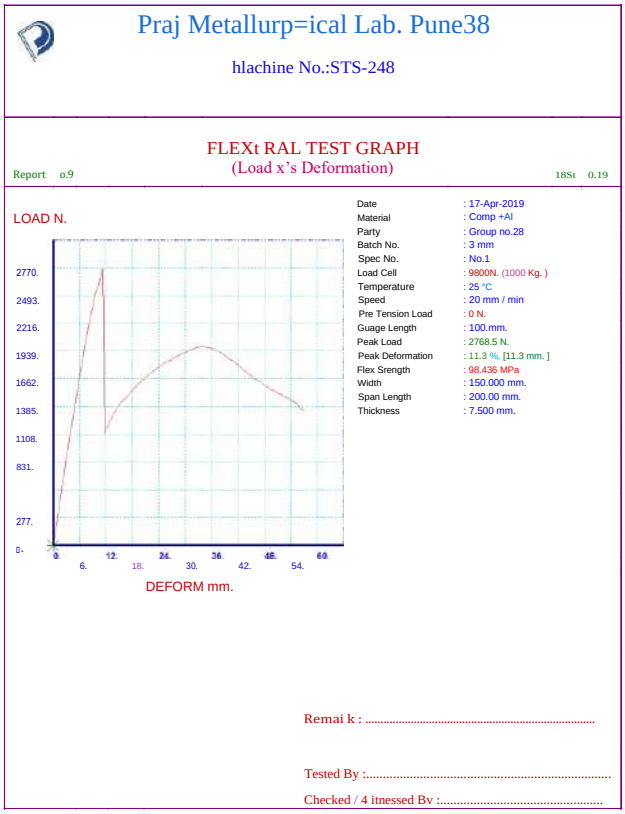


Fig. Load-Deformation Graph (3mm)

IV. CONCLUSION

The new safety regulation concerning bumper system specification be side automaker environmental make it quite complicated and much costly for the design of this structure to full fill the broad requirement. Finding the the best procedure for bumper beam development poses extra load on designer and may influence his/her performance. the previous research discussed the design process, material selection, and analysis and verification of the developed product functionally by UTM machine.

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Enhanced 5G spectrum management is facilitated by frequency reuse schemes

Rahul C. Pawar, Neha S. Shahare, Sujata Dandel, Akash Vanve, Om Pund

KJEI's Trinity Polytechnic Pune[#1], KJ college of Engineering Management and Research Pune

ABSTRACT

The growing demand for wireless communication services has resulted in a growth in the number of connected devices and data-intensive applications, putting enormous strain on the available radio frequency spectrum. The difficulties of spectrum scarcity and interference in modern wireless networks are addressed by the development of efficient spectrum management strategies, which is critical. An in-depth examination of the state-of-the-art in frequency reuse methods is provided by this survey article, with a focus on novel approaches that improve spectrum management. The primary goal of the study is to identify and evaluate alternative frequency reuse approaches offered to optimize spectrum utilization, decrease interference, and improve overall network performance. Subsequently, recent advancements and emerging frequency reuse schemes that address the limitations of traditional methods are delved into by the survey. These include adaptive frequency reuse, cognitive radio-based approaches, and software-defined networking techniques, among others. Each scheme is examined in terms of its key principles, benefits, and potential draw- backs. Key performance metrics such as throughput, spec- tral efficiency, interference mitigation, and overall system capacity are encompassed in the evaluation.

Introduction

Hand-held wireless devices have become an indispensable part of daily lives. The growing need for smartphones and tablets for applications such as live video meetings, group messaging, online gaming, and on-demand video streaming is leading to a rapidly increasing requirement for radio spectrum. Despite the increase in spectrum availability, which has evolved, the utilization of frequency in terms of resource management is considered very important in the deployment of telecommunications equipment and services. The efficient use of the available frequency will enhance user experience and will increase throughput and signal efficiency**.** With the current progress beyond the Fifth Generation (5G) communication systems, the coexistence of heterogeneous networks that provide effective wireless coverage to mobile subscribers and other wireless appliances in both indoor and outdoor environments is required to be supported by standards when compared to other Generations of telecommunication technologies (from 1G to 4G). Because high frequency is operated at by 5G, which limits the distance that can be covered, congestion is caused within the denser space of a geographical area, thereby requiring efficient utilization of the available frequency resources for service delivery to be improved by interference and congestion being reduced. Hence, significant improvement in spectrum efficiency is called for to support the increased number of users that will be using the same spectrum resource. In the process, the spectrum resource will then be reused more frequently, which will result in higher inter-cell interference. The frequent usage of the frequency resource is led to by the need for it. Frequency reuse is the method or scheme that requires the use of the same frequency band within a network in the geographical area in such a way that cells with the same frequency bands are placed far apart while cells with different frequency bands are placed adjacent back to back. Spectrum usage is optimized by frequency reuse; channel capacity is enhanced, and interference is reduced. The reuse plan is referred to as the scheme for recycling or reassigning the frequency channels throughout the coverage area. The reuse distance is called the distance between cells in the same cluster using the same frequency channel. Adequate channel isolation is ensured by the principal objective of the frequency reuse scheme to reduce channel interference while maintaining a high channel capacity.

ISBN: 978-93-343-2006-0

Background to frequency reuse

Frequency Reuse is the scheme in which channels are allocated and reused throughout a coverage region. A group of radio channels or Frequency sub-bands is allocated to each cellular base station to be used within a small geographic area known as a cell. The shape of the cell is Hexagonal. The process of selecting and allocating the frequency sub- bands for all of the cellular base stations within a system is referred to as Frequency reuse or Frequency Planning. Spectral efficiency and signal quality (QoS) are improved by frequency reuse. Protection against interference is offered by the classical frequency reuse scheme proposed for GSM systems. The tolerance capacity of the radio channel from the nearby transmitter using the same frequencies deter- mines the number of times a frequency can be reused. In the Frequency Reuse scheme, different sub-bands are used by cells from the total bandwidth that is divided. The same frequencies can be reused at different cell sites by WiMAX system operators through the frequency reuse scheme.

Cells with the same letter are assigned the same set of channels group or frequencies sub-band. To find the total number of channels allocated to a cell: S = Total number of duplex channels available to use k = Channels allocated to each cell

$S = kN;$

Frequency Reuse Factor = 1/N

$N = I^2 + I*J + J^2$

$C = MkN = MS$

$D = R*(3*N)^{1/2}$

The number of cells which collectively use the complete set of available frequencies is called a Cluster is represented by N. Where I, J = 0, 1, 2, 3... Hence, the possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19 and so on. If a Cluster is replicated or repeated M times within the cellular system, it is done. Co-Channel Cells are referred to as these cells. Interference is resulted from these Co-Channel cells. To avoid the interference, cells that use the same set of channels or frequencies are separated from one another by a larger distance. The distance between any two Co-Channels can be calculated. Where, R = Radius of a cell N = Number of cells in a given cluster

Fig 1. Frequency reuse technique of a cellular system

The distance between cells, the transmit power of each cell, and the modulation scheme used affect the SINR. An effort is made by the idea of SINR to portray these features. In particular, a receiver located at some point x in space (usually, on the plane) is considered. ()= P/1+N

- **Types of interference**

Co-Channel Interference (CCI)

The most significant type of interference that is directly resulted from frequency reuse is this. It is occurred when two or more cells that are not adjacent but use the same set of frequencies are transmitted simultaneously, and their signals are interfered with each other. Even though these "co-channel cells" are separated by a certain distance (the frequency reuse distance), the signals from base stations or mobile units in one co-channel cell can still be reached and interfered with in the reception of another co-channel cell. The signal-to-interference ratio (SIR or C/I) is degraded by CCI, leading to reduced call quality, dropped calls, and lower system capacity. A major factor in determining the frequency reuse factor (cluster size) in cellular network de- sign is this. This is primarily mitigated by careful frequency planning, ensuring sufficient spatial separation between co- channel cells (determined by the reuse pattern or cluster size), and techniques like power control, sectoring antennas, and smart antennas.

Example Calculation (for a 7-cell reuse pattern):

Let it be assumed:

$N=7$ (cluster size)

$N_I = 6$ (number of first-tier interferers)

$\gamma=4$ (path loss exponent for an urban environment)

First, Q is calculated:

$Q= 3N = 3\times7 = 21 \approx 4.58$

Now, the C/I ratio is calculated:

$I/C \approx 6/1\ (4.58)^4$

$I/C \approx 6/1\ (437.9) \approx 72.98$

To express this in decibels (dB), the formula $10\log_{10}(X)$ is used:

$C/I_{dB} = 10\log_{10}(72.98) \approx 18.63$ dB

Fig 2. Co-Channel Interference

Adjacent Channel Interference (ACI)

The occurrence of a signal from a channel adjacent in frequency to the desired channel is when interference happens with the reception of the desired signal. Even if different frequencies are assigned to adjacent cells, imperfections in receiver filters can cause spill over of signals from nearby frequencies into the desired channel. This is particularly problematic if the adjacent channel signal is much stronger than the desired signal. Distortion and reduced signal quality can be caused by ACI, especially when a strong adjacent channel transmitter is close to a mobile unit. Channels that are maximally separated in frequency are assigned to adjacent cells. Filters with sharp cutoffs are used to effectively block adjacent frequencies. The transmit power of mobile units or base stations is reduced when they are close to the receiver, thereby limiting the strength of the interfering adjacent signal.

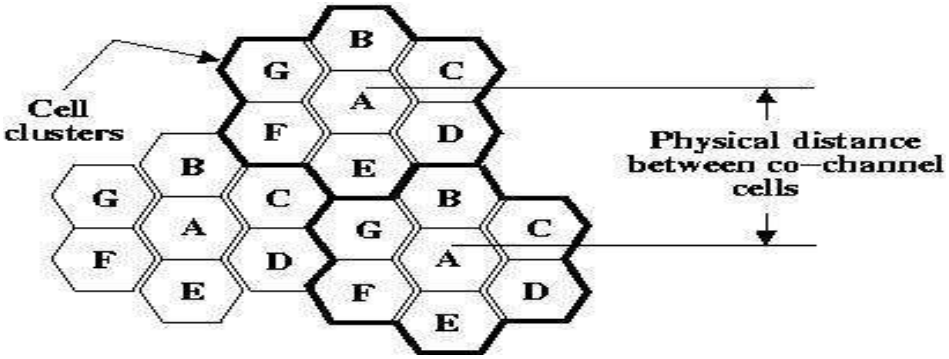
Fig 3. Adjacent Channel Interference

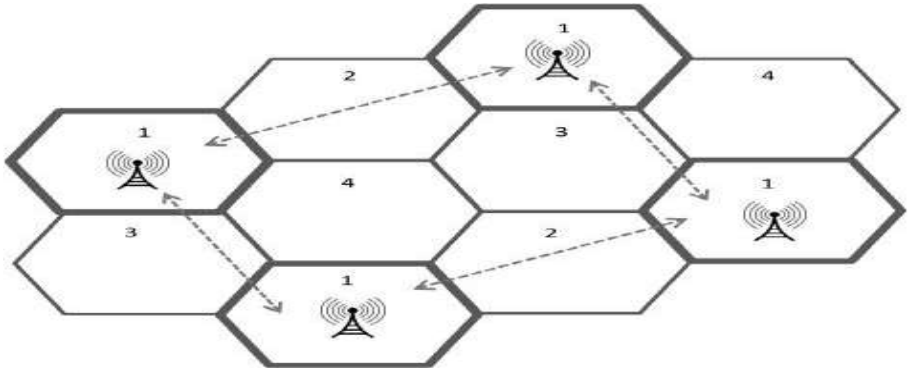
Adjacent Channel Interference can be reduced by the following factors:

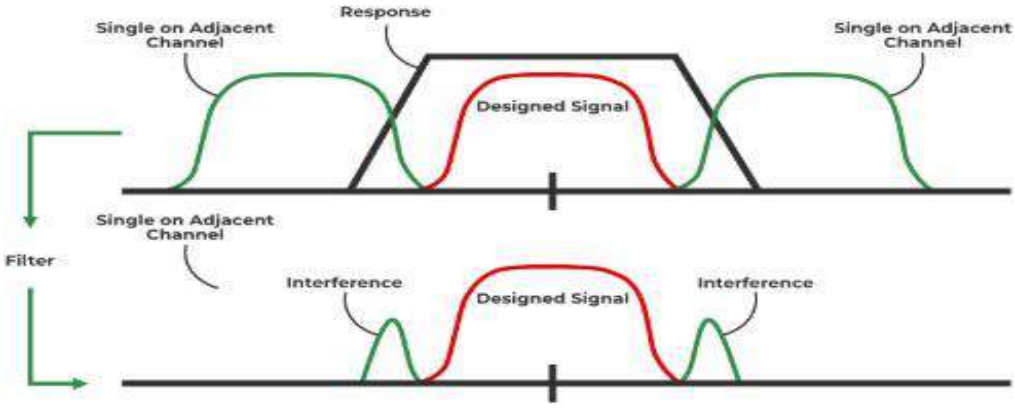
1. Proper filtering should be done.
2. Caution must be exercised when making channel assignments.
3. The space between two neighbouring cells should always be controlled and kept the same.

- Cluster:
  A cluster is defined as a group of cells that are assigned a unique set of frequencies.
- Reuse Factor (1/K):
  The reuse factor is represented by the proportion of the total available channels that can be used in each cell

ISBN: 978-93-343-2006-0


Cell clusters
Physical distance between co–channel cells
B
G
C
A
F
D
E


1
2
3
4


Single on Adjacent Channel
Response
Single on Adjacent Channel
Designed Signal
Filter
Single on Adjacent Channel
Interference
Designed Signal
Interference

within a cluster. For example, if K = 7, meaning each cluster consists of 7 cells, the reuse factor is 1/7. This indicates that only 1/7 of the available channels can be used by each cell in the cluster.

- Impact on Capacity and Interference:
  A lower reuse factor (larger K) is associated with a reduction in interference but also with a limitation on the number of users that can be accommodated in each cell. Conversely, a higher reuse factor (smaller K) is linked to an increase in capacity but also to a potential increase in interference.
- Frequency Planning:

Frequency reuse is carefully planned by cellular network designers to balance the conflicting objectives of maximizing capacity and minimizing interference.

Emerging Technology in Frequency Reuse Techniques :-

Below are some emerging technologies that have shown some level of prospects in frequency reuse application.

a. Optimization based on Machine Learning

Machine learning algorithms (e.g., deep learning, reinforcement learning, supervised/unsupervised learning) are involved in solving complex optimization problems in communication systems. Optimization of resource allocation, power control, routing, and network configuration can range from being performed to the prediction of channel conditions and user behaviour.

b. Cognitive Radio Networks

Cognitive radio (CR) is allowed by wireless devices to intelligently sense their environment, learn from it, and adapt their transmission parameters (e.g., frequency, power, modulation) to efficiently use the radio spectrum. The primary goal is to enable unlicensed users (secondary users) to opportunistically access spectrum bands that are temporarily unused by licensed users (primary users) without causing harmful interference.

c. Non-Orthogonal Multiple Access (NOMA)

NOMA is a multiple access technique in which the same time/frequency/code resources can be shared by multiple users. Unlike Orthogonal Multiple Access (OMA) schemes (such as OFDMA or TDMA) where users are kept separate, non-orthogonal transmissions are intentionally allowed by NOMA. This is typically achieved through power domain multiplexing, where different power levels are used to serve users, and successive interference cancellation (SIC) is performed at the receivers to separate the signals.

Fig 4. Non-Orthogonal Multiple Access

d. Frequency Reuse in Millimeter-Wave

A technique is known as frequency reuse, where the same frequency bands are used in different geographical cells to increase spectrum efficiency. In millimetre-wave (mm Wave) communications (typically 24 GHz to 100 GHz), the propagation characteristics are significantly different from those of lower frequencies (e.g., high path loss, sensitivity to blockages). This often necessitates that smaller cells and more directional antennas are used, which can lead to higher frequency reuse factors.

e. Techniques in the Spatial Domain

Technologies that exploit the spatial dimension of wireless propagation to improve communication performance are referred to. Key techniques are included:

- MIMO (Multiple-Input Multiple-Output): Multiple antennas are used at both the transmitter and receiver to create multiple parallel data streams, increasing capacity and reliability.
- Massive MIMO: An extension of MIMO with a very large number of antennas at the base station (typically tens or hundreds) is characterized.
- Beamforming: The radio signal energy is directed towards a specific user or direction, improving signal strength and reducing interference.
- Spatial Multiplexing: Independent data streams are transmitted over different antennas to increase data rates.
- Diversity Techniques: Multiple antennas are used to improve signal reliability against fading.

Fig 5. Massive MIMO

f. Configurations of Dynamic TDD/FDD

- TDD (Time Division Duplex): The same frequency band for both uplink (UL) and downlink (DL) communication is used, separated in time.
- FDD (Frequency Division Duplex): Separate frequency bands for UL and DL communication are used simultaneously.
- Dynamic TDD/FDD: The ability of a network to dynamically adjust the allocation of resources (time slots in TDD, or even potentially frequency assignments in FDD, though less common dynamically) between uplink and downlink based on real-time traffic demands is referred to. For TDD, this means the UL/DL slot ratio is dynamically changed.

g. Technologies for Advanced Antennas

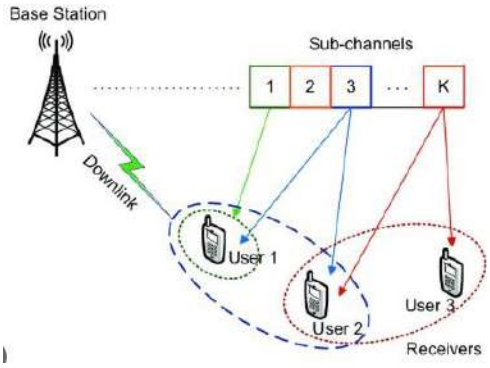
A wide range of antenna innovations beyond traditional designs is encompassed by this, which is crucial for modern wireless systems.

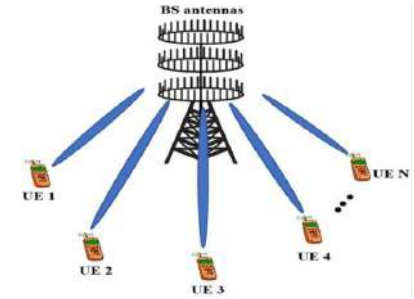
h. Slicing of Networks in 5G and Beyond

Network slicing is a key architectural concept in 5G that allows for multiple virtual logical networks to be run on top of a single shared physical network infrastructure. Each "slice" is isolated and customized with specific re- sources, topology, and functionalities to meet the diverse requirements of different applications, services, or vertical industries.

i. Secure Spectrum Sharing through Quantum Communication

This is a cutting-edge and more speculative area. Principles of quantum mechanics, particularly quantum cryptography (e.g., Quantum Key Distribution - QKD), are involved in securing the process of spectrum sharing in





wireless networks. Fundamentally unbreakable security for communication channels used to negotiate spectrum access or exchange control information could be provided

Conclusion

To sum up, an essential component of wireless communi- cation networks is frequency reuse, which maximizes spec- tral efficiency, controls interference, and improves network performance as a whole. Problems including throughput constraints, interference problems, and network congestion are solved through effective frequency reuse. The roots of efficient spectrum use are found in traditional frequency reuse systems, such as set frequency reuse patterns. Al- though success has been shown by these systems in a variety of contexts, difficulty is experienced in dynamically responding to shifting network conditions. More flexibility and adaptability are provided by advanced interference coordination approaches, such as fractional frequency reuse and spatial frequency reuse, which improve performance in dynamic and heterogeneous contexts. As new technology and methods arise, the field of frequency reuse is being changed. Promising solutions for dynamically resolving interference, improving throughput, and reducing congestion are offered by non-orthogonal multiple access (NOMA), machine learning-driven optimization, and cognitive radio networks. The potential to completely transform wireless communication is held by the combination of these new techniques with frequency reuse tactics as we approach 6G and beyond by reaching previously unheard-of levels of efficiency and dependability.

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e-KYC using Verifiable Credentials

Srirama Bandagadde
REVA Academy for Corporate Excellence,
REVA University, Bangalore, India
srirama.cs06@race.reva.edu.in
ORCID: 0009-0005-9690-4315

Abstract **-** The Know Your Customer (KYC) process is a critical procedure for any financial institutions and other regulated organizations to verify the identity of customers and assess potential risks before offering services. Traditional KYC methods typically involve manual procedures that can be cumbersome and time-consuming, often requiring the involvement of multiple authorities. These methods raise privacy concerns, as sensitive customer data is shared across different systems, increasing the risk of fraud and data breaches. To address these challenges, the adoption of Verifiable Credentials (VCs) offers a modern solution. VCs are digital credentials that securely confirm the authenticity and integrity of information. These credentials are issued by trusted entities, such as government bodies or financial institutions, and can be independently verified without needing to contact the issuer. This enhances the security of the KYC process by reducing the potential for fraudulent claims or human error. VCs also support the concept of *selective disclosure*, which allows users to share only mandatory pieces of their identity information, minimizing unnecessary exposure of personal data. For instance, a person might choose to share their age or citizenship status without disclosing additional sensitive details, such as their address or date of birth. This selective sharing is made possible through advanced cryptographic techniques, such as Boneh-Lynn-Shacham (BLS) signatures. BLS signatures are highly efficient, providing short signature lengths while ensuring fast and secure verification, making them ideal for scalable and secure applications. In summary, using Verifiable Credentials in the KYC process enhances security, efficiency, and privacy. By reducing the risk of fraud and enabling selective disclosure, VCs provide a more secure, user-friendly approach to verifying identities in financial services and other sectors.

Keywords **-** e-KYC, Digital Identity, Verifiable Credentials, Selective Disclosure

I. INTRODUCTION

The Know Your Customer (KYC) process is a critical procedure for financial institutions and other regulated organizations to verify the identity of their customers, assess potential risks, and comply with anti-money laundering (AML) regulations. Traditional KYC method involves the collection of physical documents such as passports, driver's licenses, and utility bills and verification of corresponding customer data. While it has been effective, it is often time-consuming, prone to errors, and vulnerable to identity theft and fraud.

In response to these challenges, the advent of electronic KYC (e-KYC) has revolutionized identity verification by enabling organizations to securely verify identities in a digital format. By leveraging Verifiable Credentials (VCs), a decentralized and cryptographically secure approach to digital identity management, e-KYC offers a more efficient, secure, and privacy-preserving alternative to traditional KYC methods.

Verifiable Credentials are digital representations of claims made about an entity (such as a person) and are issued by trusted authorities. These credentials are cryptographically signed, tamper-proof, and can be instantly verified by service providers without the need for a centralized database. This decentralization not only reduces the risk of data breaches but also empowers users by giving them full control over their personal data. The use of VCs in the e-KYC process enables organizations to authenticate a customer's identity quickly and securely while minimizing data exposure.

Figure 1 shows the Verifiable Credentials ecosystem with three participants Issuer, Holder and Verifier.

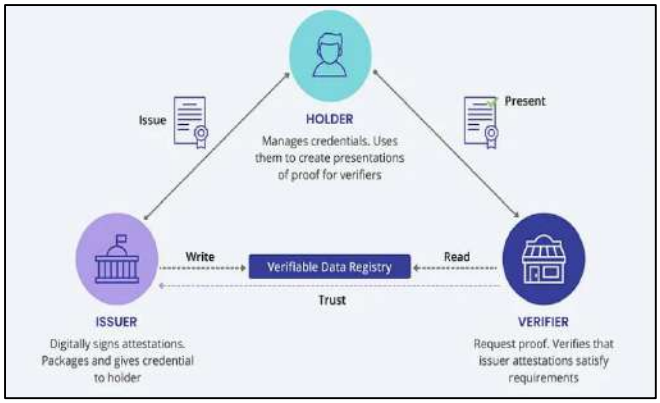


Figure. 1: SSI Ecosystem

Below mentioned approach describes on how VCs works Driving license as digital identity example:

The issuance process of a Verifiable Credential (VC) for a driving license begins with a trusted authority, such as a government agency or the department of motor vehicles (DMV), creating and issuing the credential. The VC contains essential details about the individual, including their name, license number, date of birth, license type, expiry date, and other pertinent information. To ensure the integrity and authenticity of the credential, the issuing authority digitally signs the VC, providing proof that it was issued by the trusted source. This digital signature guarantees the credential's validity and reliability.

The individual stores their Verifiable Credential (VC), such as a driving license, in a digital wallet, which is typically an app or software designed to support verifiable credentials. This wallet securely stores the VC and allows the holder to easily manage their credentials. With a self-sovereign identity model, the individual maintains full control over their data, ensuring both privacy and ownership. This approach gives the individual the ability to manage and share their credentials on their terms, without relying on centralized authorities.

When an individual needs to prove they hold a valid driving license, such as during a traffic stop or when renting a car, they can present their Verifiable Credential (VC) by scanning a QR code, or sharing a digital file. The verifier, such as a police officer or car rental agency, uses a special app or system to verify the authenticity of the VC by validating the digital signature and credential information through a public key infrastructure (PKI), without needing to contact the issuing authority directly. The individual can maintain privacy by sharing only the necessary information, such as confirming the validity of the driving license, while withholding personal details like their full name or date of birth. Additionally, verifiers can instantly check the VC against a revocation list to confirm whether the credential is still valid, ensuring real-time validation.

An important feature of this system is Selective Disclosure, which allows customers to share only the necessary and mandatorily required identity information for verification, ensuring privacy and compliance with data protection regulations. This process is made more robust through the use of BLS Signatures, which enable the aggregation of multiple credentials into a single, compact, and verifiable signature.

This e-KYC project, based on Verifiable Credentials, aims to modernize the customer verification process by incorporating cutting-edge cryptographic techniques and decentralized identity frameworks. It enhances security, privacy, efficiency, and user experience, providing a secure, streamlined, and regulatory-compliant solution for organizations in the digital age. Through the use of Verifiable Credentials and Selective Disclosure, this project promises to reshape how financial institutions and other organizations manage identity verification, offering a future-proof solution for the growing demand for digital-first services.

The rest of this document is structured as follows. Related literature works are reviewed in Section II. Section III explains the methodology of e-KYC using VCs with BLS signatures. Section IV explains VC issuance, presentation, and verification process with sample input and outputs. Section V describes the outcome of e-KYC API using Verifiable credentials. Section VI concludes the paper and shares future work.

II. Literature Review

Kuperberg [2] carried out a comprehensive review of technologies and approaches within the SSI domain and assessed the currently available SSI solutions. Čučko and M. Turkanovic [3] developed a systematic mapping of decentralized and self-sovereign identity (SSI) solutions, providing a structured overview of the existing landscape. K. Schmidt, A. Muhle, A. Gruner, and C. Meinel [4] conducted a systematic literature review to structure the SSI ecosystem. As part of the survey [5], the study examined the basic components of SSI, including identification, authentication, verifiable claims, and attribute storage.

Decentralized Identifiers (DIDs) [6] are a new class of identifiers designed to enable cryptographically verifiable and self-sovereign digital identities. DIDs are fully under the control of the user. They are globally unique and persistent, and they can be used to secure communication through cryptographic techniques [7]. DIDs work in conjunction with Distributed Ledger Technology (DLT) [8] to ensure that the identifiers are tamper-evident and can be resolved to reveal the DID Document.

Verifiable Credentials [9] are important element of the decentralized system, offering a secure and privacy-preserving way of sharing credentials. Verifiable Credentials provide a standardized, secure, and interoperable framework for digital identity verification and credential management. By incorporating cryptographic signatures, expiration dates, and selective disclosure mechanisms, VCs ensure that the integrity, authenticity, and privacy of digital credentials are maintained throughout their lifecycle.

Selective Disclosure [10] is an important feature of Verifiable Credentials that allows users to share only mandatorily required set of identity information with designated parties. Instead of presenting the entire credential, individuals can disclose only the necessary attributes, thereby enhancing privacy, minimizing data exposure, and maintaining greater control over their personal information.

BLS signatures were introduced by Boneh, Lynn, and Shacham in their paper on short signatures [11] where they proposed a method for constructing efficient digital signatures using bilinear pairings on elliptic curves. BLS (Boneh-Lynn-Shacham) signatures are a type of cryptographic signature scheme known for their efficiency, particularly in multi-signature settings and aggregate signatures. BLS signatures are having the ability to aggregate multiple signatures [12] into a single compact signature. This capability significantly reduces both the size and complexity of signature management, particularly in scenarios involving multiple signers. BLS signatures are widely regarded as secure cryptographic primitives that offer efficient and effective solutions for digital signature applications, particularly in contexts where aggregation of signatures and efficiency in verification are crucial.

InterPlanetary File System (IPFS) [13] is a decentralized protocol designed to create a peer-to-peer method of storing and sharing data in a distributed file system. As mentioned in IPFS paper [14], provides an in-depth analysis of the theoretical foundations and practical implementations of decentralized storage using IPFS, focusing on scalability, performance, and data integrity.

The literature review clearly indicates the advantages of Verifiable Credentials usage in e-KYC over traditional system by emphasizing benefits such as enhanced security, privacy, efficiency, and interoperability. e-KYC with Verifiable Credentials empowers individuals by giving them greater control over their personal data. Also, it is evident that lack of Selective disclosure of claims from multiple credentials and signature aggregation need to be addressed for enhanced user privacy and security.

III. Methodology

The methodology is divided into three phases as per three participants involved in the SSI ecosystem, namely the Issuer, Holder, and Verifier.

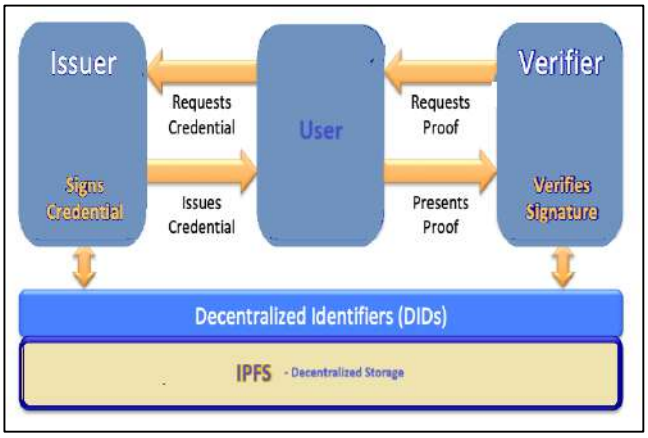


Figure. 1: SSI Ecosystem

Figure 2 shows the SSI ecosystem with three stakeholders to support the issuance to verification of Verifiable Credentials in e-KYC.

The Issuer plays a crucial role in the e-KYC process by issuing Verifiable Credentials (VCs) to users. These Issuers can be government agencies (like driver's license authorities), educational institutions, employers, or other trusted organizations. Before issuing a VC, the Issuer rigorously verifies the user's identity through checks such as document verification, biometric authentication, and background checks. Once verified, the Issuer creates a VC containing the user's attributes and digitally signs it using their private key to ensure the VC's authenticity and integrity.

The User is the individual who holds and manages Verifiable Credentials (VCs). They receive VCs from authorized Issuers and are responsible for storing and managing them securely. When a Verifier requests proof of identity, the User presents the relevant information from their VC. Importantly, the User has the control to selectively disclose only the necessary attributes from their VC, enhancing their privacy and control over their personal information.

The Verifier is the entity that requests and verifies the authenticity of Verifiable Credentials (VCs) presented by Users. Examples of Verifiers include banks, insurance companies, employers, and government agencies. When a Verifier needs to verify a user's identity, they request proof from the User. They then retrieve the VC from the designated storage, verify the Issuer's digital signature to ensure its authenticity, and check the validity of the attributes within the VC. Based on the verification results, the Verifier makes decisions, such as approving loan applications or granting access to services.

Verifiable Credentials (VCs) are digital records of user attributes that are cryptographically signed by an Issuer. These credentials are designed to be machine-readable and interoperable across different systems. Key features of VCs include: containing structured data about the user (e.g., name, date of birth, qualifications), being digitally signed by the Issuer to ensure authenticity and integrity, adhering to standardized formats like the W3C Verifiable Credentials Data Model to enable seamless exchange across various platforms, and providing a secure and reliable way to represent and share identity information.

In a typical SSI ecosystem, all attributes issued by the Issuer will be shared with the Verifier resulting in potential Privacy concerns. To address this privacy concern, BLS Signatures are used in this project. Boneh-Lynn-Shacham (BLS) signatures are a type of digital signature scheme that offers several unique advantages over traditional signature schemes like ECDSA (Elliptic Curve Digital Signature Algorithm).

BLS signatures produce short signatures compared to other signature schemes. This is beneficial for efficiency in terms of storage and transmission of signatures. Using the aggregate feature of BLS signatures, if you have n signatures from n different parties, you can aggregate them into one signature without needing access to the underlying messages. This property is particularly useful in scenarios where multiple parties need to sign the same message or set of messages, such as in multi-party transactions or threshold signatures. Unlike some other signature schemes, BLS signatures do not require a complex key distribution mechanism for multi-party scenarios. Each party can independently generate their key pair (private and public keys), and the aggregation can be performed later without requiring interaction among the signing parties. This property simplifies verification and ensures consistency.

IV. Implementation

The Verifiable Credentials Ecosystem for e-KYC involves the development of three APIs for Issuer, Holder and Verifier using JavaScript and NodeJS. Private and Public Key pairs will be created for the Issuer and Holder using crypto and BLS Signatures SDK methods. This is a one-time activity and these keys will be used for Digital Signatures for VCs. DID will be created for the Issuer and Holder.

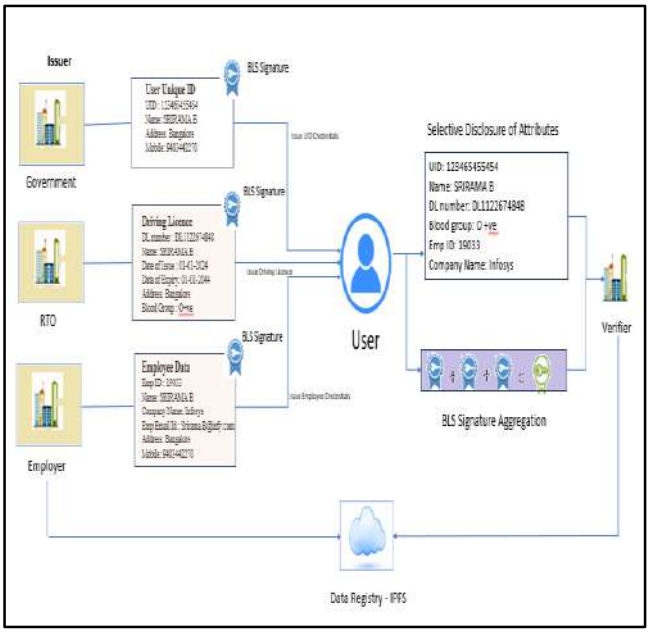


Figure. 3: Overall e-KYC Process Diagram

Figure 3 shows the overall e-KYC process followed in this project. To cover the end-to-end flow of e-KYC issuance to verification, three REST APIs have been created as described below:

A. Verifiable Credentials Issuance

The Issuance process is the foundation of the e-KYC system using Verifiable Credentials (VCs).

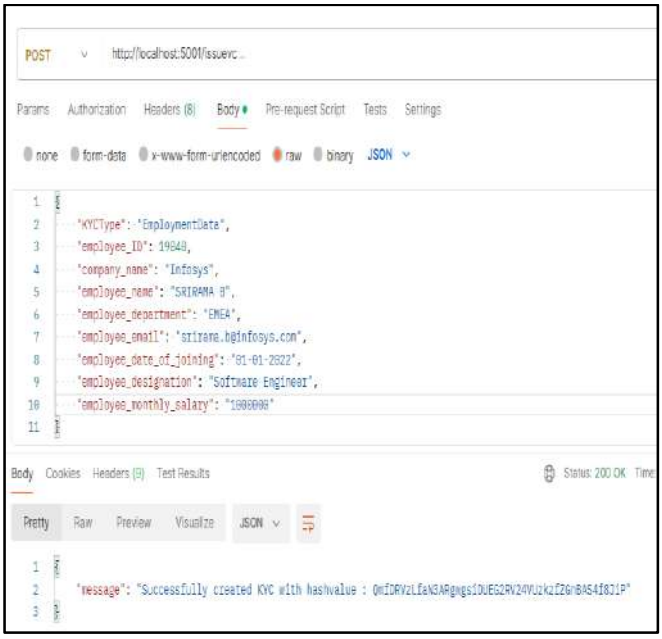


Figure. 4: Issuer API

It begins with rigorous identity verification conducted by the Issuer, such as examining physical or digital copies of IDs, conducting biometric checks, and potentially performing background checks. Once the user's identity is confirmed, the Issuer creates a VC containing the verified attributes. This VC is structured in a standardized format, often following the W3C Verifiable Credentials Data Model, to ensure interoperability across different systems. Issuer digitally signs the VC using their private key. This digital signature acts as a cryptographic seal, guaranteeing the authenticity and integrity of the VC. It also serves as proof that the Issuer is the legitimate source of the credential, establishing trust in the VC. Once signed, the VC is stored in IPFS, generating a Content Identifier (CID) for confirmation.

The e-KYC is then issued to the user as this CID. The request body includes user details and credential information in JSON format, while the response provides the signed VC as a content-based hash. Additionally, Figure 4 illustrates the sample request and response details for the Issuer API.

B. Verifiable Presentation Creation

The Presentation process is the stage where the User shares their Verifiable Credential (VC) with the Verifier. When the Verifier requests proof of identity, the User initiates the presentation process. A key aspect of this process is the User's ability to selectively disclose only the necessary attributes from their VC. This selective disclosure gives the User control over their personal information, enhancing their privacy. The User can choose which specific pieces of information to share with the Verifier, minimizing the amount of sensitive data revealed. This granular control over data sharing is a significant advantage of using VCs for e-KYC. The response provides a signed verifiable presentation as a content-based hash, with Figure 5 illustrating the sample request and response details for the User API.

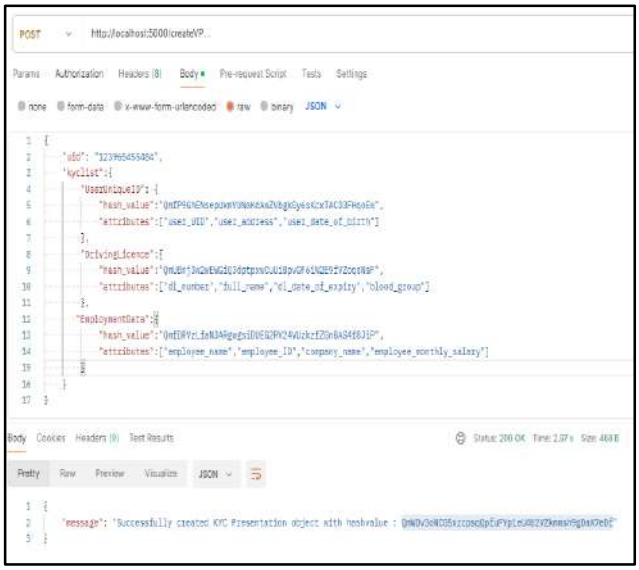


Figure. 5: User API

C. Verifiable Credentials Verification

The Verification process is a critical step in the e-KYC system where the Verifier ensures the authenticity and validity of the presented Verifiable Credential (VC). The process begins with the Verifier retrieving the VC from the designated storage, often a decentralized system like IPFS. The Verifier uses the Issuer's public key to verify the digital signature applied on the VC. This step is critical as it confirms that the VC was issued by the claimed Issuer and has not been

tampered with any other participants. Following this, the Verifier meticulously checks the validity of the attributes within the VC. This may involve data validation (e.g., checking date formats, verifying address validity) and revocation checks to ensure the VC has not been revoked by the Issuer. Based on the successful verification of the signature and attributes, the Verifier can proceed with the requested transaction or service, such as approving a loan application or granting access to a service. The request body contains the CID of the Verifiable Presentation in JSON format, and the response provides the verification outcome along with a list of attributes disclosed by the user as part of the e-KYC. Figure 6 illustrates the sample request and response details for the Verifier API.

The above-mentioned design of Issuer, User and Verifier APIs can support any number of use cases with valid input payload agreement between all the three participants in the ecosystem. Verifiable Credentials ecosystem implemented for e-KYC solves the issues faced in traditional KYC systems and also helps to achieve all the objectives in an efficient way as part of this project. This cryptographic method to issue, store, and verification of credentials also empowers the users to have control over their data achieving enhanced privacy and security.

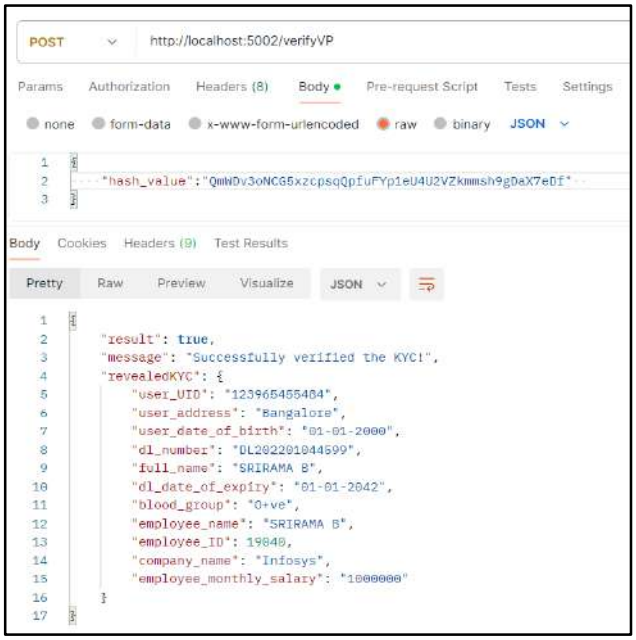


Figure. 6: Verifier API

V. Analysis and Results

Verifiable Credentials are a pivotal technology in modernizing e-KYC processes, offering a secure, efficient, and privacy-preserving method for representing and verifying user attributes. As digital transformation accelerates across industries, the adoption of VCs promises to enhance trust, compliance, and operational efficiency in identity management and verification as part of e-KYC.

The e-KYC process leverages digital representation through JWTs with BLS signatures to modernize and secure customer identity verification, enhancing integration, automation, and security. VCs are tamper-proof and cryptographically secure, stored in IPFS for decentralized and immutable access, ensuring they cannot be altered. Following W3C standards, VCs allow for instant generation and verification without manual intervention which eliminated the need for a central authority and thereby reducing data breach risks while enhancing user trust and control over their credentials. The system supports selective disclosure, enabling users to share only necessary attributes during Verifiable Presentation creation, facilitated by BLS signatures. Additionally, the APIs accommodate multiple use cases, including Government-issued User Unique ID, Driving License, and Employment data, each with a structured payload.

Traditional digital KYC systems rely heavily on centralized databases and require users to submit full identity documents such as scanned Aadhaar cards, PAN cards, or utility bills which are then verified through API calls to issuing authorities or manual checks. This approach often leads to excessive data sharing, as users are forced to disclose more information than necessary, increasing the risk of privacy violations and data breaches. Verification is dependent on real-time connectivity with central servers, making the system less reliable in offline or low-connectivity environments. Additionally, traditional KYC documents can be easily tampered with, leading to higher fraud risks, and revocation or expiration is difficult to track in real time. Consent mechanisms are usually vague or one-time, offering limited control to users over how their data is used.

In contrast, e-KYC based on Verifiable Credentials (VCs) introduces a privacy-first, user-centric, and decentralized model. Credentials are digitally signed and issued by trusted authorities, then stored securely by the user in a digital wallet. When needed, users can share only the specific pieces of information required such as proving their age or address without exposing the entire document. These credentials are tamper-proof, can be verified offline using cryptographic proofs, and do not require constant access to the issuer's database. Revocation and expiry can be checked instantly through registries or ledgers. VC-based systems also enable explicit and ongoing user consent, aligning better with data protection regulations like GDPR and India's DPDP Act. Overall, VC-based e-KYC is faster, more secure, cost effective, and scalable, while significantly enhancing privacy, trust, and user experience across industries.

VI. Conclusions and Future Scope

The combination of IPFS for decentralized data storage and Verifiable Credentials for digital identity management holds tremendous potential to transform how personal data is handled securely and efficiently. By leveraging these technologies, organizations can enhance security, privacy, and compliance while providing individuals with greater control over their digital identities and credentials in an increasingly digital world. This approach not only mitigates risks associated with identity theft and fraud but also paves the way for innovative applications across various sectors. Selective Disclosure allows users to share only the mandatorily required information as part of the verification process. For example, if a service requires proof of age, the individual can disclose

only their birth date from a Verifiable Credential, without revealing other personal details like their name or address. The privacy-preserving aspect of VCs is important in terms of regulations like the General Data Protection Regulation (GDPR) in the EU and the California Consumer Privacy Act (CCPA) in the US. By allowing individuals to prove their e-KYC data without revealing any additional information, VCs help organizations maintain compliance with these data protection laws.

Mobile apps can significantly enhance the user experience when it comes to managing Verifiable Credentials. By leveraging mobile apps, users can easily store, access, and share their credentials securely and conveniently. A common method for sharing VCs is through QR codes, which can be scanned using a smartphone or any other devices. This process simplifies and speeds up the verification process.

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A Blockchain-Based eVault For Legal Records

[1]. Shalaka Bibikar
Research scholar
Department of Computer Engineering
K J College of Engineering & Management Research,
Pune, Maharashtra 412205.
Email: shalakabibikar23@gmail.com

[2] Aparna Hambarde
Assistant Professor
Department of Computer Engineering
K J College of Engineering & Management Research,
Pune, Maharashtra 411048.
Email: aparnahambarde..kjcoemr@kjei.edu.in

***ABSTRACT* :- The research introduces a Blockchain-Based eVault for Legal Records (BEvLR), designed to address the shortcomings of traditional legal record management systems. The InterPlanetary File System (IPFS) and blockchain technology are integrated by the BEvLR to guarantee the secure, transparent, and immutable storage of legal documents. Documents are safeguarded from tampering, unauthorised access, and alterations by utilising the decentralised ledger of the blockchain. In order to guarantee that only authorised personnel, including lawyers, clients, and judges, have the ability to access or modify the documents, the system implements role-based access control (RBAC). Furthermore, the incorporation of an audit trail improves accountability and transparency by monitoring document interactions. The research demonstrates how this system improves the security, integrity, and scalability of legal document management, providing a foundation for future advancements like smart contract integration to automate legal processes.**

Keywords - Blockchain Technology, Legal Records, eVault, Data Security, InterPlanetary File System (IPFS).

I. INTRODUCTION

The management and storage of legal records are critical components of the legal system, as they maintain the integrity and authenticity of sensitive documents[1]. Traditional methods of storing these records, such as physical archives and centralized databases, often expose legal data to security risks, unauthorized access, and potential alterations[2]. A more sophisticated, tamper-proof solution is urgently required due to the growing demand for secure and efficient legal document management.[3]. The decentralised and immutable character of blockchain technology offers a transformative solution for the secure storage and management of documents [4]. It guarantees that a document cannot be altered or tampered with after it is published by utilising the cryptographic features of blockchain technology, thereby providing verifiable proof of authenticity [5]. The storage capabilities are improved by the incorporation of InterPlanetary File System (IPFS), which provides simple retrieval and decentralised and secure file storage[6].This research suggests the creation of a Blockchain-Based eVault for Legal Records (BEvLR), a system that is designed to resolve the current deficiencies in legal document administration [7]. The system employs role-based access control to guarantee that only authorised users, including attorneys, clients, and judges, have the ability to access or modify the records [8]. Additionally, all document interactions are tracked in a verifiable audit trail, enhancing transparency and accountability [9]. The system is designed to serve as a foundation for future advancements, including the integration of smart contracts to automate legal processes and improve scalability [10]. The BEvLR system will not only improve the security and integrity of legal records but also provide the necessary infrastructure for future advancements in legal technology, such as smart contracts for automating legal processes. Additionally, the research explores how the system's scalability could support the growing demands of the legal industry, ensuring that it can evolve with emerging needs [11].

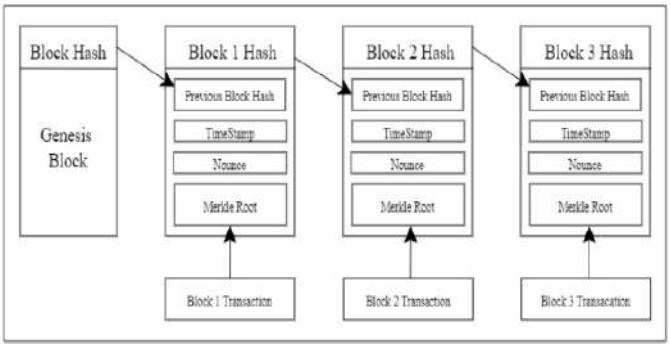


Fig 1. Blockchain Proposal [12]

The emergence of blockchain technology has created new opportunities for digital record-keeping and safe data management, particularly for sectors like the legal industry where data integrity and authenticity are critical [13]. Blockchain is a distributed and decentralized ledger system that stores data on many computers, guaranteeing that it is visible, safe, and unchangeable [14]. since of these characteristics, it is the perfect technology for handling private legal documents since it removes the possibility of illegal data changes and offers an auditable record for each transaction [15]. The paper aims to contribute to the ongoing exploration of blockchain applications in legal services, proposing a secure, efficient, and innovative solution for

managing legal records [16]. The Blockchain-Based eVault for Legal Records (BEvLR) will address critical issues that traditional legal document management systems face, particularly concerning security, transparency, and data integrity. With blockchain's decentralized ledger technology, once a document is uploaded to the system, its data becomes immutable, ensuring that the document cannot be tampered with, altered, or deleted without leaving an indisputable trace. This guarantees that all legal records remain authentic and reliable. The integration of IPFS (InterPlanetary File System) further enhances the system's functionality by providing a decentralized, distributed storage system. This allows legal documents to be stored securely while ensuring that they can be retrieved efficiently. IPFS's decentralized nature ensures that files are not stored in a single, centralized server, reducing the risk of data loss or unauthorized access due to server failures or hacking attempts.

II. Related Works

Pallavi R et al. (2023) discussed the implementation of blockchain for legal record management, highlighting how blockchain's decentralized and immutable features can prevent tampering and ensure data integrity. They explain that traditional legal record systems are prone to inefficiencies and security issues, which blockchain addresses by offering secure and transparent transactions. Additionally, they emphasize the potential of smart contracts to automate legal processes, enhancing efficiency and accuracy in record management. The study demonstrates blockchain's ability to improve trust and transparency in legal systems, making it a promising solution for the future of legal record-keeping[17].

Kakarlapudi, P.V., and Mahmoud, Q.H. (2021) discussed the development of a blockchain-based system for private data management in their study. They highlight the importance of blockchain's decentralized and immutable nature in ensuring the privacy and security of user data, particularly in sectors like healthcare and data management. The authors present a proof-of-concept prototype developed using Hyperledger Fabric, a permissioned blockchain platform, to enhance data privacy and consent management. Their system ensures that sensitive data is protected from unauthorized access and exploitation while maintaining transparency to build user confidence[18].

Swetha R et al. (2024) discussed the development of a blockchain-based eVault for legal records, addressing challenges in legal document management. They highlight how blockchain technology's decentralized structure and immutable ledger ensure data integrity, authenticity, and accessibility, offering a secure solution for storing and managing legal documents. The authors emphasize the use of smart contracts and cryptographic techniques to automate verification, access control, and auditing, enhancing security and streamlining operations. The system also ensures compliance with legal standards and provides a transparent, auditable record of all interactions, fostering trust and accountability among stakeholders[19].

Yeshwantrao, S.A., Satpute et.al (2024) proposed an innovative solution for managing legal records through blockchain technology in their work on eVault. The authors emphasize how blockchain's decentralized architecture and immutability overcome traditional challenges in legal record management, such as data tampering and fragmented access. The system they introduce ensures secure, tamper-proof storage for legal documents like contracts and court records, providing confidentiality through encryption. They argue that by combining blockchain's transparency with user-friendly interfaces, the eVault can greatly enhance the management and accessibility of legal records, fostering trust and security in legal processes[20].

Pratima Sharma et.al (2020) proposed cloud technology gained popularity in recent years because of its efficiency and availability, which have shown promise in both academics and business. Despite being a widely used technology, the explosion of data sources has led to a rise in storage and use issues since traditional data management tools are unable to handle the rapidly expanding data. In the original cloud storage notion, The network may be the internet or an intranet, the front end platform can be a client or mobile device, and the back end platform can be a server or data storage[21].

Naveen Kumar et.al (2020) proposed the two main issues that users of e-health systems worry about are security and privacy of personal health information. Unauthorised users, including third-parties, should not be able to connect the owners of outsourced e-health records to them for privacy concerns. In order to achieve unobservable outsourced data access as well as data integrity, this paper suggests a symmetric, key-based strategy which uses multiple networks and blockchain. Blockchains enable forward secrecy, a crucial security need that prevents a medical health care professional from seeing any future health documents after her session ends[22].

Mahalakshmi, B. et.al (2024) proposed a blockchain-based eVault system for managing legal records in their study. They discuss how blockchain technology ensures the security, transparency, and immutability of legal documents by leveraging decentralization and cryptographic protocols. The system includes functionalities for user registration, document upload, and

judge review, with all actions securely recorded on the blockchain. By integrating Interplanetary File System (IPFS) for document storage, the eVault ensures end-to-end encryption and tamper-proof data storage. Their work highlights the potential of blockchain to provide reliable, transparent, and efficient solutions for legal document management, while fostering trust in the legal system through immutable records of judgments and metadata[23].

Jadhav, V., Jadhav et.al (2025), presented SecureChain, a blockchain-based e-vault system for legal records. They propose a solution that addresses the limitations of traditional legal record-keeping systems, such as tampering, lack of transparency, and inefficient workflows. By using Ethereum smart contracts and IPFS, SecureChain ensures the tamper-proof storage and secure management of case records. The authors also discuss the integration of Aadhaar-based authentication and MetaMask for identity verification, along with role-based access control for lawyers, judges, and clients. Their system automates judge allocation through verifiable random functions (VRFs) and tracks case progress in real-time, providing transparent access to public case metadata[24].

Dinde, S., and Shirgave, S. (2024) discussed a decentralized legal document storage and access framework using blockchain technology in their paper. They emphasize the challenges faced by the legal sector due to traditional centralized systems that expose legal documents to risks like unauthorized access and tampering. Blockchain provides a solution through its decentralized ledger, ensuring data integrity and security. The authors propose using a permissioned blockchain to manage document metadata while storing actual documents off-chain for efficiency. They also implement a Role-Based Access and Security model (RBAS) to ensure that only authorized personnel can access sensitive legal documents[25].

III. Methodology

Here, this study proposes a Blockchain-Based eVault for Legal Records (BEvLR) system to enhance the security and integrity of legal document management[26]. The methodology integrates blockchain technology and the InterPlanetary File System (IPFS) with role-based access control (RBAC) to ensure secure, transparent, and immutable storage of legal documents. The approach is validated through a systematic process that ensures robustness and efficiency.

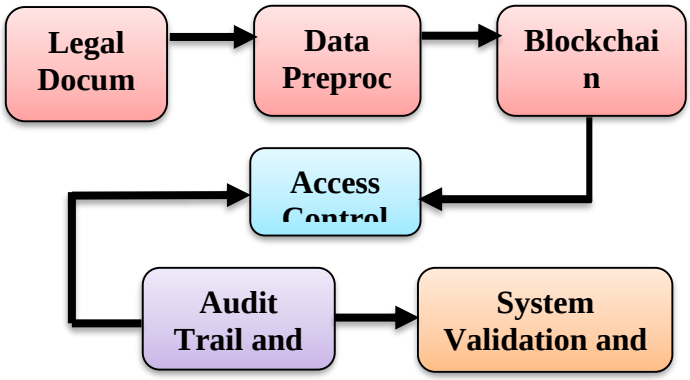


Fig. 2. The Flow Diagram of the Proposed Work

The process involves multiple stages:

Legal Documents Upload: Legal documents are initially selected for upload into the BEvLR system. The documents are securely uploaded using IPFS to ensure decentralized storage. Data Preprocessing and Encryption: Preprocessing operations, such as data encryption and file verification, are carried out to guarantee that the documents are securely stored and ready for blockchain integration. This step ensures that no unauthorized access or modification is possible[27]. Blockchain Integration and Validation: Once uploaded, documents are associated with a unique IPFS hash, and the transaction is recorded on the blockchain. This ensures that any interaction with the document, such as access or modifications, is transparent and traceable. Blockchain's decentralized ledger ensures that document integrity is maintained[28].

Access Control: Role-based access control (RBAC) ensures that only authorized users (lawyers, clients, judges) can access or modify documents. The system verifies user credentials through secure authentication processes, providing differentiated access based on the role of the user[29].

Audit Trail and Smart Contracts: An audit trail is automatically created for every interaction with the document, enhancing transparency and accountability. The system’s potential integration with smart contracts is explored to automate document processing and legal workflows, improving operational efficiency[30].

System Validation and Performance Metrics: The system is validated through simulated use cases and feedback from stakeholders. Metrics such as security, transparency, and data retrieval efficiency are measured to assess the system's effectiveness. The system’s scalability is also tested to ensure it can handle increasing data volumes without compromising performance[31].

Algorithm: Blockchain-Based eVault for Legal Records (BEvLR)

Start

Input: User selects a legal document to upload.

Upload Document to IPFS:

Upload the selected document to the InterPlanetary File System (IPFS).

Generate a unique IPFS hash for the document.

Encrypt Document:

Encrypt the document using AES encryption.

Hash the encrypted document using SHA-256.

Store Metadata on Blockchain:

Create metadata including the IPFS hash, timestamp, and user details.

Store this metadata on the blockchain to ensure immutability and traceability.

Authenticate User:

User logs in by providing credentials.

Validate credentials using JWT tokens and assign a role (lawyer, client, judge).

Grant Access Based on Role:

Based on the role (stored in JWT), grant access permissions (read, write, modify) to the document.

Track Interactions (Audit Trail):

Record all document interactions (view, modify, etc.) on the blockchain for accountability.

Execute Smart Contracts (Optional):

If needed, use smart contracts to automate document workflows (e.g., approval, review).

End

This algorithm encapsulates the core steps for securely managing legal documents, ensuring data integrity, and providing role-based access control.

IV. RESULTS AND DISCUSSION

Here, this study explores the development and implementation of the Blockchain-Based eVault for Legal Records (BEvLR), a system designed to address the challenges faced by traditional legal record management methods. By integrating blockchain technology and the InterPlanetary File System (IPFS), this research investigates how these advanced technologies can enhance the security, integrity, and transparency of legal document storage and management. The study evaluates the effectiveness of the BEvLR system in safeguarding legal records and explores its potential for future advancements in the legal sector.



Fig 3. Lawyer Login Interface

The figure depicts the login screen of the Blockchain-Based eVault for Legal Records. It includes role-based logins for Lawyer, Client, and Judge users. The roles are icon-based, making it convenient for users to choose their role prior to login. The Lawyer Login area is live, in which the user (here "lawyer1") is invited to input the username and password. Once the credentials are input, the Login button can be pressed to gain entry into the system. The design is such that it is user-friendly, with a strong focus on role selection and safe authentication, so that each category of user enters only the applicable features of the legal document management system.

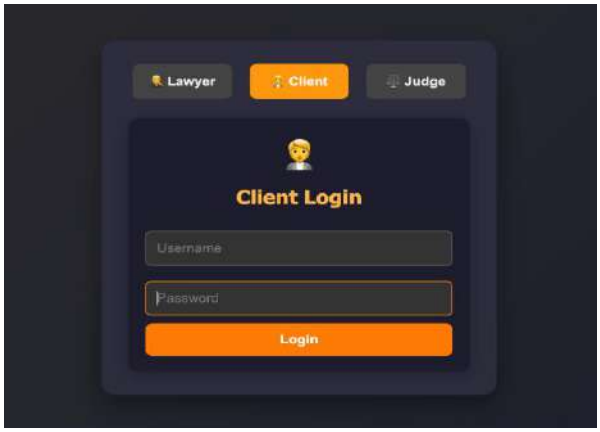


Fig 4. Client Login Interface

The figure shows the Client Login Interface for the Blockchain-Based eVault for Legal Records system. Similar to the lawyer login, the Client login section is highlighted, where users can log in by selecting the Client role. In the Client Login section, the user is prompted to enter their username and password. After entering the correct credentials, the Login button can be clicked to access the system. The interface is designed for easy navigation, ensuring that clients can securely access their relevant documents and features, while maintaining proper

access control based on user roles.



Fig 5. Judge Login Interface

The figure shows the Judge Login Interface for the Blockchain-Based eVault for Legal Records system. Similar to the Lawyer and Client login, the Judge Login section is highlighted, where users can log in by selecting the Judge role. In the Judge Login section, the user is prompted to enter their username and password. Once the correct credentials are provided, the Login button can be clicked to gain access to the system. This interface is designed for easy navigation and role-based access control, ensuring that judges can securely access the relevant legal documents and features within the system.



Fig 7. Successful Document Upload to IPFS

This figure represents the confirmation message displayed after a successful document upload to IPFS in the Blockchain-Based eVault for Legal Records system. The notification at the top of the screen shows the message "Document uploaded successfully!" confirming that the user's selected document, "sample-document.docx", has been successfully uploaded to IPFS. The user can now proceed to either Display IPFS Hash to view the unique identifier for the document or continue with other tasks. The interface also provides an option to Logout once the task is completed. This message assures the user that their document has been securely stored and can be retrieved later using its IPFS hash.

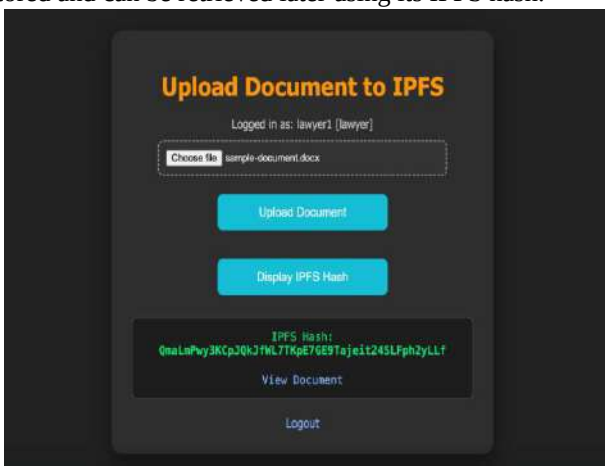


Fig 8. Display IPFS Hash after Document Upload

This figure shows the successful display of the IPFS hash after a document has been uploaded to the Blockchain-Based eVault for Legal Records system. After uploading the document, the system generates and displays the IPFS hash for the uploaded file, in this case, "QmaLmP..." which serves as a unique identifier for the document stored on IPFS. Additionally, the system provides a View Document option that allows the user to access the document using the generated IPFS link. This link ensures secure retrieval of the document in a decentralized manner. The Logout button is also available for the user to end their session once the task is complete. This interface ensures that the uploaded document can be easily accessed and tracked using its unique IPFS hash.

V. CONCLUSION

The Blockchain-Based eVault for Legal Records (BEvLR) offers a transformative solution for the secure and efficient management of legal documents. By combining blockchain technology with IPFS, the system ensures data immutability, transparency, and secure storage, addressing the vulnerabilities present in traditional legal record-keeping systems. Role-based access control and an audit trail enhance security and accountability, providing a clear and verifiable history of document interactions. The BEvLR system's scalability allows it to handle increasing volumes of data, making it a future-proof solution for the legal industry. This research shows that blockchain technology can effectively revolutionize legal document management, improving both security and operational efficiency, while setting the stage for future innovations

like automated legal processes via smart contracts.

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Depression Recognition Using Optimal Feature Selection - CNN Model

[1]Mrs. Pradnya Shinde
Assistant Professor
Department of Computer Engineering
SCSCOE, Dhangawadi,
Pune, Maharashtra 412205.
PG Student, KJCOEMR, Pune, Maharashtra 411048.
Email: pradnya2206@gmail.com

[2]Dr. Umar Mulani
Assistant Professor
Department of Computer Engineering
K J College of Engineering & Management Research,
Pune, Maharashtra 411048.
Email: umarmulani.kjcoemr@kjei.edu.in

ABSTRACT **– A machine learning (ML) model is proposed by the review of the literature to help diagnose depression condition. A self-report questionnaire can be used to diagnose depressive disorder, but mood evaluation and the consistency of subjective and objective observations need to be confirmed. Millions of people worldwide suffer from depression. It is possible for people with the same illness to have different mental health conditions. Video-recorded clinical sessions are analyzed to determine the severity of depression. An estimated 350 million people worldwide suffer from depression. People with depression frequently find it difficult to concentrate on their work in the software sector. When diagnosing depressive illnesses, camera-based technologies can speed up the process and provide useful information for intervention plans. Through the use of CNN, a deep learning technique that decodes vector-based data, a model for diagnosing depressive disorders can be developed by tracking eye and lip movements and determining emotional states from a set of images taken of individuals who will regularly be evaluated for depression.**

Index Terms - CNN, depressive disorder, deep learning, facial expression.

I. INTRODUCTION

Emotions are crucial to our experience. While many people feel joy, surprise, and fear in different proportions, they also occasionally experience sadness, loneliness, or depression. These feelings are typical reactions to personal difficulties, the loss of possessions, or a decline in one's sense of value. Prolonged periods of these feelings may be associated with physical symptoms that prevent people from leading normal, active lives while also indicating depression.

The user is continuously tracked by a camera installed within the system. Facial expressions are captured by analyzing their lip and eye movements. A model to help diagnose depressive disorders is created using CNN, a deep learning method that recognizes vector-based data. Next, this model is assessed in conjunction with a framework for emotion detection that has already been trained. When depression symptoms are found, they are entered into the database. Positive and negative emotions are just two of the many ways that depression can manifest.

While wrath, despair, or depression are examples of negative emotions, love, laughing, and joy are examples of positive emotions. Many deaths may result from negative emotions, which can be widespread and quite intense. Depression is a prevalent and dangerous illness that can impact one's mental and physical health. It has an impact on a person's feelings, ideas, and actions. Depression is categorized as a behavioral and mental illness. Depression is scientifically linked to a number of things, including personal experiences, major health problems, and chemical abnormalities in the brain. A serious and mostly inevitable public health issue is suicide. The most common cause of suicide is depression. Suicide rates rise as a result of the physical and mental health issues that sad people experience. Numerous factors, including substance addiction, emotional, sexual, and physical abuse, interpersonal problems, the loss of a loved one, and chronic, severe illness, can contribute to depression.

In order to shed light on the nuances of feature extractio n, data collection, model architectures, and training meth odologies, the goals are to demonstrate the practical appl ications of depression detection and investigate the basic strategies used in the creation of depression detection sy stems.Through extensive research, performance evaluati ons, and empirical analysis, this study aims to demonstra te the effectiveness of depression detection systems and t heir potential influence on clinical practice and public he alth initiatives. In order to promote cooperation, creativity, and more research in this quickly developing field, the aim

of this work is to provide insight into the developments and difficulties in depression detection systems. By supporting the creation of more strong and trustworthy depression detection systems, it ultimately aims to improve the lives of those who suffer from depression and advance mental health.

Traditional methods often rely on manual examinations and structured questionnaires, which can overlook subtle nuances and individual variations in depression symptoms. Additionally, the subjective nature of self-reporting, coupled with the stigma surrounding mental health, can make accurate diagnosis and effective intervention more difficult.

II. RELATED WORK

KAI SHAO, YANJIE LIU, YIJUN MO [1] Early detection and treatment of depression are essential for achieving full recovery. However, traditional clinical assessments depend heavily on patient participation, the expertise of healthcare providers, and the use of diagnostic tools. According to recent studies, a promising method for diagnosing depression is functional near-infrared spectroscopy (fNIRS) based on deep learning. However, it is still difficult to gather sizable fNIRS datasets inside a conventional experimental framework, which restricts the use of deep networks that need more data. In order to overcome these obstacles, we provide in this study a cross- modal data augmentation (fCMDA) based fNIRS-driven depression identification architecture that transforms fNIRS data into pseudo-sequence activation images. To provide a variety of data, the method uses a time-domain augmentation process that includes time warping and time masking.

JIANWEN TAO, AND HAOTE XU [2] By simultaneously investigating face appearance and dynamics feature representations, They propose a novel framework called Latent Domain Adaptation Depression Recognition (LatDADR), designed to identify a discriminative, domain-invariant subspace. This approach focuses on advancing cross-dataset Automated Depression Recognition (ADR). This subspace would lower the between-domain distribution disparity semantically while Effectively maintaining the geometric structures within the domain. In latDADR, two target classifiers are individually optimized for appearance and dynamic features, while a source classifier is trained on appearance features. Low-rank and sparse regularization terms are then applied to capture shared components across the domain classifiers.

YU MA, JIAN SHEN, ZEGUANG ZHAO [3] According to recent research, facial expressions may be a reliable and significant indicator of depression. Even if there have been several advancements in automatic sadness recognition, it is difficult to investigate the subtleties of facial expressions that could indicate the fundamental distinctions between healthy subjects and depressed patients when exposed to varied stimuli. This research aims to create a classification model that integrates data collection, feature extraction, depression detection, and facial action analysis to identify differences in facial movements between individuals with depression and healthy controls. The need for such a system arises from the absence of a seamless method to monitor the mental states of depressed patients in diverse, natural living environments.

JIANWEN TAO , HAOTE XU , AND JIANJING FU [4] By merging facial appearance and dynamics features, they introduce a new Less-rank limited latent Domain Adaptation Depression Recognition (LDADR) system. This approach focuses on face-based depression recognition, where infinite differences in facial picture capture may cause a shift in the feature distribution. To minimize domain distribution bias in depression detection, they concentrate on identifying a condensed and a more insightful latent

space for representing appearance features. This will enable
us to share more distinctive structures across different domains while minimizing the divergence in domain distributions. In this ideal latent space, the classification loss functions for both the source and target domains are incorporated into the co-regression function, with the common features of the classifier models represented as a low-rank constraint term.

BRIAN STASAK, ZHAOCHENG HUANG, JULIEN EPPS, AND DALE JOACHIM [5] While the psychological Stroop color test has been widely used to assess delays in temporal cognitive processing, limited research has focused on the differences in verbal test response patterns both correct and incorrect between individuals with clinical depression and those in good mental health. Furthermore, the exploration of speech error features related to sequential responses in the Stroop test remains unexplored in the context of automatic depression classification. This study utilizes speech data recorded by smart devices to analyze n-gram error sequences, revealing that individuals with clinical depression tend to make more mistakes, especially consecutive errors, on the Stroop color test compared to healthy individuals.

YAN DING , XUEMEI CHEN [6] People are competing with each other more and more because of the constant

population growth, survival pressure, and learning pressure. Additionally, mental health disorders have demonstrated an accelerated development tendency, and some college students have experienced worry and terror for a long period. In addition to giving college students easier ways to communicate, the growth of social networks like Weibo, QQ, and WeChat has given them a new outlet for their emotions. Through social networks, they can share real-time footage of their living situations and communicate with others to communicate their feelings and decompress. Simultaneously, social network development has made it possible to identify sad users in a new method. In order to identify sadness, modern computer technology examines social network data.

ZHIYONG WANG , LONGXI CHEN [7] This research proposes an audio-based depression recognition method using a convolutional neural network and generative adversarial network model. The approach involves preprocessing the dataset by eliminating extended periods of silence before merging the remaining data into a new audio file. The audio difference normalization process is employed to extract key speech features such as spectral entropy, short-term energy, and Mel-frequency Cepstral Coefficients (MFCCs). The foundation for model training is built on the extracted matrix vector feature data, which captures the unique vocal characteristics of each subject.

ZIXUAN SHANGGUAN, ZHENYU LIU [8] Depression is a prevalent mental condition that has caused significant harm to people. Given the growing concern about mental disease and the current research linking depression to numerous objective physiological signs, automated depression diagnosis is critical and urgent. In order to help with online diagnosis and depression rehabilitation engineering, we look into the issue of facial expression classification for depression. In this study, we introduce a weakly supervised learning approach utilizing multiple instance learning (MIL), based on 150 video clips from 75 individuals with depression and 75 healthy controls. Additionally, we propose a novel MIL dual-stream aggregator that prioritizes symptom-relevant information by considering both sample-level data and collection-level data. In particular, our approach, ADDMIL, employs max-pooling at the instance level to gather symptom data, and then uses attention weights to further integrate each instance's input at the bag level.

MUHAMMAD RIZWAN, MUHAMMADF AHEEM
MUSHTAQ1 [9] Depression Early detection of depression may even prevent the severe repercussions of long-term depression, such as suicide, therefore it could be highly helpful to detect depression from social media texts like Facebook comments or Tweets. This study uses a labeled Twitter dataset to classify the severity of depression. This study also investigates the use of Tweets to classify depression severity by assessing the performance of four transformer-based, pre-trained small language models with fewer than 15 million tunable parameters. The models evaluated include Electra Small Generator (ESG), Electra Small Discriminator (ESD), XtremeDistil-L6 (XDL), and Albert Base V2 (ABV). Various hyper parameters are fine-tuned to enhance the models' performance.

CHAO JIANG, YINGJIE LI, CUNTAI GUAN[10] Research has shown that individuals with depression exhibit distinct neurophysiological responses when exposed to both positive and negative stimuli, with these signals differing significantly from those of healthy individuals. In this study, a novel approach for detecting depression using electroencephalogram (EEG) data, incorporating geographical information to enhance the classification process. A support vector machine (SVM) was employed for classification tasks, while differential entropy, combined with a genetic algorithm, was utilized for feature extraction and selection. To enhance spatial differentiation, a task-specific common spatial pattern (TCSP) method was introduced prior to the feature extraction process.

III. OBJECTIVES

The primary goal of this study is to increase the adaptability and user-friendliness of man-machine interaction. Human experts will have distinct information that codes the facial features of aging, including wrinkles, inflammation, under-eye bags, smoothness, and face structure, when it comes to determining age. Test photo privileged knowledge is not available to automated age estimations. We hypothesize that asymmetric data could help resolve this problem. be investigated and used to improve the trained model's generalizability.

- To identify the facial expression
- To find out the depression level
- To identify individuals who may be experiencing depression by analyzing their emotional patterns

To enhance the field's understanding of mental health int ervention and monitoring, this work attempts to address present issues in depression identification and suggest future options. This study aims to promote cooperation and creativity in the creation of more accurate and dependable depression detection systems by acting as a thorough resource for clinicians and stakeholders. This will

ultimately improve mental health outcomes and people's well-being globally.

IV. PROPOSED SYSTEM

This system employs image processing techniques to identify faces, extract features, and classify them as depressed or not Depression symptoms are used to train it, and it uses these signs to identify patterns linked to the illness. In order to forecast depression, the algorithm examines facial features and extracts qualities from the faces it detects. The user is classified as either depressed or not based on the features that were extracted and the intensity of their depressive symptoms. By concentrating on facial clues associated with depression, this method offers a trustworthy classification and guarantees an accurate assessment. The system's ability to provide accurate and efficient predictions through the combination of picture analysis and symptom-based learning aids in the early detection and possible treatment of depression.

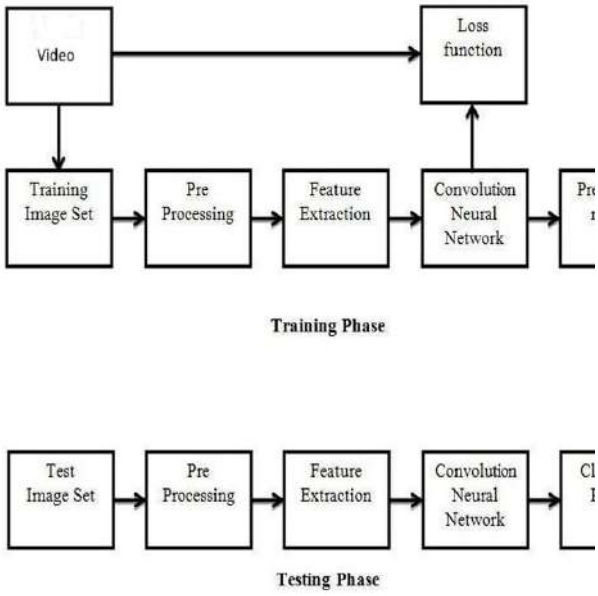


Figure 1. System Architecture

It is expected that the study would cover ethical issues pertaining to data security, consent, and patient privacy. The system that is put into place should guarantee the safe management of patient data and conform to ethical standards. It is anticipated that the created CNN-based technology will be useful in actual clinical scenarios. It should be easily incorporated into current healthcare systems, giving doctors an easy-to-use tool for quick and precise diagnosis of depression. By attaining these anticipated outcomes, the study hopes to make a large contribution to the field of depression detection by offering a trustworthy, comprehensible, and morally sound CNN-based solution that can have a major positive influence on patient care and results.

The research paper's technique on a convolutional neural network (CNN)-based depression detection system includes a methodical approach to system development and evaluation. The first step in the procedure is defining the objectives and specifications of the study, which includes the precise objectives of the depression detection system and the choice of suitable datasets for testing and training. Before feeding the input into neural network models, this means filling in the missing values, cleaning the data, and standardizing or normalizing the data.

Algorithms and its working:

i. Convolutional Neural Network
ii. Image processing
iii. Classification Techniques
iv. Feature Extraction

i. Convolutional Neural Network

Convolutional Neural Networks (CNNs) play a pivotal role in depression recognition by leveraging their ability to analyze visual data, such as facial images, to detect subtle patterns and features associated with depressive symptoms. CNNs consist of multiple layers, including convolutional, pooling, and fully connected layers, which work together to extract and hierarchically process image features. In depression recognition, the network is trained on labeled datasets containing images of individuals with and without depression. Through this training, the CNN learns to identify specific facial traits, expressions, or anomalies correlated with depression. Once trained, the model can predict whether a person shows signs of depression by analyzing new facial images, offering a non-invasive and automated approach to early diagnosis.

ii. Image processing

Image processing in depression recognition involves analyzing facial images to extract and interpret characteristics linked to symptoms of depression. The procedure starts with detecting and isolating faces within images, followed by preprocessing steps like normalization and enhancement to improve image quality. Key facial features, such as expressions, eye movements, and micro-expressions, are then extracted using advanced algorithms or neural networks. These features are analyzed to identify patterns linked to depression, such as reduced expressiveness, asymmetry, or distinct eye behavior. The extracted data is fed into machine learning or deep learning models, such as Convolutional Neural Networks (CNNs), to classify individuals as depressed or not. This approach enables non-invasive, automated, and scalable recognition of depression through subtle facial cuts.

iii. Classification Techniques

Classification techniques in depression recognition involve training algorithms to categorize data into predefined classes, such as "depressed" or "not depressed," based on input features. These techniques utilize machine learning models like Convolutional Neural Networks (CNNs) for image-based analysis. The process begins with extracting relevant features from input data, such as facial expressions, vocal tones, or textual content. These features are then fed into the classification model, which learns patterns and correlations indicative of depression during the training phase. Advanced models like CNNs are particularly effective for image and video analysis, automatically learning hierarchical features from raw data. The trained model is evaluated on unseen data to ensure generalizability and accuracy in predicting depressive states.

iv. Feature Extraction

Feature extraction in depression recognition involves identifying and isolating key facial characteristics that correlate with depressive symptoms. This process typically begins with pre-processing techniques to enhance image quality and standardize input data. Facial regions of interest, such as eyes, mouth, and overall expressions, are then detected using advanced algorithms. These regions are analyzed to extract specific features, including micro-expressions, asymmetry, and variations in facial muscle movement, which are indicative of emotional states. Additionally, spatial and temporal patterns are captured to identify subtle changes over time. These extracted features serve as input for machine learning models, enabling the system to classify individuals based on the presence or absence of depressive indicators, ensuring accuracy and interpretability in the recognition process.

V. RESULTS AND DISCUSSION

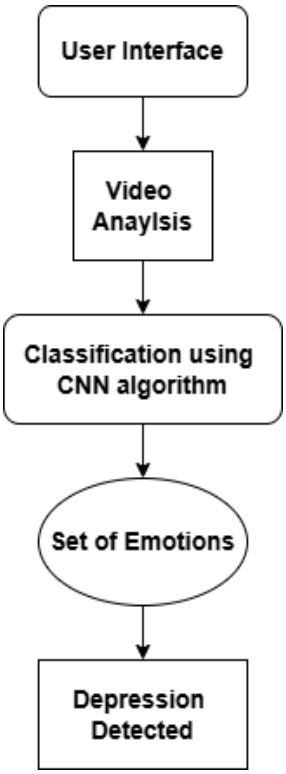


Figure 2. Flowchart of System Architecture

A. User Interface

The user interface is the main way that our depression detection technology is accessed, and it is also essential for ensuring user engagement and system use. Designed to be user-friendly, the interface offers a web-based platform that works with a variety of devices, making it easy to submit video analysis for the detection of depression. After selecting the Video option, users are guided seamlessly into the video analysis phase, where they are requested to record a short video clip. The core of this process is a sophisticated algorithm based on convolutional neural networks. It serves as the system's cornerstone and is skilled at identifying complex facial expressions and nuanced emotional clues in the recorded videos. Anger, happiness, fear, sorrow, surprise, and disgust are the six clusters into which the CNN algorithm deftly divides the emotions it detects. A fundamental aspect of human emotional expression is represented by each cluster.

These clusters provide a comprehensive basis for understanding the emotional landscape depicted in the user-submitted videos. When users select the Video feature, they are asked to record a brief video clip, which smoothly moves them into the video analysis stage. A sophisticated convolutional neural network-based method .

The core of this process is networks (CNNs). In the captured movies, the system's basic algorithm can interpret subtle emotional cues and intricate facial expressions. The CNN algorithm deftly separates emotions into six clusters: anger, happiness, fear, sorrow, surprise, and disgust. Each cluster represents a fundamental aspect of human emotional expression. These clusters provide a comprehensive basis for understanding the emotional landscape depicted in the user-submitted videos.

B. Experimental Result

An easy user experience is guaranteed by the model's smooth interaction with our website. The system effectively preprocesses, extracts frames, and transmits the video to the CNN-based model after it has been submitted. Because of this integration, users can fully utilize the model's features without requiring specialist technical knowledge. Our website has a user-centric approach to HAR, serving as a bridge between users and the model while guaranteeing usability and accessibility for all users. Using Python deep learning libraries like TensorFlow and Pandas, we can classify the emotion on the face by selecting the projection and work region and putting a squared margin over it.

C. Workflow

The Emotion-Based Depression Detection System gives users a comprehensive platform to assess their emotional well-being through a range of input options, including video, which offers a unique way for users to enter information for a depression assessment while accounting for personal preferences. In conclusion, the system's website offers users a variety of input options, all of which use advanced machine learning algorithms to interpret emotional data. Watching films can help users understand their emotional states and potential risk factors for depression. The system's flexibility and in-depth analysis enable users to take proactive control of their mental health.

VI. CONCLUSION

The facial expression conveys the objective of the task, causing the employee to lose interest upon understanding it. To address this, we can provide

instructions once the production process is expanded. By increasing their level of engagement, this approach can be implemented using a Convolutional Neural Network (CNN) algorithm. To enhance the accuracy of the test results, the CNN incorporates ReLU activation functions into a single flattened layer, followed by dense layers preceding the kernel module. These layers are then connected through a SoftMax function. By tackling current challenges and proposing new research directions, this study paves the way for future advancements in depression detection. It aims to lead the field in mental health monitoring and intervention, combining practical application with a strong commitment to ethical standards and continuous improvement. The use of advanced machine learning algorithms in diagnosing depression holds significant promise, offering vast opportunities for continued exploration and real-world implementation through interdisciplinary collaboration and innovative research.

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Development of optimized Ensemble machine learning model through XG Boost and Random Forest for UPIfraud detection

[1]. Firdous Attar
Research scholar
Department of Computer Engineering
K J College of Engineering & Management Research,
Pune, Maharashtra 412205.
Email: pradnya2206@gmail.com

[2] Geetanjali Bansod
Assistant Professor
Department of Computer Engineering
K J College of Engineering & Management Research,
Pune, Maharashtra 411048.
Email: geetanjalibansod..kjcoemr@kjei.edu.in

ABSTRACT **:- A machine learning (ML) model is proposed by the review of the literature to help diagnose depression condition. A self-report questionnaire can be used to diagnose depressive disorder, but mood evaluation and the consistency of subjective and objective observations need to be confirmed. Millions of people worldwide suffer from depression. It is possible for people with the same illness to have different mental health conditions. Video-recorded clinical sessions are analyzed to determine the severity of depression. An estimated 350 million people worldwide suffer from depression. People with depression frequently find it difficult to concentrate on their work in the software sector. When diagnosing depressive illnesses, camera-based technologies can speed up the process and provide useful information for intervention plans. Through the use of CNN, a deep learning technique that decodes vector-based data, a model for diagnosing depressive disorders can be developed by tracking eye and lip movements and determining emotional states from a set of images taken of individuals who will regularly be evaluated for depression.**

Keywords - XGBoost, Random Forest, Logistics Regression.

I. INTRODUCTION

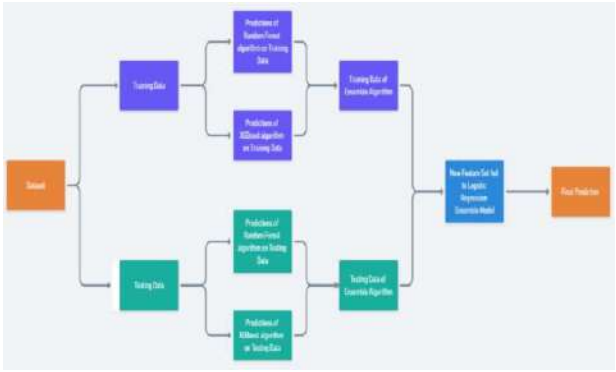
Unified Payments Interface (UPI) is a real-time payment system developed by the National Payments Corporation of India (NPCI) that enables seamless and instant money transfers between bank accounts through mobile devices [1]. Launched in 2016, UPI has revolutionized digital payments in India by offering a fast, secure, and convenient platform for peer-to-peer and merchant transactions [2]. It allows users to link multiple bank accounts in a single mobile application and conduct transactions using a unique UPI ID, eliminating the need for traditional banking details like account numbers and IFSC codes. With its interoperability, low transaction costs, and 24/7 availability, UPI has witnessed exponential growth, becoming one of the most widely used digital payment methods in India. However, the rapid adoption of UPI has also led to a rise in fraudulent activities, highlighting the need for robust security measures and fraud detection mechanisms. Despite its convenience and widespread adoption, Unified Payments Interface (UPI) transactions are vulnerable to various security threats and fraudulent activities [3][4]. Cybercriminals exploit loopholes through phishing attacks, fake UPI links, social engineering scams, and unauthorized access to user credentials. Fraudsters often impersonate bank representatives or use malicious apps to deceive users into sharing their One-Time Passwords (OTP) and UPI PINs, leading to unauthorized transactions[5][6]. Additionally, SIM swapping and malware attacks pose significant risks, enabling attackers to gain control over users' mobile banking credentials [7]. While regulatory bodies and financial institutions continuously enhance security through multi-factor authentication, transaction limits, and AI-driven fraud detection systems, users must remain vigilant by verifying payment requests, avoiding untrusted apps, and safeguarding their credentials to prevent financial losses. Enhancing the security of UPI transactions is crucial to prevent fraud, phishing attacks, and unauthorized access. Stronger security measures ensure safer digital payments, protecting users' financial data and maintaining trust in the system. Implementing features like multi-factor authentication and AI-driven fraud detection enhances overall transaction security.

This research paper explores the application of machine learning algorithms to detect fraudulent transactions, focusing specifically on Unified Payments Interface (UPI)

fraud detection. The study employs two widely used machine learning techniques—XGBoost (Extreme Gradient Boosting) and Random Forest—to analyze and classify fraudulent activities in financial transactions [8][9]. A publicly available online payment fraud detection dataset from Kaggle is used to train and evaluate these models, ensuring a comprehensive assessment of their performance. The effectiveness of these algorithms is measured using key evaluation metrics, including Accuracy, Precision, F1-Score, Macro Average, and Weighted Macro Average [10]. The findings suggest that XGBoost performs optimally on smaller datasets, whereas Random Forest demonstrates better performance when applied to larger datasets [11]. To further enhance fraud detection accuracy, an ensemble model is introduced by combining XGBoost and Random Forest using logistic regression. This ensemble approach is designed to leverage the strengths of both algorithms, resulting in improved predictive performance across different dataset sizes. By integrating multiple machine learning techniques, this research aims to develop a more reliable fraud detection system that adapts to varying data volumes[12][13]. The results highlight the potential of ensemble learning in UPI fraud detection, offering a practical solution for real-world applications [14]. The study provides valuable insights into the effectiveness of different machine learning models in combating fraudulent activities, emphasizing the need for continuous innovation in UPI fraud prevention strategies.

II. Proposed Methodology

The block diagram illustrates a machine learning-based fraud detection methodology using an ensemble approach. The process begins with a dataset that is split into training and testing sets. The training data is separately processed through two machine learning algorithms: Random Forest and XGBoost. Each of these models generates predictions on the training data, which are then combined to form the training dataset for the ensemble algorithm. Similarly, the testing data is passed through both the Random Forest and XGBoost models to generate predictions on unseen data. These predictions are used to create the testing dataset for the ensemble algorithm. The ensemble model utilizes these predictions as new features, forming a new feature set. This feature set is then fed into a logistic regression model, which acts as the final classifier for fraud detection. The logistic regression model analyzes the combined strengths of both individual models to improve overall prediction accuracy. The approach leverages the high interpretability of logistic regression while benefiting from the predictive power of



Random Forest and XGBoost. The ensemble method is designed to address the limitations of individual models by balancing performance across different dataset sizes. XGBoost is effective for handling smaller datasets, while Random Forest performs well with larger datasets. By combining these models, the ensemble approach enhances fraud detection capabilities, making the predictions more reliable. The methodology aims to increase accuracy, precision, and overall performance in financial fraud detection. The final prediction made by the ensemble model provides a more robust fraud classification. This approach can be applied to real- world fraud detection systems to improve security in online transactions. The proposed methodology demonstrates the effectiveness of ensemble learning in detecting fraudulent activities. The block diagram provides a clear representation of the workflow and interconnections between the different stages of the model.

III. Dataset Description

The Online Payments Fraud Detection dataset consists of multiple features that help in identifying fraudulent transactions. The step feature represents a unit of time where each step equals one hour. The type feature indicates the type of online transaction being performed. The amount represents the monetary value of the transaction. The nameOrig refers to the customer initiating the transaction. The oldbalanceOrg records the balance of the sender before the transaction, while the newbalanceOrig captures the balance after the transaction. Similarly, the nameDest represents the recipient of the transaction. The oldbalanceDest is the recipient's balance before receiving funds, whereas the newbalanceDest is their updated balance after thetransaction. The dataset also includes the isFraud feature, which identifies whether a transaction is fraudulent. Fraudulent transactions can be detected by analyzing unusual patterns, such as a sender transferring an amount equal to their total balance. Additionally, discrepancies in the recipient's balance updates can signal potential fraud. The dataset enables various analytical approaches, including machine learning models, to predict fraudulent activities. Feature engineering can help improve fraud detection by deriving new attributes, such as balance

differences before and after transactions. Exploratory Data Analysis (EDA) can reveal patterns and anomalies in fraudulent versus non-fraudulent transactions. Additionally, classification models like Random Forest, Logistic Regression, and XGBoost can be applied for predictive fraud detection. With proper preprocessing, this dataset can serve as a valuable tool for building robust fraud detection systems.

IV. Working Mechanism

4.1 Experimental Overview.

The experiment was conducted to evaluate the performance of different machine learning models in detecting fraudulent activities across datasets of varying sizes. Specifically, two datasets were utilized: a small dataset consisting of 750 data points and a large dataset containing 5,000 data points. These datasets were selected to analyze how different models perform under different data volume conditions.

4.2 Fraud Detection Models.

For fraud detection, two widely used machine learning algorithms were employed: XGBoost and Random Forest. These models were chosen due to their robustness, ability to handle complex patterns in data, and effectiveness in classification tasks. XGBoost (Extreme Gradient Boosting): A powerful gradient-boosting algorithm that optimizes performance through parallel tree boosting, reducing over fitting and improving accuracy.Random Forest: An ensemble learning method that operates by constructing multiple decision trees and aggregating their predictions, making it highly resistant to over fitting and effective for large datasets.

4.3 Model Performance and Findings.

The experiment produced insightful results regarding the effectiveness of these models across datasets of different sizes:

1.Performance on the Small Dataset:

The XGBoost model outperformed Random Forest when applied to the small dataset
of 750 data points. XGBoost's gradient boosting mechanism and feature-weighting capabilities allow it to perform well even with limited data, where deep decision trees might over fitting.

2.Performance on the Larger Dataset:

The Random Forest model demonstrated superior results when tested on the large dataset of 5,000 data points. Due to its ensemble nature, Random Forest effectively captures patterns from a larger volume of data while maintaining robustness against over fitting.

4.4 Requirement of Ensemble Model.

The varying performances of the two models across different dataset sizes highlight the need for a hybrid approach that leverages the strengths of both algorithms. Instead of relying solely on one model, a combination of XGBoost and Random Forest is required to ensure optimal fraud detection performance across different datasets. This combined approach is known as an ensemble model, where multiple algorithms are integrated to improve predictive accuracy and generalizability.

4.5 Development of Ensemble Model.

Logistic regression was used as a meta-classifier for the ensemble model due to its compatibility with different models, ease of interpretation, and computational efficiency. It effectively combines XGBoost and Random Forest outputs, ensuring fast training, clear decision-making, and high predictive performance for fraud detection.

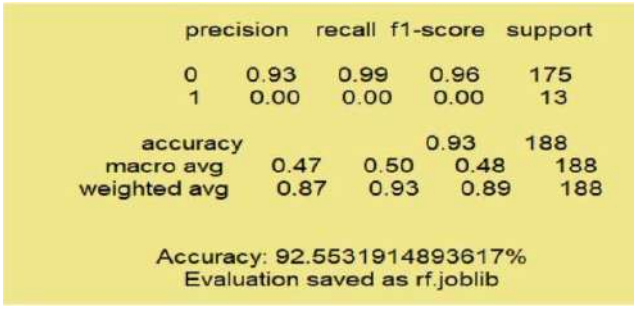
V. Results & Discussion

While wrath, despair, or depression are examples of negative emotions, love, laughing, and joy are examples of positive emotions. Many deaths may result from negative emotions, which can be widespread and quite intense. Depression is a prevalent and dangerous illness that can impact one's mental and physical health. It has an impact on a person's feelings, ideas, and actions. Depression is categorized as a behavioral and mental illness.

5.1 Random Forest with small data points

The results of the Random Forest model on a smaller dataset of 750 data points indicate that while the overall accuracy is 92.55%, the model exhibits significant class imbalance issues. The precision, recall, and F1-score for the majority class (0) are 0.93, 0.99, and 0.96, respectively, demonstrating strong predictive performance. However, for the minority class (1), the model fails to detect any instances correctly, resulting in a precision, recall, and F1-score of 0.00. The macro average scores (0.47 precision, 0.50 recall, and 0.48 F1-score) further highlight this imbalance, while the weighted averages remain higher due to the dominance of class 0 in the dataset. Despite the high overall accuracy, the model is ineffective in identifying fraudulent cases, indicating a need for techniques such as oversampling, undersampling, or cost-sensitive learning to

improve performance on the minority class. The evaluation results have been saved as rf.joblib for further analysis and refinement.



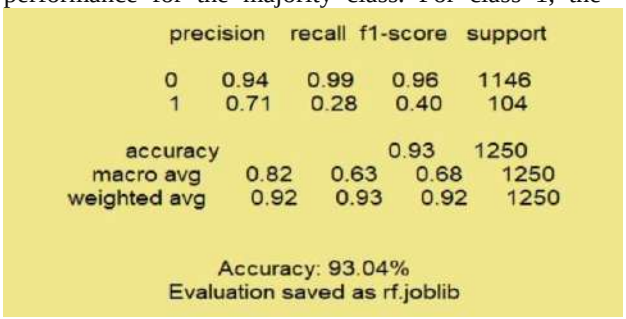
	precision	recall	f1-score	support
0	0.93	0.99	0.96	175
1	0.00	0.00	0.00	13
accuracy			0.93	188
macro avg	0.47	0.50	0.48	188
weighted avg	0.87	0.93	0.89	188

Accuracy: 92.5531914893617%
Evaluation saved as rf.joblib

Fig 2. Result of Random Forest with small data points

5.2 XGBoost with small data points

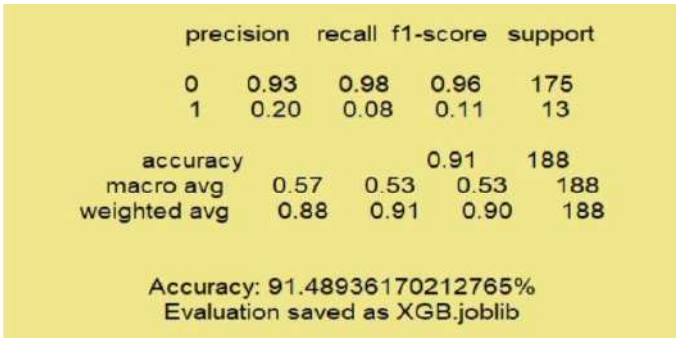
The results of the XGBoost model on a smaller dataset of 750 data points show an overall accuracy of 91.49%, which is slightly lower than the Random Forest model. However, unlike Random Forest, XGBoost exhibits some ability to detect the minority class (1). The precision, recall, and F1-score for class 0 are 0.93, 0.98, and 0.96, respectively, indicating strong predictive performance for the majority class. For class 1, the



	precision	recall	f1-score	support
0	0.94	0.99	0.96	1146
1	0.71	0.28	0.40	104
accuracy			0.93	1250
macro avg	0.82	0.63	0.68	1250
weighted avg	0.92	0.93	0.92	1250

Accuracy: 93.04%
Evaluation saved as rf.joblib

model achieves a precision of 0.20, recall of 0.08, and F1-score of 0.11, which, while still low, shows a minor improvement in detecting fraudulent cases compared to Random Forest. The macro average scores (0.57 precision, 0.53 recall, and 0.53 F1- score) indicate a slightly better balance between classes, while the weighted averages remain high due to class imbalance. These results suggest that XGBoost performs better than Random Forest in identifying fraud cases, though it still struggles with recall. Further enhancements such as data balancing techniques or hyperparameter tuning may be necessary for improved fraud detection. The evaluation has been saved as XGB.joblib for further analysis.



	precision	recall	f1-score	support
0	0.93	0.98	0.96	175
1	0.20	0.08	0.11	13
accuracy			0.91	188
macro avg	0.57	0.53	0.53	188
weighted avg	0.88	0.91	0.90	188

Accuracy: 91.48936170212765%
Evaluation saved as XGB.joblib

Fig 3. Result of XGBoost with small data points

5.3 Random Forest with large data points

The Random Forest model was evaluated on a larger dataset of 5,000 data points, and the results indicate an overall accuracy of 93.04%. The model performs exceptionally well for the majority class (0), achieving a precision of 0.94, recall of 0.99, and an F1-score of 0.96 across 1,146 instances. However, while its performance on the minority class (1) has improved compared to the smaller dataset, challenges remain. The model attains a precision of 0.71, recall of 0.28, and an F1-score of 0.40 for class 1, indicating that while it can identify some fraudulent cases, it still struggles with recall, meaning many fraudulent cases go undetected. The macro average scores (0.82 precision, 0.63 recall, and 0.68 F1-score) suggest a more balanced performance between the two classes, though the weighted averages remain high due to the dominance of class 0. These results demonstrate that the Random Forest model benefits from a larger dataset, showing significant improvement in detecting fraudulent transactions compared to its performance on the smaller dataset. However, further optimization, such as cost-sensitive learning or data resampling techniques, may be necessary to enhance recall for the minority class. The evaluation has been saved as rf.joblib for further analysis and model refinement.

Fig 4. Result of Random Forest with Larger data points

5.4 XGBoost with large points

The XGBoost model was evaluated on a larger dataset of 5,000 data points, yielding an overall accuracy of 92.64%. The model performs well for the majority class (0), achieving a precision of 0.94, recall of 0.98, and an F1-score of 0.96 across 1,146 instances. For the minority class (1), the model shows a precision of 0.62, recall of 0.31, and an F1-score of 0.41, indicating that while it has improved in detecting fraudulent cases compared to the smaller dataset, it still struggles with recall, meaning that

many fraudulent cases remain undetected.The macro average scores (0.78 precision, 0.65 recall, and 0.69 F1-score) suggest a more balanced performance between the two classes compared to smaller datasets. The weighted averages remain high due to the dominance of class 0. These results indicate that XGBoost benefits from a larger dataset, showing enhanced fraud detection capabilities while maintaining overall accuracy. However, additional techniques such as oversampling, cost-sensitive learning, or further hyper parameter tuning may be necessary to improve the recall for fraudulent cases. The evaluation has been saved as XGB.joblib for further analysis and refinement.

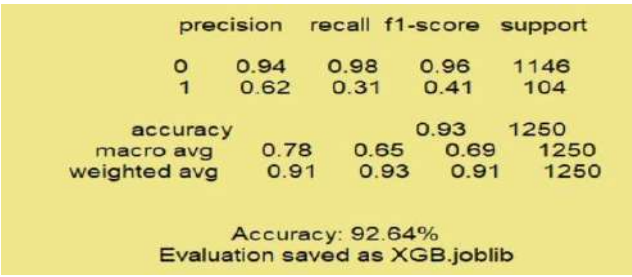


Fig 5. Result of XGBoost with Larger data points

5.5 Ensemble Model with small data points

The ensemble model was evaluated on a smaller dataset of 750 data points, achieving an overall accuracy of 93.09%. The model performs exceptionally well for the majority class (0), with a precision of 0.93, recall of 1.00, and an F1-score of 0.96 across 175 instances. However, its performance on the minority class (1) is significantly lacking, with a precision, recall, and F1-score of 0.00, indicating that the model fails to detect any fraudulent cases.The macro average scores (0.47 precision, 0.50 recall, and 0.48 F1-score) highlight the imbalance between the two classes, while the weighted averages remain high due to the dominance of class 0. These results suggest that while the ensemble model maintains high overall accuracy, it struggles with fraud detection in imbalanced datasets. Further improvements, such as data resampling techniques or cost-sensitive learning, may be necessary to enhance fraud detection capabilities. The evaluation has been saved as meta_model.joblib for further analysis and refinement.

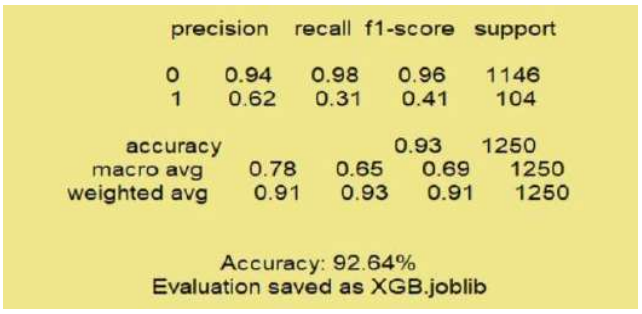


Fig 6. Result of Ensemble Model with small data points

5.6 Ensemble Model with larger data points

The ensemble model was evaluated on a larger dataset of 5,000 data points, yielding an overall accuracy of 93.04%. The model demonstrates strong performance for the majority class (0), achieving a precision of 0.94, recall of 0.99, and an F1-score of 0.96 across 1,146 instances. However, its ability to detect the minority class (1) remains a challenge, with a precision of 0.71, recall of 0.28, and an F1-score of 0.40 for the 104 fraudulent cases. The macro average scores (0.82 precision, 0.63 recall, and 0.68 F1-score) indicate some improvement in balance between the two classes, although the weighted averages remain high due to the overwhelming presence of class

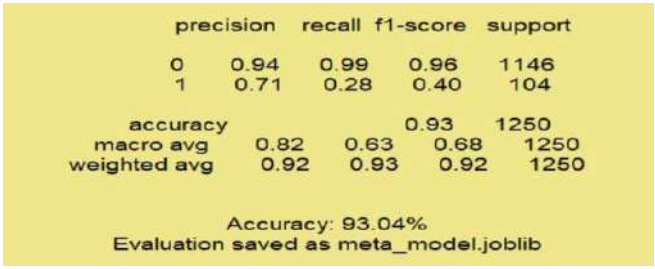


Fig 7. Result of Ensemble Model with Large data points

VI. Conclusion

The evaluation of the ensemble model on a larger dataset of 5,000 data points demonstrates a strong overall accuracy of 93.04%. The model performs exceptionally well for the majority class (0), with high precision (0.94), recall (0.99), and an F1-score of 0.96. However, its effectiveness in detecting the minority class (1) remains limited, as indicated by a recall of 0.28 and an F1-score of 0.40. The macro average scores (0.82 precision, 0.63 recall, and 0.68 F1-score) suggest some improvement in balancing class predictions, yet the weighted averages remain high due to class imbalance. These findings highlight the benefits of using an ensemble approach with

a larger dataset but also underscore the need for further optimization to improve recall for minority class instances. Future research could explore advanced resampling techniques, cost- sensitive learning, or alternative ensemble strategies to enhance the model's ability to detect fraudulent cases effectively.

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Fashion trends prediction tool

Satish Yedage
Assistant Professor
Dept of Computer Engineering
KJ College of Engineering and
Management Research, Pune
satishyedage..kjcoemr@kjei.edu.in

Kunal Sapkal
Final Year
Dept of Computer Engineering
KJ College of Engineering and
Management Research, Pune
kmsapkal007@gmail.com

Tejas Sonar
Final Year
Dept of Computer Engineering
KJ College of Engineering and
Management Research, Pune
tejas.sonar547@gmail.com

Sanket Suradkar
Final Year
Dept of Computer Engineering
KJ College of Engineering and
Management Research, Pune
sandysuradkar12@gmail.com

Sumit Rasal
Final Year
Dept of Computer Engineering
KJ College of Engineering and
Management Research, Pune
sumitrasal8975@gmail.com

***ABSTRACT* :- Fashion trend forecasting is a critical component in the fashion industry, influencing design, production, and marketing strategies. Traditional forecasting models often rely on broad industry trends or generalized consumer behaviour data, which fail to capture unique customer preferences. This misalignment results in overproduction, inventory mismatches, and lost revenue opportunities. To address these issues, this study proposes a hybrid forecasting framework that integrates global fashion trends with customer-specific insights derived from historical sales data. The proposed model employs a time-series forecasting approach using Facebook's Prophet, a robust forecasting tool designed for handling missing data, outliers, and seasonality. Additionally, an interactive visualization dashboard is implemented using Dash, enabling real-time trend exploration and predictive analysis. The system architecture consists ofa data processing pipeline that aggregates and normalizes trend-related attributes such as fabric type, color, brand, and category. Prophet's forecasting model is then trained on historical trend data, allowing stakeholders to visualize trend evolution and make data-driven decisions.**

Keywords -. Trend Prediction, Prophet, Timeseries

I. INTRODUCTION

The fashion industry is highly dynamic, with trends evolving rapidly due to social media influence, cultural shifts, and consumer preferences. Accurate forecasting can provide a competitive advantage by enabling proactive decision-making. Traditional forecasting methods rely on domain expertise, whereas modern data-driven approaches use machine learning to identify patterns and make predictions.

The current fashion trend prediction models predominantly rely on broad industry trends or generalized customer behaviour data, often failing to accurately capture the unique preferences of individual consumers. This disconnects between high-level trend analysis and specific customer preferences can lead to misaligned inventory, overproduction, and lost sales opportunities, impacting both profitability and sustainability in fashion retail.

This project aims to address these challenges by developing a hybrid model that integrates global fashion trends with customer-specific preferences derived from previous sales data. The goal is to create a predictive system that not only reflects industry-wide shifts but also adapts to individual tastes in fabric, style, and clothing type. This approach seeks to enhance trend prediction accuracy, improve inventory alignment with consumer demand, and support sustainable practices by reducing waste and overproduction in the fashion industry.

II. SYSTEM ARCHITECTURE AND TOOLS

2.1 Front-End Technologies

front-end technologies used in this project are primarily based on Dash (by Plotly), which is a Python framework for building web applications with interactive visualizations

- Dash (Plotly)

Uses Dash Core Components (dcc) and Dash HTML Components (html) for UI elements.

- Plotly (for Visualizations)

Used for rendering dynamic charts and graphs such as: Line Graphs (for forecasting trends) Bar Charts (for popularity analysis) Pie Charts (for category distribution)

- JavaScript (Behind the Scenes)

Dash uses React.js under the hood to update UI components dynamically. JavaScript enhances client-side interactivity and responsiveness.

- HTML & CSS (for Styling)

html.Div(), html.Label(), and other Dash components render into standard HTML. CSS (either inline or external) is used for styling and layout adjustments.

- Flask (as Dash's Backend)

Dash applications run on Flask, a Python- based web framework. This allows easy API integrations and deployment to web servers.

2.2 Back-End Technologies

The backend of this fashion trend forecasting system is built primarily using Python and relies on several key frameworks and libraries to handle data processing, forecasting, and serving the web application.

- Prophet (for Time Series Forecasting)

Facebook's Prophet is used for trend prediction. Automatically detects trends, seasonal patterns, and fluctuations. Generates future forecasts based on historical sales and trend data.

- Dash Callbacks (for Backend Interactivity)

Dash uses Python-based callback functions to process user input. Filters data, runs the Prophet model, and returns predictions in real-time.

- Flask (via Dash)

Dash runs on Flask, a lightweight Python web framework. Handles HTTP requests and responses. Manages communication between the front-end and backend components.

- Pandas (for Data Processing)

Used to load, clean, and transform the fashion trend dataset. Handles time-series aggregation for trend forecasting. Manages filtering and selection of data based on user inputs.

III. METHODOLOGY

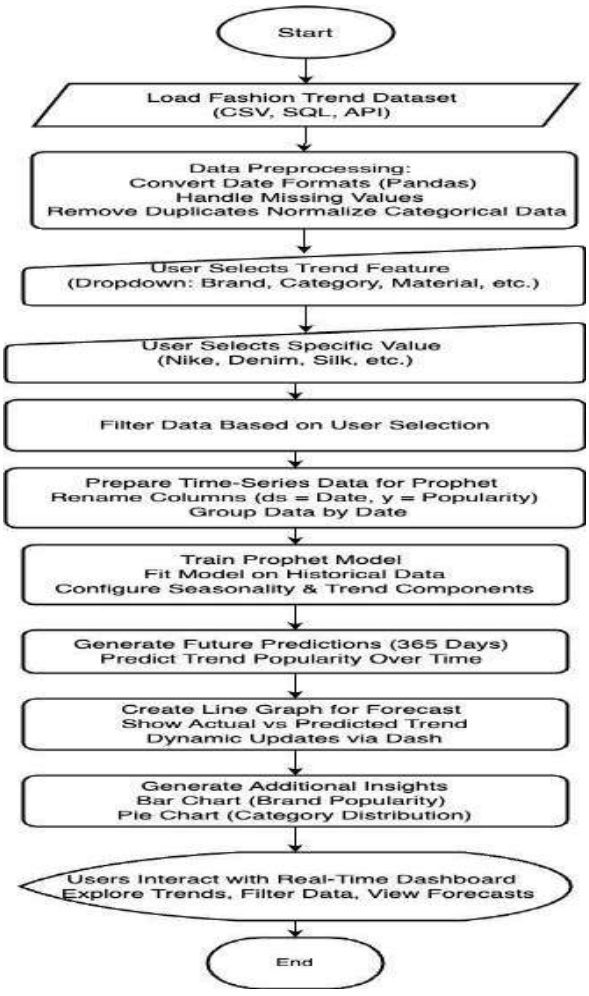


Fig 1:- Methodology

Our forecasting system integrates the Dash web framework for interactive visualization and the Prophet forecasting model for trend prediction.

3.1 AI model Implementation

Fashion trends are inherently cyclical, seasonal, and highly volatile, making accurate forecasting essential for retailers. Traditional models like ARIMA (Autoregressive Integrated Moving Average) and exponential smoothing fail to adapt to the

sudden changes in fashion demand driven by influencer culture, viral trends, and consumer sentiment shifts. Deep learning approaches, while powerful, often require large amounts of labelled data and are computationally expensive.

To address these challenges, we leverage Facebook's Prophet model, a Bayesian time- series forecasting tool designed to handle missing data, trend shifts, and multiple seasonality levels. Prophet uses an additive regression approach that decomposes time- series data into three key components:

$y(t)=g(t)+s(t)+h(t)+\epsilon t$

Where:

- $g(t)g(t)g(t)$ represents the overall trend.
- $s(t)s(t)s(t)$ models seasonal variations (weekly, monthly, yearly).
- $h(t)h(t)h(t)$ captures external influences such as fashion events, holidays, or promotions.
- ϵt\epsilon is the error term.

Prophet is optimized for fashion forecasting, incorporating additional regressors like social media sentiment, Google Trends, and influencer engagement to improve predictive accuracy.

Prophet's forecasting process involves:

Trend Component (g(t)):

- Uses piecewise linear regression with automatic changepoint detection:

$g(t)=k+mt+i\sum \delta i\ (ti-t)$

Where k is the initial trend, m is the growth rate, and δi captures trend shifts.

Logistic Growth Constraints: To prevent overestimation of trend spikes, a logistic function is used for fashion demand saturation.

Seasonal Component (s(t)):

- Modeled using a Fourier series:

$s(t)=n=1\sum N\ (an\cos(P2\pi nt)+bn\sin(P2\pi nt))$

Captures weekly, monthly, and yearly cycles in fashion trends.

Holiday & Event Effects (h(t)):

- External regressors added for Fashion Weeks, Christmas Sales, Influencer Collabs.
- Impact modeled as:

$h(t)=j\sum \beta j\ Xj\ (t)$

Where Xj (t) is an event indicator, and βj is its trend influence.

Model Training & Hyperparameter Tuning:

- Changepoint Prior Scale (changepoint_prior_scale): Controls trend flexibility.
- Seasonality Mode (seasonality_mode = 'multiplicative' for fashion trends).
- Fourier Order Tuning (yearly_seasonality=10, weekly_seasonality=5)

IV. **RESULTS & DISCUSSION**

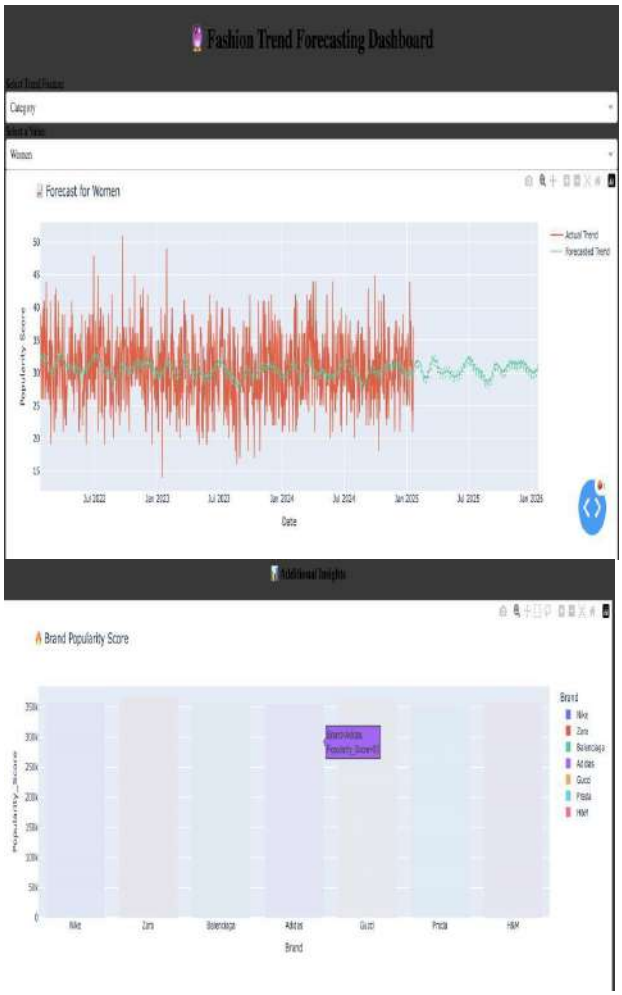


Fig 2:- Results

IV. **CONCLUSION**

The implementation of the Prophet model for fashion trend forecasting demonstrates its capability to effectively capture time-series patterns and provide reliable predictions. By leveraging historical trend data, Prophet models the underlying seasonality and long- term growth patterns, enabling fashion retailers to anticipate shifts in consumer preferences with a high degree of accuracy. The comparative analysis between actual and predicted trend popularity scores reveals that the model closely follows real-world fluctuations, with minimal deviations, suggesting that it successfully learns both periodic and non-periodic variations in trend dynamics. However, while Prophet excels in capturing general trend patterns, minor prediction errors indicate potential areas for enhancement. The model's assumption of piecewise linear growth may lead to slight underfitting in cases where abrupt changes in trend popularity occur due to external influences such as viral social media moments,

celebrity endorsements, or geopolitical events. Integrating exogenous variables such as sentiment analysis from social media platforms, macroeconomic indicators, and industry reports could refine the predictive power of the model. Overall, the use of Prophet for fashion trend forecasting provides a strong foundation for data-driven decision-making in the fashion industry. By continuously refining the model with domain-specific adjustments and incorporating additional external factors, businesses can maximize forecasting accuracy, leading to improved inventory management, reduced waste, and better alignment with consumer demand in an ever- evolving market landscape.

V. FUTURE DIRECTIONS

Significant enhancement is the hybridization of Prophet with deep learning models, such as Long Short-Term Memory (LSTM) networks or Transformer- based models. While Prophet effectively models time-series data with strong seasonality, LSTMs can capture complex temporal dependencies and nonlinear trend shifts. An ensemble approach combining Prophet with LSTMs or XG-Boost can improve predictive accuracy, particularly in scenarios where abrupt changes in consumer behaviour occur due to marketing campaigns or celebrity endorsements. Furthermore, automated hyperparameter tuning using Bayesian Optimization or Grid Search can optimize Prophet's seasonal decomposition, changepoint detection, and growth parameters, leading to a more adaptive forecasting model. Enhancing the model's ability to dynamically adjust trend inflection points will improve its responsiveness to emerging fashion movements. Using clustering algorithms alongside Prophet's time-series forecasting can help businesses tailor inventory management strategies and marketing efforts to specific regions, improving customer engagement and reducing supply chain inefficiencies.

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Customer & Price Analysis For Customer Retention Using Churn Modelling Research Paper

Mayuri Vengurlekar
Assistant Professor
Dept of Computer Engineering
KJ College of Engineering and Management Research, Pune
mayurivengurlekar.kjcoemr@kjei.edu.in

Aditya Swami
Final Year
Dept of Computer Engineering
KJ College of Engineering and Management Research, Pune
adityaswami25092003@gmail.com

Akash Varade
Final Year
Dept of Computer Engineering
KJ College of Engineering and Management Research, Pune
akashvarade08@gmail.com

Athurv Bhogate
Final Year
Dept of Computer Engineering
KJ College of Engineering and Management Research, Pune
athurvbhogate@gmail.com

Swapnil Atpadkar
Final Year
Dept of Computer Engineering
KJ College of Engineering and Management Research, Pune
swapnilatp2004@gmail.com

ABSTRACT **:- Customer retention has emerged as a vital business objective, especially in competitive industries where acquiring new customers is more expensive than retaining existing ones. This research proposes a semi-automated churn prediction system that integrates machine learning with manual data handling to provide actionable insights for businesses, particularly small and medium-sized enterprises (SMEs) lacking dedicated analytics teams Clients can easily send their customer data through everyday platforms like email or WhatsApp, making it simple for anyone to use without needing technical skills. Once the data is received, it's carefully checked and cleaned up—missing information is filled in, categories are properly labeled, and features are scaled and selected to make sure everything is ready for analysis. Then, the system looks for important patterns in the data that might explain why customers leave. Multiple popular machine learning methods, like Decision Trees, Logistic Regression, Random Forest, XGBoost, SVM, and Artificial Neural Networks, are trained and tested to find out which works best. Using clear measurements of success like accuracy and recall, the system picks the top model to predict how likely each customer is to churn and groups them into high, moderate, or low risk. A comprehensive report is then generated, presenting model results, key churn factors, and tailored business recommendations. This report is manually reviewed for quality and clarity before being delivered to the client through their preferred communication platform. Unlike fully automated systems, the human-in-the-loop approach ensures enhanced interpretability and contextual relevance. The system not only demonstrates the effective application of machine learning for churn analysis but also provides a scalable foundation for future automation, making it adaptable across industries such as telecommunications, banking, e-commerce, and subscription services.**

Keywords **-** classification models, predictive analytics, small and medium enterprises (SMEs), customer segmentation, business intelligence.

I. INTRODUCTION

Customer churn—the rate at which customers stop doing business with a company—has a direct impact on revenue and long-term sustainability. Studies show that improving customer retention rates by even 5% can increase profits by 25% to 95% [1]. Traditional retention strategies often rely on reactive customer service efforts or broad loyalty programs. However, predictive analytics, particularly machine learning, allows businesses to anticipate churn and proactively intervene [2].

This research proposes a system that bridges the technical gap for SMEs. Unlike large enterprises that deploy in-house data science teams and automated pipelines, SMEs require solutions that are accessible, scalable, and interpretable. The proposed churn prediction system collects customer data through user-friendly channels, processes it with a combination of automated and manual techniques, and returns actionable business intelligence. The inclusion of a human-in-the-loop enhances both the

interpretability of complex models and the customization of business recommendations [3].

Churn prediction has evolved substantially over the past decade, from rule-based systems to highly sophisticated ensemble learning methods. Early work by Khan et al. (2015) focused on behavioral modeling in telecom, achieving high model accuracy within the domain but lacking generalizability [4]. Keramati et al. (2016) employed decision tree classifiers in e-banking, successfully identifying churn-prone segments but failing to benchmark performance against ensemble techniques [5]. More recent studies have emphasized profit-based optimization. Höppner et al. (2017) introduced ProfTree, a decision tree model tailored for economic gains rather than classification accuracy, although its complexity made it less user-friendly [6]. Social network-based models, such as those by Óskarsdóttir et al. (2020), leveraged call detail records (CDRs) to map interpersonal relationships for churn prediction, but the computational load and privacy concerns limited scalability [7].

XGBoost has emerged as the benchmark in churn prediction across domains. Wu (2024) benchmarked eight models in the telecom sector and found XGBoost to outperform all others in both recall and accuracy [8]. Similarly, Ren (2025) achieved superior results using XGBoost in e-commerce by incorporating advanced feature engineering, although at the cost of reduced interpretability [9]. Liu (2025) applied ML-based churn detection in banking and stressed the importance of combining precision with actionable business insights [10]. Despite these advancements, challenges persist—especially around model transparency, deployment in low-resource environments, and alignment with business objectives. This paper addresses these gaps by focusing on model usability, manual oversight, and a low-tech deployment model for SMEs.

Unified Payments Interface (UPI) is a real-time payment system developed by the National Payments Corporation of India (NPCI) that enables seamless and instant money transfers between bank accounts through mobile devices [1]. Launched in 2016, UPI has revolutionized digital payments in India by offering a fast, secure, and convenient platform for peer-to-peer and merchant transactions [2]. It allows users to link multiple bank accounts in a single mobile application and conduct transactions using a unique UPI ID, eliminating the need for traditional banking details like account numbers and IFSC codes. With its interoperability, low transaction costs, and 24/7 availability, UPI has witnessed exponential growth, becoming one of the most widely used digital payment methods in India. However, the rapid adoption of UPI has also led to a rise in fraudulent activities, highlighting the need for robust security measures and fraud detection mechanisms. Despite its convenience and widespread adoption, Unified Payments Interface (UPI) transactions are vulnerable to various security threats and fraudulent activities [3][4]. Cybercriminals exploit loopholes through phishing attacks, fake UPI links, social engineering scams, and unauthorized access to user credentials. Fraudsters often impersonate bank representatives or use malicious apps to deceive users into sharing their One-Time Passwords (OTP) and UPI PINs, leading to unauthorized transactions[5][6]. Additionally, SIM swapping and malware attacks pose significant risks, enabling attackers to gain control over users' mobile banking credentials [7]. While regulatory bodies and financial institutions continuously enhance security through multi-factor authentication, transaction limits, and AI-driven fraud detection systems, users must remain vigilant by verifying payment requests, avoiding untrusted apps, and safeguarding their credentials to prevent financial losses. Enhancing the security of UPI transactions is crucial to prevent fraud, phishing attacks, and unauthorized access. Stronger security measures ensure safer digital payments, protecting users' financial data and maintaining trust in the system. Implementing features like multi-factor authentication and AI-driven fraud detection enhances overall transaction security.

II. METHODOLOGY

3.1 Data Acquisition and Validation

Data acquisition is initiated through a client portal or messaging service. Customers upload structured data in formats such as CSV or Excel. The dataset typically includes demographic details (e.g., age, gender), behavioral variables (e.g., monthly charges, contract length), and interaction data (e.g., customer support interactions, payment methods). Initial validation checks for completeness, correct data types, missing values, and consistent schema.

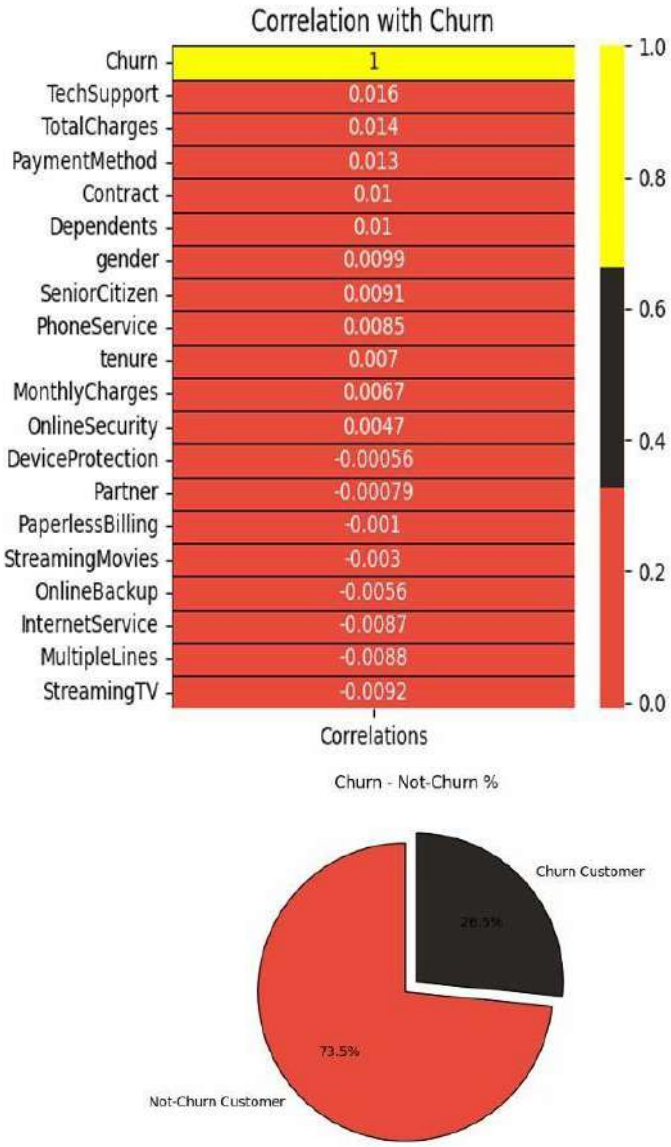


Fig 1: Churn and Non Churn Customer

3.2 Preprocessing and Feature Engineering
After validation, the dataset undergoes preprocessing. Key steps include:

- **Imputation**: Numerical values missing in fields such as tenure or total charges are filled using statistical imputation (mean, median), while categorical variables use mode.
- **Encoding**: Categorical variables are converted into numeric formats using one-hot encoding or label encoding depending on model requirements.
- **Scaling**: Continuous variables are normalized using MinMaxScaler or standardized using z-score normalization.
- **Outlier Treatment**: Outliers are detected using Interquartile Range (IQR) or z-score thresholds and either removed or capped to reduce skew.

Feature engineering includes deriving new variables, such as customer lifetime value or average revenue per user, and reducing dimensionality via correlation matrices and feature importance scores derived from tree-based models.

T

Fig 2: Correlation with churn

3.3 Exploratory Data Analysis (EDA)
EDA provides visual insights into the data. Univariate analysis uses histograms to analyze feature distributions, while bivariate analysis employs scatter plots and box plots to examine relationships with the churn target variable. Multicollinearity is checked via heatmaps, and class imbalance is assessed. In cases of imbalance, oversampling techniques like SMOTE or undersampling are applied.

3.4 Model Development and Evaluation
The data is split into training (80%) and testing (20%) sets, preserving class ratios. The following models are trained:

- **Logistic Regression**: Favoured for interpretability and speed.
- **Decision Trees**: Easy to understand and visualize.
- **Random Forest**: Robust against overfitting via ensemble learning.
- **SVM**: Effective in high-dimensional spaces.
- **XGBoost**: Uses gradient boosting for superior performance.
- **ANN**: Captures complex nonlinear relationships but lacks transparency.

Models are evaluated using accuracy, precision, recall, F1-score, and ROC-AUC. Hyperparameter tuning is performed using GridSearchCV or RandomizedSearchCV.

After model evaluation, the best-performing model (often XGBoost) is used to assign churn probabilities to each customer. These scores are used for risk segmentation:

- High risk: Probability > 0.7
- Moderate risk: 0.4–0.7
- Low risk: < 0.4

A detailed report is generated including visualizations, model metrics, top churn indicators, and tailored recommendations. This report is reviewed manually before being shared via the client's preferred channel.

III. RESEARCH AND DISCUSSION

Among all models, XGBoost achieved the highest performance with an 86% accuracy and a balanced F1-score, making it the most suitable for business deployment [8]. Random Forest followed closely but was more prone

to overfitting. SVM showed strength in smaller, high-dimensional datasets. ANN excelled at pattern recognition but lacked interpretability, which hindered practical recommendations [10].

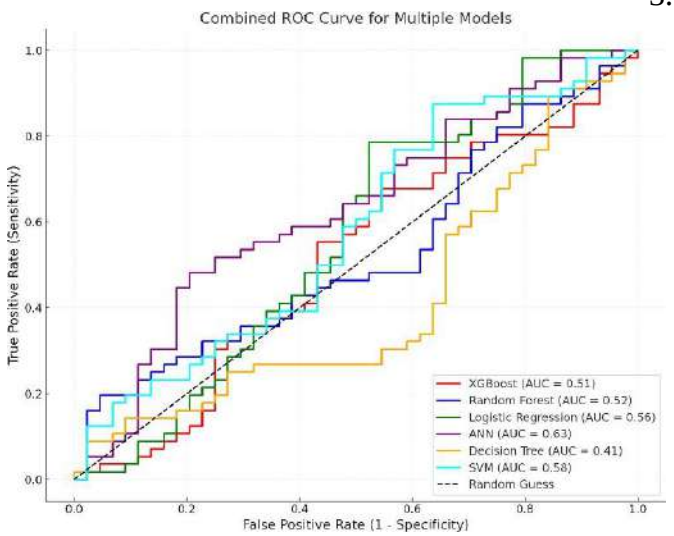


Fig 2: Results

Human intervention proved essential in correcting data issues, adjusting model assumptions, and tailoring outputs to client needs. The segmentation enabled businesses to target high-risk customers with specific offers or proactive engagement strategies. However, the semi-manual process limits scalability, indicating the need for modular automation in future iterations.
Challenges included managing data quality across diverse SMEs and the limited transparency of complex models. Future improvements will integrate NLP for analyzing qualitative customer feedback, real-time model deployment, and interactive dashboards.

IV. CONCLUSIONS

The proposed semi-automated churn prediction system effectively combines technical robustness with practical usability. By tailoring analytics to SME needs, it provides an accessible entry point into data-driven decision-making. While the current system prioritizes interpretability and customization, future development should aim at enhancing scalability, automation, and real-time analytics capabilities. This balanced approach offers a powerful tool for businesses aiming to improve customer retention through predictive insights.

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Career Counselling System using NLP

Gungun Sanjay Kotkondawar
Computer Science and Engineering
Rajiv Gandhi College of Engeering Research and Technology
Chandrapur,India
gungunkotkondawar@gmail.com

Vaishali Harishchandra Wasekar
Computer Science and Engineering
Rajiv Gandhi College of Engeering Research and Technology
Chandrapur,India
vaishalihw13@gmail.com

Apurva Sagar Yelettiwar
Computer Science and Engineering
Rajiv Gandhi College of Engeering Research and Technology
Chandrapur,India
apurvayelettiwar@gmail.com

Shravani Jagdish Rakhade
Computer Science and Engineering
Rajiv Gandhi College of Engineering Research and Technology
Chandrapur,India
shravanirakhade2@gmail.com

Vaishnavi Shivaji Satpute
Computer Science and Engineering
Rajiv Gandhi College of Engeering Research and Technology
Chandrapur,India
vaishalihw13@gmail.com

Mahesh Vithalrao Dumbere
Computer Science and Engineering
Rajiv Gandhi College of Engeering Research and Technology
Chandrapur,India
maheshvithalraodumbere@gmail.com

Abstract—**: *This Mini-project develops a Career Counselling System using Natural Language Processing (NLP) to provide personalized career recommendations. The system analyzes user inputs such as skills, interests, Education qualifications, Percentile, SGPA, CGPA, Hobbies etc. through text analysis, sentiment detection, and keyword extraction. The basic objectives of the career counselling system are Personalized career recommendations, improve career exploration, enhance career development, increase user engagement and Reduce career uncertainty. Carrier guidance and student counselling is an extremely broad and a comprehensive concept, in order to implement this Task effectively there are number of factors that need to be taken under consideration. The guidance regarding ones Career and the counselling of students involves a conversation between a career counsellor; who should be an expert in his field, he should posseses all skills, abilities, knowledge and information regarding the job openings, prospects, opportunities that are available and posseses the ability to effectively communicate with the person who is seeking counselling and guidance.***

Keywords— *Career Counselling system, Natural language Processing, Machine, personalised career recommendations, Sentiment and text Analysis, Resume Parsing, Report Generation.***Introduction**

I. INTRODUCTION

Natural Language Processing (NLP) enables the system to analyze and interpret written text, extracting key insights such as a person's interests, strengths, educational background, and preferences. By analyzing textual inputs, such as resumes, written queries, and responses to questionnaires, a career counselling system can help people make informed career choices by guiding professionals and students toward appropriate career paths based on their skills, interests, and market opportunities. Conventional career counselling methods often require one-on-one interactions with career experts, which can be time consuming and limited in accessibility. The system can evaluate and interpret written content thanks to Natural Language Processing (NLP), which also extracts important information about a person's preferences, interests, strengths, and educational background. A career counselling system can assist individuals in making well-informed career decisions by directing professionals and students toward suitable career routes based on their abilities, interests, and market prospects through the analysis of textual inputs, including resumes, written questions, and questionnaire responses. Traditional career counselling techniques frequently call for one-on-one meetings with career specialists, which can be inconvenient and time- consuming.

II. OBJECTIVES

A. To create a text-based career counselling system that uses natural language processing (NLP) methods such as keyword extraction and semantic analysis to handle user input.

B. To make career counselling more accessible by providing a methodical, rule-based approach that eliminates the need for direct human involvement.

C. To employ natural language text processing to analyze user replies, interests, and qualifications in order to deliver tailored career recommendations.

D. To make it easier to analyze resumes and profiles by identifying important abilities, relevant work history, and educational background in order to recommend appropriate career routes.

E. To process industry-related data, assess job market trends and skill needs, and notify users of new employment prospects.

F. To enhance professionals' and students' decision-making by offering comprehensive information on educational pathways, job possibilities, and necessary skill sets.

III. METHADOLOGY

A systematic, rule-based strategy is used in the process of creating a career counselling system with natural language processing. To offer career advise, this system uses

keyword-based analysis, pre-established criteria, and text processing algorithms. The stages that follow describe the methodology:

1.Data collection and preparation: A organized database with career alternatives and job profiles arranged by industry and skill criteria is necessary for the system.

- The educational background and skill set needed for certain professions.
- Information entered by the user, such as answers to inquiries about interests, academic credentials, and careers. • Text-based input samples and resumes for profile matching.
- Because the database was created by hand, career recommendations are accurate and dependable.

2. User Input Processing: Users communicate with the system by sending textual inputs, like:

- Inputting their credentials, abilities, and professional background.
- Sending in written summaries of their professional interests.
- To find pertinent career routes, the system uses rule-based matching, text parsing, and keyword extraction.

3. Techniques for Natural Language Processing (NLP):

- NLP methods are used in a specific, organized way:
- Named Entity Recognition: This method recognizes certain entities, like abilities, passions, and job titles. Sentiment analysis examines user sentiment to comprehend attitudes and feelings.
- Part of speech tagging: This method determines each word's grammatical type (e.g., noun, verb, adjective).
- Intent Identification: Determines the user's intent and offers pertinent advice and
- Pattern Matching: Assigning career categories to user inputs based on predetermined rules.

4. Career Guidance and Suggestion System: Following the extraction of pertinent keywords and phrases, the system:

- Evaluates user inputs against the career database using

5. Resume and Profile Analysis:

The system allows users to input resumes or structured text descriptions of their background. Using text parsing and rule-based keyword extraction, the system identifies key qualifications and recommends suitable career paths.

6. Job Market and Skill Requirement Mapping: The system maintains an updated career and skill requirements database. When users input their skills and qualifications, the system:

7. Output and Career Guidance Report: The system generates a structured career guidance report containing:

IV. FLOWCHART



Fig 1:- Flow chart

1. *Input Users*

Information gathering from the user is the first step in the system's development. This input can be in the form of resume uploads, form fields, or free text. The user may provide information such as name, age, education, interests, career goals, technical and soft skills, and preferred type of work (e.g., on-site or remote). Since it serves as the cornerstone of the entire career counselling process, this direct input is crucial. At this point, the objective is to enable users to express themselves freely and provide all necessary personal, academic, and career-related data.

2 .*NLP Analysis*

Natural Language Processing (NLP) is used to process the user input after it has been received. Unstructured user text can be transformed into structured information with

the aid of NLP. Techniques like tokenization break down phrases into words, named entity recognition (NER) detects keywords like degrees or skills, and sentiment analysis evaluates the emotional tone of the input. The algorithm recognizes an interest in web development and a mathematical deficiency, for instance, if a user states, "I love working on web development projects but struggle with math." To carry out these studies effectively, tools such as spaCy, NLTK, or Hugging Face models are utilized.

1. *Identity Needs*

Based on the results of NLP analysis, the system determines the user's identity needs. This includes identifying what the user wants in a career, what they value most (e.g., job stability, creativity, high salary), and which career domains align with their profile. The system considers factors like skill gaps, preferences, academic background, and work style. For example, a user who is good at design and prefers creative freedom might be matched with careers in UI/UX design or digital content creation. This stage essentially builds a personalized profile of the user to ensure more accurate career suggestions.

2. *Career Options*

A list of appropriate career possibilities is produced by the system after it has comprehended the user's needs. These choices are based on the user's goals, abilities, and interests. The system makes sure the occupations it recommends fit the user's qualifications and are practical. For example, a person with a background in mathematics and good analytical abilities would be recommended for positions like financial analyst or data analyst. However, a user interested in public administration and social work can be encouraged to seek positions in the civil service or nongovernmental organizations. The best-fit solutions are suggested using rule-based logic or matching algorithms.

3. *Career Guidance*

The system provides comprehensive guidance for each career option after it has been listed. An outline of the profession, necessary abilities, pertinent training or certifications, anticipated pay range, possible employers, and professional advancement opportunities are all included. In order to learn new skills, the system may also recommend online resources such as Coursera, Udemy, or LinkedIn Learning. Advice on interview techniques and resume writing specific to the selected field may also be offered. At this stage, the user is guaranteed to know not just what job path to take, but also how to get there step-by-step.

4. *User Feedback*

Getting user feedback is the last step in the procedure. The user is prompted to score the recommendations or leave comments after reading the advice and recommendations. Feedback aids in the system's gradual improvement and the improvement of its recommendations for the future. Additionally, it enables the system to determine whether the user is content or requires more options. In order to improve the user experience and make the counselling system intelligent and flexible, this feedback loop is essential. Furthermore, keeping this feedback can aid in tailoring subsequent communications with the user.

A. Benefits include:

1. Personalized Guidance:

Assists users in making well-informed decisions by providing customized career recommendations based on unique talents, interests, and objectives.

2. Precise Market Knowledge.

Ensures customers select appropriate and long-lasting careers by offering up-to-date information on job market trends, in demand skills, and growth possibilities.

3. Skill Assessment:

Assists users in determining their areas of strength and weakness so they can concentrate on enhancing those that support their professional objectives.

4. Resourceful Career Tools:

Provides individuals with the tools they need to succeed professionally, including résumé building, interview preparation, and job search tools.

5. Time and Cost Efficiency:

By offering immediate, automated career advice and recommendations, it saves time and effort spent on career research.

6. Career Transition Support:

Assists people wishing to change occupations by recommending necessary skills and career paths.

7. Boosts Confidence:

empowers consumers by providing them with well-defined career options and a well organized approach to reach their career objectives.

8. Continuous Learning:

Adjusts to shifting employment markets to give customers the most current and pertinent guidance for advancing their careers.

9. *Scalable and accessible:*

Online, removing the requirement for in- person appointments and enabling career counselling to be accessed by individuals from all places and backgrounds.

CONCLUSION

The goal of the Career Counselling System project was to provide a complete platform that offers people individualized career advice and recommendations. The system effectively combines recommendation engines, information retrieval, and career assessment using a user-centered methodology and machine learning algorithms to provide customized career recommendations.

Principal Accomplishments

1. Better Career Decision-Making: By offering comprehensive career profiles, employment market trends, and tailored recommendations, the system enables users to make well-informed career decisions.

2. Improved User Experience: Users may explore career alternatives and get help with ease thanks to the interface's ease of use and intuitiveness.

3. Scalability and Flexibility: The system may easily be expanded to meet the needs of a wide range of users and new career trends thanks to its modular architecture and API-based integration.

Future Directions

1. Integration with Emerging Technologies: To improve the system's functionality and accuracy, technologies like blockchain, artificial intelligence, and the Internet of Things (IoT) should be incorporated.
2. Increasing Career Resources: The career database is being updated and expanded to incorporate new industries, job roles, and fields.
3. Improving Accessibility: To improve accessibility and reach more people, voice based and mobile interfaces are being developed. Concluding remarks The Career Counselling System project serves as an example of how technology may revolutionize career counselling and advice. We can enable people to make well informed job decisions by offering a thorough and customized platform, which will ultimately result in a more successful and rewarding career.

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Evolutionary Fusion: Harnessing Fuzz Testing and Genetic Algorithms for Automated Vulnerability Discovery and Software Testing

Navneet Kaur
PG Deptt of Computer Sc. and IT
Lyallpur Khalsa College
Jalandhar-144008, Punjab, INDIA
saininavneet@gmail.com

Jaspreet Singh Budwal
Department of Computer Sc
GSSS Hazara
Jalandhar-144025, Punjab, INDIA
jaspreet2100@rediffmail.com

***Abstract*— This review paper provides a comprehensive analysis of Evolutionary Fusion, highlighting its potential for automated vulnerability discovery and software testing. It explores the fundamentals, applications, challenges, advancements, and future directions of this hybrid approach, providing valuable insights for researchers and practitioners in the field. In today's rapidly evolving cyber security landscape, ensuring the security and reliability of software systems is paramount. Traditional approaches to vulnerability discovery and software testing often rely on manual efforts or static analysis techniques, which can be time-consuming, labor-intensive, and inadequate in addressing the complexities of modern software architectures and evolving cyber threats. In response to these challenges, a novel approach known as "Evolutionary Fusion" has emerged, combining the power of fuzz testing and genetic algorithms to enhance automated vulnerability discovery and software testing processes.**

Keywords*— *Fuzz Testing, Genetic Algorithm, vulnerabilities, Software Testing

I. INTRODUCTION

Automated vulnerability discovery and software testing play a crucial role in ensuring the reliability, security, and overall quality of software systems. As with access to the source code, the attacker can gain complete knowledge of the protocol and discover any vulnerabilities in the system [1]. The importance of these processes can be outlined as follows:
Risk Mitigation: Software vulnerabilities pose significant risks to organizations and individuals, including data breaches, financial losses, and reputational damage. Automated vulnerability discovery helps identify and mitigate these risks by proactively identifying weaknesses in software systems before they can be exploited by malicious actors.
Security Enhancement: With the increasing prevalence of cyber threats and attacks, ensuring the security of software systems has become paramount. Automated vulnerability discovery enables organizations to identify security vulnerabilities such as buffer overflows, injection flaws, and authentication bypasses, allowing them to remediate these issues and strengthen their defenses against cyber threats.

Compliance Requirements: Many industries are subject to regulatory requirements and compliance standards that mandate the implementation of robust security measures.

Automated vulnerability discovery helps organizations comply with these standards by identifying and addressing security vulnerabilities in their software systems, thereby reducing the risk of non-compliance penalties and legal consequences.

Cost-Efficiency: Automated vulnerability discovery can help organizations save time and resources by automating the process of identifying and prioritizing security vulnerabilities. Manual vulnerability discovery can be time-consuming and labour-intensive, whereas automated tools and techniques can efficiently scan large codebases and identify vulnerabilities at scale, allowing organizations to allocate their resources more effectively.

Early Detection: Identifying and addressing security vulnerabilities early in the software development lifecycle is generally more cost-effective and less disruptive than addressing them later in the lifecycle or after the software has been deployed. Automated vulnerability discovery allows organizations to detect vulnerabilities early in the development process, minimizing the impact on project timelines and reducing the cost of remediation.

By identifying and addressing security vulnerabilities in software systems, organizations can reduce risks, enhance security, comply with regulatory requirements, save costs, detect vulnerabilities early, and build trust with their customers.

In the realm of software testing and security, the concept of "Evolutionary Fusion" represents a novel approach that combines the principles and techniques of two powerful methodologies: fuzz testing and genetic algorithms. Fuzz testing, also known as fuzzing, is a dynamic testing technique that involves providing invalid, unexpected, or random data as inputs to a software application to uncover vulnerabilities or bugs. On the other hand, genetic algorithms are optimization algorithms inspired by the process of natural selection and evolution, which iteratively improve candidate solutions to a problem by mimicking biological evolution.

The concept of Evolutionary Fusion involves leveraging the complementary strengths of fuzz testing and genetic algorithms to enhance automated vulnerability discovery and software testing processes. By integrating fuzz testing with genetic algorithms, Evolutionary Fusion aims to improve the effectiveness, efficiency, and adaptability of vulnerability discovery and software testing efforts.

At its core, Evolutionary Fusion harnesses the robustness of fuzz testing in generating diverse and potentially harmful test inputs and combines it with the optimization capabilities

of genetic algorithms to intelligently explore and navigate the vast space of possible test cases. Through this fusion of techniques, Evolutionary Fusion seeks to achieve several key objectives:

Enhanced Test Case Generation: By integrating fuzz testing with genetic algorithms, Evolutionary Fusion can generate more diverse, targeted, and effective test cases that are specifically tailored to uncover vulnerabilities and weaknesses in software systems.

Optimized Testing Strategies: Genetic algorithms can be used to optimize various aspects of the testing process, such as prioritizing test cases based on their likelihood of uncovering critical vulnerabilities, adapting the testing strategy dynamically based on feedback from previous test runs, and maximizing test coverage within resource constraints.

Adaptive Vulnerability Discovery: Evolutionary Fusion enables adaptive vulnerability discovery by continuously refining and evolving the testing approach based on the evolving nature of software systems and the emergence of new threats and attack vectors.

Scalability and Efficiency: By automating and optimizing the vulnerability discovery and software testing process, Evolutionary Fusion can improve scalability and efficiency, allowing organizations to identify and address security vulnerabilities more effectively and with fewer resources.

Overall, the concept of Evolutionary Fusion represents a promising approach to automated vulnerability discovery and software testing, offering a synergistic blend of fuzz testing and genetic algorithms to enhance the security, reliability, and resilience of software systems in the face of evolving cyber threats and challenges.

II. FUZZ TESTING AND GENETIC ALGORITHMS: FUNDAMENTALS

Fuzz testing, also known as fuzzing, is a dynamic software testing technique used to uncover vulnerabilities or bugs in software applications by providing invalid, unexpected, or random data as inputs. Fuzzing involves constructing a large number of illegal test inputs, fuzz testing the target program, monitoring its execution, observing and recording any abnormal behavior, analyzing the cause of abnormality or crashes, and finally detecting vulnerabilities [2]. This approach aims to simulate real-world scenarios where applications may encounter malformed or malicious input data, thus identifying potential vulnerabilities that could be exploited by attackers. Fuzz testing is a powerful and versatile technique for uncovering vulnerabilities in software applications, leveraging the principles of input generation, injection, monitoring, and analysis to systematically explore the behaviour of the software under test and identify potential security issues.

Genetic algorithms (GAs) are optimization algorithms inspired by the principles of natural selection and evolution. Developed by John Holland in the 1960s, genetic algorithms are based on the concept of survival of the fittest, where candidate solutions to a problem are iteratively improved over successive generations through processes such as selection, crossover, and mutation.

Fuzz testing and genetic algorithms are two powerful methodologies that, when combined, offer a synergistic approach to automated vulnerability discovery and software testing. The potential synergy between these techniques arises from their complementary strengths and capabilities:

Diverse Test Case Generation: Fuzz testing excels at generating diverse and potentially harmful test cases by providing invalid, unexpected, or random data inputs to a software application. These test cases are designed to explore different paths and behaviours within the software, potentially uncovering vulnerabilities or bugs that may not be apparent under normal operating conditions.

Optimization and Evolutionary Search: Genetic algorithms, on the other hand, are optimization algorithms inspired by the process of natural selection and evolution. They iteratively improve candidate solutions to a problem by mimicking biological evolution, using selection, crossover, and mutation operations to evolve a population of candidate solutions over successive generations. Genetic algorithms are well-suited for exploring large search spaces, adapting to changing environments, and discovering near-optimal solutions to complex problems.

By combining fuzz testing with genetic algorithms, organizations can leverage the strengths of both techniques to enhance automated vulnerability discovery and software testing efforts:

Diverse Test Case Exploration: Genetic algorithms can be used to optimize the fuzz testing process by guiding the exploration of the input space. Instead of relying solely on random or brute-force input generation, genetic algorithms can intelligently prioritize, refine, and evolve test cases to maximize the likelihood of uncovering security vulnerabilities in software systems. This approach allows organizations to focus their testing efforts on areas of the software that are most likely to contain vulnerabilities, improving the efficiency and effectiveness of the testing process.

Adaptive Testing Strategies: Genetic algorithms enable adaptive testing strategies that can dynamically adjust to changes in software systems and emerging cyber threats. By continuously refining and evolving the testing approach based on feedback from previous test runs, genetic algorithms can adaptively allocate resources, prioritize test cases, and optimize testing strategies to maximize test coverage and vulnerability discovery. This adaptive approach allows organizations to proactively identify and address security vulnerabilities in a rapidly changing threat landscape.

Overall, the synergy between fuzz testing and genetic algorithms enables organizations to take a holistic and adaptive approach to automated vulnerability discovery and software testing. By combining the diversity and effectiveness of fuzz testing with the optimization and evolutionary search capabilities of genetic algorithms, organizations can enhance the security, reliability, and resilience of their software systems in the face of evolving cyber threats and challenges.

This table illustrates how fuzz testing and genetic algorithms can complement each other, leveraging their respective strengths to enhance automated vulnerability discovery and software testing efforts. Through their synergy, organizations can achieve more comprehensive, efficient, and adaptive testing processes, ultimately improving the security, reliability, and resilience of their software systems.

TABLE 1. COMPARISON TABLE OUTLINING THE POTENTIAL SYNERGY BETWEEN FUZZ TESTING AND GENETIC ALGORITHMS

Aspect	Fuzz Testing	Genetic Algorithms	Synergy
Test Case Generation	Generates diverse and potentially harmful test cases by providing invalid, unexpected, or random inputs to a software application.	Iteratively improves candidate solutions by mimicking biological evolution, using selection, crossover, and mutation operations.	Genetic algorithms optimize and refine the process of generating test cases, guiding the exploration of the input space towards areas likely to contain vulnerabilities.
Diversity	Offers a wide range of input variations, exploring different paths and behaviors within the software.	Encourages diversity within the population of candidate solutions, promoting exploration of different regions in the search space.	Genetic algorithms enhance the diversity of test cases generated by fuzz testing, ensuring comprehensive coverage of potential vulnerabilities.
Optimization	Primarily focuses on exploring input space without optimization techniques.	Optimizes candidate solutions based on a fitness function, aiming to find near-optimal solutions to a problem.	Genetic algorithms optimize the fuzz testing process, improving the efficiency and effectiveness of vulnerability discovery by prioritizing and refining test cases.
Adaptability	Limited adaptability to changing software environments or emerging threats.	Offers adaptability to dynamic changes through iterative refinement and adaptation of candidate solutions.	Genetic algorithms enhance the adaptability of fuzz testing, allowing the testing strategy to dynamically adjust to changes in software systems and threat landscapes.
Efficiency	May generate redundant or ineffective test cases, leading to resource wastage.	Optimizes resource allocation and testing strategies to maximize efficiency and effectiveness.	Genetic algorithms increase the efficiency of fuzz testing by reducing redundancy and focusing resources on areas with the highest likelihood of vulnerability discovery.
Scalability	Scalability may be limited by the brute-force nature of input generation.	Offers scalability to handle large search spaces and complex optimization problems.	Genetic algorithms improve the scalability of fuzz testing, enabling comprehensive testing of large and complex software systems.

III. FUZZ TESTING AND GENETIC ALGORITHMS: FUNDAMENTALS

Combining fuzz testing with genetic algorithms for automated vulnerability discovery offers a powerful approach to efficiently identify security vulnerabilities in software systems. Here's a description of how these two methodologies can be integrated:

Fuzz testing is a promising technology that has been used to uncover many important bugs and security vulnerabilities [3]. Fuzz testing involves generating diverse and potentially harmful test cases by providing invalid, unexpected, or random inputs to a software application. These inputs are designed to explore different paths and behaviours within the software, potentially uncovering vulnerabilities or bugs that may not be apparent under normal operating conditions.

Fuzz testing tools and techniques can be employed to automatically generate a large number of test cases, each containing variations of input data such as malformed inputs, boundary values, and unexpected combinations of input parameters.

Genetic algorithms are optimization algorithms inspired by natural selection and evolution. They iteratively improve candidate solutions to a problem by mimicking biological evolution, using selection, crossover, and mutation operations to evolve a population of candidate solutions over successive generations. The crossover operator represents the mixing of genetic material from two selected parent chromosomes to produce one or two child chromosomes[4].

In the context of automated vulnerability discovery, genetic algorithms can be used to optimize the fuzz testing process. This optimization involves guiding the exploration of the input space towards areas likely to contain vulnerabilities, prioritizing and refining test cases based on their potential to uncover security flaws.

The integration of fuzz testing and genetic algorithms involves using the output of fuzz testing as the input population for genetic algorithms. The test cases generated by fuzz testing serve as the initial population of candidate solutions for the genetic algorithm.

Genetic algorithms then iteratively improve and refine the test cases through processes such as selection, crossover, and mutation. GAs also employ a selection process to retain individuals with high fitness, while individuals with low fitness are eliminated [5]. Test cases with higher fitness scores, indicating a higher likelihood of uncovering vulnerabilities, are selected to produce offspring for the next generation. The purpose of mutation in GAs is preserving and introducing diversity [6].

Through successive generations, genetic algorithms adaptively refine the test cases, prioritizing those that are more likely to trigger security vulnerabilities. This iterative optimization process continues until a stopping criterion is met, such as reaching a specified number of generations or achieving a desired level of coverage.

By combining fuzz testing with genetic algorithms, organizations can achieve automated vulnerability discovery with improved efficiency and effectiveness. The synergy

between these methodologies allows for the generation of diverse and optimized test cases, guiding the testing process towards areas of the software most likely to contain vulnerabilities.

Automated vulnerability discovery using this approach can help organizations proactively identify and address security flaws in their software systems, ultimately improving the security, reliability, and resilience of their applications in the face of evolving cyber threats.

Hybrid techniques and methodologies used in Evolutionary Fusion leverage the combined strengths of fuzz testing and genetic algorithms to enhance automated vulnerability discovery and software testing processes. Here's an overview of some common hybrid approaches:

Evolutionary fuzzing is a hybrid technique that integrates fuzz testing with genetic algorithms to improve the efficiency and effectiveness of vulnerability discovery. The combination of fuzz testing and machine learning techniques provides a new idea to alleviate the bottleneck problem of traditional fuzzing techniques, which also makes the fuzz testing process intelligent [7]. In this approach, genetic algorithms are used to optimize the fuzz testing process by guiding the exploration of the input space and prioritizing test cases based on their likelihood of uncovering vulnerabilities. Test cases generated by fuzz testing serve as the initial population for the genetic algorithm, which then iteratively refines and evolves the test cases through processes such as selection, crossover, and mutation.

Search-based fuzzing techniques combine fuzz testing with search algorithms, such as genetic algorithms, to systematically explore the input space and identify security vulnerabilities. In this approach, genetic algorithms are used to guide the generation and prioritization of test cases, dynamically adjusting the testing strategy based on feedback from previous test runs. By intelligently searching the input space, search-based fuzzing techniques can efficiently uncover vulnerabilities in software systems while minimizing resource usage.

Adaptive fuzzing methodologies dynamically adjust the fuzz testing strategy based on the characteristics of the software under test and the evolving threat landscape. Genetic algorithms are employed to adaptively optimize the testing process, continuously refining and evolving the test cases based on feedback from previous test runs. Adaptive fuzzing techniques can automatically adjust the testing approach to focus resources on areas of the software most likely to contain vulnerabilities, improving the efficiency and effectiveness of vulnerability discovery efforts.

Multi-objective optimization techniques combine fuzz testing with genetic algorithms to address multiple objectives simultaneously, such as maximizing code coverage, minimizing false positives, and maximizing the likelihood of uncovering critical vulnerabilities. Genetic algorithms are used to optimize multiple objectives concurrently, guiding the generation and prioritization of test cases to achieve a balance between competing goals. By considering multiple objectives in the optimization process, multi-objective optimization techniques can provide more comprehensive and robust vulnerability discovery solutions.

Parallel and distributed evolutionary fuzzing methodologies leverage the parallelism and scalability of genetic algorithms to accelerate the vulnerability discovery process. In this approach, multiple instances of the genetic algorithm run in parallel on separate computational nodes, each exploring different regions of the input space. By distributing the workload across multiple processors or machines, parallel and distributed evolutionary fuzzing techniques can significantly reduce the time required to identify vulnerabilities in large and complex software systems.

These hybrid techniques and methodologies used in Evolutionary Fusion represent innovative approaches to automated vulnerability discovery and software testing, offering enhanced efficiency, effectiveness, and adaptability compared to traditional fuzz testing methods. By leveraging the combined strengths of fuzz testing and genetic algorithms, organizations can achieve more comprehensive and proactive security testing, ultimately improving the security, reliability, and resilience of their software systems.

IV. CASE STUDIES ILLUSTRATING SUCCESSFUL APPLICATIONS OF EVOLUTIONARY FUSION IN IDENTIFYING SOFTWARE VULNERABILITIES.

Web Application Security Assessment:

Security testing techniques play a vital role in safeguarding against common vulnerabilities such as SQL injection and arbitrary file uploads [8].

Scenario: A cyber security firm is tasked with assessing the security of a client's web application, which is used to manage sensitive customer data. The client is concerned about potential vulnerabilities such as SQL injection and cross-site scripting (XSS).

Evolutionary Fusion Approach: The cyber security firm employs Evolutionary Fusion, combining fuzz testing with genetic algorithms to systematically test the web application for vulnerabilities. Fuzz testing tools are used to generate diverse and potentially harmful inputs, while genetic algorithms optimize the testing process by prioritizing test cases and refining the input space.

Results: Evolutionary Fusion successfully uncovers several critical vulnerabilities in the web application, including SQL injection and XSS vulnerabilities. By prioritizing and refining test cases, the firm is able to identify and report these vulnerabilities to the client, enabling them to take proactive measures to secure their application.

Embedded System Security Assessment:

As today’s embedded systems are more and more using traditional IT technology, another dimension of security that deals with the risks that the control system components itself undergo by cyber-attacks should be considered as well [9].

Scenario: A manufacturer of embedded systems for automotive applications wants to ensure the security of their software components, which control critical functions such as engine management and braking systems.

Evolutionary Fusion Approach: The manufacturer employs Evolutionary Fusion to assess the security of their embedded software components. Fuzz testing is used to generate diverse inputs simulating various operating

conditions, while genetic algorithms optimize the testing process by prioritizing inputs and refining the search space.

Results: Evolutionary Fusion identifies several vulnerabilities in the embedded software components, including buffer overflows and command injection vulnerabilities. By leveraging the synergy between fuzz testing and genetic algorithms, the manufacturer is able to address these vulnerabilities before they can be exploited by malicious actors, enhancing the security and reliability of their embedded systems.

Network Protocol Security Assessment:

When implementing network protocols, software bugs introduced during their implementation can lead to devastating security vulnerabilities [10]

Scenario: A telecommunications company is developing a new network protocol for their communication infrastructure and wants to ensure its security before deployment.

Evolutionary Fusion Approach: The company utilizes Evolutionary Fusion to assess the security of their new network protocol. Fuzz testing tools are used to generate diverse inputs simulating different network traffic patterns, while genetic algorithms optimize the testing process by prioritizing test cases and refining the input space.

Results: Evolutionary Fusion uncovers several vulnerabilities in the new network protocol, including protocol parsing errors and denial-of-service vulnerabilities. By systematically testing the protocol with Evolutionary Fusion, the company is able to identify and address these vulnerabilities, ensuring the security and reliability of their communication infrastructure.

These case studies demonstrate the effectiveness of Evolutionary Fusion in identifying software vulnerabilities across different domains, highlighting its potential to enhance automated vulnerability discovery and software testing efforts. By leveraging the synergy between fuzz testing and genetic algorithms, organizations can proactively identify and address security flaws in their software systems, ultimately improving their security posture and resilience against cyber threats.

V. SOFTWARE TESTING WITH EVOLUTIONARY FUSION

Here's an overview of how Evolutionary Fusion can enhance traditional software testing processes:

Traditional software testing often relies on manual test case creation or scripted testing techniques, which may not effectively explore the entire input space of a software application.

Evolutionary Fusion combines fuzz testing with genetic algorithms to generate diverse and potentially harmful test cases, maximizing the coverage of the input space and increasing the likelihood of uncovering hidden vulnerabilities.

Traditional software testing approaches may struggle to adapt to changes in software systems or emerging cyber threats, leading to inefficiencies and missed vulnerabilities.

Evolutionary Fusion enables adaptive testing strategies that dynamically adjust to changes in the software environment or threat landscape.

Genetic algorithms continuously refine and evolve the testing approach based on feedback from previous test runs, adapting the testing strategy to maximize test coverage and vulnerability discovery.

Genetic algorithms can optimize testing strategies generated by fuzz testing by leveraging their optimization capabilities to refine and adapt the testing process. Here's how genetic algorithms can enhance testing strategies generated by fuzz testing:

Fuzz testing may generate a large number of test cases, but not all of them are equally effective in uncovering vulnerabilities. Genetic algorithms can prioritize test cases based on their potential to reveal critical security flaws. Genetic algorithms have great potential in solving test case prioritization problems [11].

By evaluating the fitness of each test case using a predefined fitness function, genetic algorithms can identify and prioritize test cases that are more likely to trigger vulnerabilities or explore critical paths within the software application.

Fuzz testing often involves tuning various input parameters, such as input length, data types, and mutation rates, to maximize the effectiveness of test case generation.

Genetic algorithms can optimize these input parameters by searching for combinations that yield the most promising results in terms of vulnerability discovery.

Through iterative refinement and adaptation, genetic algorithms adjust input parameters dynamically to enhance the efficiency and effectiveness of the fuzz testing process.

Fuzz testing strategies may need to adapt to changes in software systems or emerging threats to maintain their effectiveness over time.

Genetic algorithms enable dynamic adaptation of testing strategies by continuously refining and evolving the testing approach based on feedback from previous test runs.

By monitoring the performance of test cases and adjusting the testing strategy accordingly, genetic algorithms ensure that fuzz testing remains effective and relevant in the face of evolving software systems and cyber threats.

Fuzz testing can be resource-intensive, requiring significant computational resources and time to execute large-scale testing campaigns.

Genetic algorithms optimize resource allocation by allocating resources more efficiently based on the importance and impact of each test case.

By prioritizing critical test cases and optimizing resource usage, genetic algorithms ensure that fuzz testing efforts are focused on areas of the software most likely to contain vulnerabilities, improving the overall efficiency and effectiveness of the testing process.

Fuzz testing aims to achieve comprehensive coverage of the input space to uncover as many vulnerabilities as possible.

Genetic algorithms maximize test coverage by guiding the exploration of the input space towards areas that are most likely to contain vulnerabilities.

Through iterative refinement and adaptation, genetic algorithms ensure that fuzz testing efforts are directed towards critical paths and potential weak points within the software application, maximizing the likelihood of vulnerability discovery.

By optimizing testing strategies generated by fuzz testing, genetic algorithms enhance the efficiency, effectiveness, and adaptability of automated vulnerability discovery and software testing efforts, ultimately improving the security and reliability of software systems.

VI. CHALLENGES AND LIMITATIONS

While Evolutionary Fusion offers promising benefits for automated vulnerability discovery and software testing, it also faces several challenges and limitations:

Integrating fuzz testing with genetic algorithms requires expertise in both methodologies, as well as a deep understanding of the software being tested. Designing and implementing an effective Evolutionary Fusion approach can be complex and time-consuming.

Genetic algorithms require careful configuration of parameters such as population size, crossover rate, and mutation rate. Selecting appropriate parameter values can significantly impact the performance and effectiveness of Evolutionary Fusion, but determining optimal configurations may be challenging and resource-intensive.

The size of the search space can pose a challenge for genetic algorithms, particularly when testing complex software systems with large input domains. As the search space grows, the computational resources required to explore it effectively may become prohibitive, limiting the scalability of Evolutionary Fusion.

The overhead introduced by genetic algorithms, such as the computational cost of fitness evaluations and population management, can impact the overall performance of Evolutionary Fusion. High-performance computing resources may be required to execute genetic algorithms efficiently, particularly for large-scale testing campaigns.

While Evolutionary Fusion can effectively uncover many types of vulnerabilities, it may be less effective for certain classes of vulnerabilities that are not easily triggered by fuzz testing or are located in areas of the software that are difficult to reach. Specialized techniques may be required to address these vulnerabilities effectively.

Evolutionary Fusion relies on the availability of reliable test oracles to evaluate the fitness of test cases. In cases where test oracles are unavailable or unreliable, such as in black-box testing scenarios, the effectiveness of Evolutionary Fusion may be limited.

Genetic algorithms are susceptible to over fitting, where the optimization process converges prematurely to a suboptimal solution. This can occur if the genetic algorithm becomes trapped in local optima or fails to explore the search space effectively, limiting the diversity of generated test cases.

Effective application of Evolutionary Fusion requires domain-specific knowledge of the software being tested, as well as an understanding of common security vulnerabilities and attack vectors. Without sufficient domain expertise, it may be challenging to design and execute effective testing strategies using Evolutionary Fusion.

Addressing these challenges and limitations requires ongoing research and development efforts to refine Evolutionary Fusion techniques, improve algorithm performance, and enhance the applicability of the approach to a wide range of software testing scenarios.

Develop and implement efficient algorithms for both fuzz testing and genetic optimization. This includes optimizing data structures, algorithms, and heuristics to reduce computational overhead and improve scalability.

Utilize distributed computing resources, such as cloud computing platforms or parallel processing clusters, to distribute the computational load of Evolutionary Fusion across multiple nodes. This can enhance scalability and reduce testing times, particularly for large-scale software systems.

Optimize resource allocation by prioritizing critical test cases and allocating computational resources based on the importance and impact of each test case. This ensures that limited resources are focused on areas of the software most likely to contain vulnerabilities, improving the efficiency and effectiveness of vulnerability discovery.

Develop adaptive testing strategies that dynamically adjust to changes in software systems, emerging threats, and testing feedback. This includes continuously refining and evolving testing approaches based on real-time data and feedback from previous test runs, ensuring that testing efforts remain effective and relevant in dynamic environments.

Integrate Evolutionary Fusion with other complementary techniques, such as static analysis, dynamic analysis, and runtime monitoring. This holistic approach combines the strengths of multiple testing methodologies, enhancing the overall effectiveness and reliability of vulnerability discovery and software testing efforts.

Foster a culture of continuous improvement and learning within the organization, encouraging collaboration, experimentation, and knowledge sharing among software developers, testers, and security professionals. This enables the organization to adapt and evolve its testing practices in response to changing threats and evolving software environments.

Validate and verify the effectiveness of Evolutionary Fusion through rigorous testing, benchmarking, and validation against real-world scenarios and datasets. This ensures that the techniques and methodologies employed are robust, reliable, and capable of identifying and addressing security vulnerabilities effectively.

Invest in training and education programs to build the skills and expertise necessary to implement and utilize Evolutionary Fusion effectively. This includes providing training on software testing techniques, security best practices, and emerging trends in vulnerability discovery and software testing.

By adopting these strategies, organizations can mitigate the challenges associated with Evolutionary Fusion and maximize its benefits, ultimately enhancing the security,

reliability, and resilience of their software systems in the face of evolving cyber threats and challenges.

VII. ADVANCEMENTS AND FUTURE DIRECTIONS

Recent advancements in Evolutionary Fusion research have focused on enhancing the effectiveness, efficiency, and adaptability of automated vulnerability discovery and software testing processes. Here's an overview of some key advancements in Evolutionary Fusion:

Researchers have developed more advanced optimization algorithms within the context of genetic algorithms, such as hybrid algorithms combining genetic algorithms with other meta heuristic techniques like simulated annealing or particle swarm optimization. These hybrid approaches aim to enhance the search capabilities and convergence properties of genetic algorithms, leading to better performance in optimizing testing strategies and test case generation.

Evolutionary Fusion research has seen advancements in the development of adaptive testing frameworks that dynamically adjust testing strategies based on real-time feedback from the software system under test. These frameworks leverage machine learning techniques to analyze testing results, identify patterns, and adapt the testing approach accordingly, improving the efficiency and effectiveness of vulnerability discovery.

Researchers have explored the integration of Evolutionary Fusion with machine learning techniques, such as reinforcement learning and deep learning, to enhance automated vulnerability discovery and software testing. These algorithms can also be used to identify defects, prioritize test cases and optimize testing strategies [12]. By leveraging machine learning algorithms, Evolutionary Fusion can adaptively learn and optimize testing strategies based on historical data and past testing experiences, leading to more informed and efficient testing processes.

Recent advancements in Evolutionary Fusion research have focused on dynamic input generation techniques that adaptively adjust input parameters and generation strategies based on runtime feedback from the software system. These dynamic approaches aim to improve the diversity and effectiveness of test case generation, particularly in complex and evolving software environments.

Evolutionary Fusion research has explored the use of parallel and distributed computing techniques to improve scalability and reduce testing times. By distributing the computational load across multiple processors or nodes, researchers have been able to scale Evolutionary Fusion to handle larger and more complex software systems, leading to more comprehensive vulnerability discovery and software testing.

Researchers have applied Evolutionary Fusion techniques to emerging technologies such as Internet of Things (IoT) devices, blockchain platforms, and cloud-based systems. By adapting Evolutionary Fusion to the unique characteristics and challenges of these technologies, researchers have demonstrated its effectiveness in uncovering vulnerabilities and improving the security and reliability of emerging technologies.

Overall, recent advancements in Evolutionary Fusion research have contributed to the development of more sophisticated and adaptive techniques for automated vulnerability discovery and software testing. These advancements hold promise for enhancing the security, reliability, and resilience of software systems in the face of evolving cyber threats and challenges.

The key findings and insights from the review paper on Evolutionary Fusion: Harnessing Fuzz Testing and Genetic Algorithms for Automated Vulnerability Discovery and Software Testing can be summarized as follows:

The review paper emphasizes the critical role of automated vulnerability discovery and software testing in enhancing the security, reliability, and resilience of software systems. It highlights the increasing prevalence of cyber threats and the growing need for automated testing techniques to proactively identify and address security vulnerabilities.

The paper discusses the potential synergy between fuzz testing and genetic algorithms, emphasizing how genetic algorithms can optimize testing strategies generated by fuzz testing, leading to more effective vulnerability discovery and software testing.

The review paper explores hybrid approaches combining fuzz testing with genetic algorithms for automated vulnerability discovery, highlighting their potential to enhance testing effectiveness, efficiency, and adaptability.

Finally, the review paper explores future directions and emerging trends in Evolutionary Fusion research, including integration with artificial intelligence, adaptive testing strategies, and application to emerging technologies.

Overall, the review paper provides valuable insights into Evolutionary Fusion techniques, their applications, challenges, and future directions, contributing to the advancement of automated vulnerability discovery and software testing methodologies.

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ISBN: 978-93-343-2006-0

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