International Conference on Intelligent Electronics and Communication Systems (ICIECS) - 2025

Sponsored by

THE INSTITUTION OF ELECTRONICS AND TELECOMMUNICATION ENGINEERS, VIJAYAWADA CENTRE

Organized by

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Message by the President



I am very pleased to note that the **Department of Electronics and Communication Engineering** of **Prasad V. Potluri Siddhartha Institute of Technology**, sponsored by **Siddhartha Academy of General and Technical Education (SAGTE), Vijayawada**, is organizing the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)** on **27th December 2025**.

Our vision is to create world-class engineers enriched with strong technical competence and human values, capable of serving society and the nation. In pursuit of this vision, the institute actively encourages all departments to organize national and international conferences, workshops, and seminars that promote technical enrichment and research culture among faculty members and students.

I sincerely appreciate the efforts of the **Department of Electronics and Communication Engineering** in organizing ICIECS-2025. We strongly support such academic initiatives, as they enable faculty members to stay abreast of the latest technological advancements and provide a platform to contribute innovative ideas and research outcomes.

I wish ICIECS-2025 a **grand success** and hope the conference proves to be **technically enriching, intellectually stimulating and rewarding** for all participants.

Sri M. Rajaiah Garu

Message by The Secretary



I feel immense pleasure and pride in being associated with the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)**, organized by the **Department of Electronics and Communication Engineering**, **Prasad V. Potluri Siddhartha Institute of Technology**, and scheduled to be held on **27th December 2025**.

I congratulate the organizing committee for successfully planning this international conference and for bringing out the conference proceedings. Such conferences are the need of the hour, as they provide academicians, researchers and students an opportunity to gain exposure to the latest developments and emerging technologies in the field of Electronics and Communication Engineering. Continuous updating of knowledge is essential in the life of an engineer, and Prasad V. Potluri Siddhartha Institute of Technology has always supported and encouraged such academic and research-oriented initiatives.

In today's rapidly evolving technological environment, contemporary curricula must be complemented with dynamic teaching–learning practices and platforms for knowledge exchange. I am confident that this international conference organized by the Department of ECE will contribute significantly towards fulfilling the aspirations and dreams of the younger generation.

On this occasion, I take the opportunity to congratulate all the faculty members and students of the **ECE Department** for their dedication, efforts, and initiative in organizing ICIECS-2025. I wish them continued success and excellence in all their future endeavours.

Sri P. Lakshmana Rao Garu

Message by the Convener



I am pleased to note that the **Department of Electronics and Communication Engineering** of **Prasad V. Potluri Siddhartha Institute of Technology (PVPSIT)** is organizing the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)** on **27th December 2025** and is releasing the conference proceedings on this occasion.

For more than **25 years**, Prasad V. Potluri Siddhartha Institute of Technology has been rendering commendable service in the field of engineering education by providing excellent infrastructure, a conducive learning environment, and a dedicated team of highly qualified and experienced faculty. These strengths have enabled the institution to move forward with confidence and distinction in this highly competitive era of technological advancement.

PVPSIT has been consistently fulfilling its responsibility of nurturing and empowering the youth, who are the true national asset and the future of India. In the years to come, the institute will undoubtedly continue to shape thousands of competent engineers, innovative entrepreneurs, and responsible citizens who will contribute meaningfully to the nation and society.

On this auspicious occasion, I extend my **heartfelt best wishes** to the faculty members and students of the **ECE Department** for the successful conduct of ICIECS-2025. I wish the conference every success and hope it serves as a valuable platform for knowledge sharing, collaboration and technological innovation.

Sri Vellanki Nagabhushana Rao Garu

Message by the principal



I would like to personally welcome all the delegates to the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)**, being organized by the **Department of Electronics and Communication Engineering** on **27th December 2025** in association with **The Institution of Electronics and Telecommunication Engineers (IETE)., Vijayawada Local Centre**.

The field of **Intelligent Electronics and Communication Systems** is both dynamic and exciting, offering immense opportunities for learning, innovation and real-world impact. I am delighted to note the enthusiastic participation of distinguished scholars, academicians, researchers and students who have come together to share their expertise and explore advanced methods for the design and development of intelligent systems for future applications.

I sincerely hope that ICIECS-2025 will serve as a valuable platform for exchanging ideas, discussing recent technological advances and fostering meaningful collaborations. I am confident that this conference will be a grand success and mark the beginning of long-term academic and research cooperation that will help shape a smarter and more connected future.

I extend my best wishes to the organizing team of the **Department of Electronics and Communication Engineering** for the successful conduct of this international conference.

Dr. K. Sivaji Babu

Message by Head of the Department



It gives me immense pleasure to welcome you all to the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)**, scheduled to be held on **27th December 2025**. In today's rapidly evolving technological landscape, intelligent Electronics and advanced Communication Systems are playing a pivotal role in transforming the way we live, work and connect. From artificial intelligence and embedded systems to next-generation communication technologies and smart applications, these innovations are redefining the future of Engineering and Technology.

ICIECS-2025 provides an excellent platform to deliberate on cutting-edge research, innovative solutions, and emerging trends in intelligent Electronics and Communication Systems. This conference brings together students, researchers, academicians, and industry professionals from across the globe to exchange knowledge, foster collaboration and gain inspiration from novel ideas and research outcomes.

I would like to express my sincere gratitude to our management, **Siddhartha Academy of General and Technical Education (SAGTE)** for their constant support and encouragement in organizing this prestigious international conference. I extend my heartfelt thanks to our beloved Principal, **Dr. K. Sivaji Babu** for his valuable guidance and motivation, which have been instrumental in making this event possible.

I am confident that the deliberations and technical sessions of ICIECS-2025 will enrich our understanding and inspire innovative approaches to address real-world challenges through intelligent Electronics and Communication Technologies.

I also extend my sincere thanks to The **Institution of Electronics and Telecommunication Engineers (IETE), Vijayawada Centre** for sponsoring this conference and to all the authors and researchers who have contributed their valuable research papers for presentation. Your participation truly adds academic depth and significance to this conference.

Dr. C. Subba Rao

Message by President, IETE



It gives me immense pleasure to extend my warm greetings to all participants, organizers, researchers, academicians, industry experts, and students attending the *International Conference on Intelligent Electronics and Communication Systems*.

I congratulate the IETE Vijayawada Centre to organise this international conference for bringing together distinguished experts and young innovators on a common platform to deliberate on emerging trends and transformative technologies in intelligent electronics and advanced communication systems.

The rapid evolution of artificial intelligence, smart sensing technologies, next-generation communication networks, embedded systems, and automation is redefining the global technological landscape. Conferences of this nature play a crucial role in fostering collaboration between academia, research institutions, and industry, thereby accelerating innovation and sustainable technological development.

I am confident that this conference will provide a vibrant forum for exchanging ideas, presenting cutting-edge research, and exploring practical solutions to contemporary challenges in electronics and communication engineering. The technical sessions, keynote addresses, and deliberations will undoubtedly inspire meaningful discussions and future collaborations.

I extend my best wishes for the grand success of the conference and hope that the deliberations will contribute significantly to advancements in intelligent electronics and communication systems for the benefit of society.

With warm regards and best wishes

Sri. SUNIL
President, IETE

Message by Chairman IETE



It gives me immense pleasure to extend my warm greetings to all the delegates, researchers, academicians, industry experts, and students on the occasion of the *International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)* organized by the **IETE Vijayawada Centre** in association with the Department of Electronics and Communication Engineering, **Prasad V. Potluri Siddhartha Institute of Technology**.

The Institution of Electronics and Telecommunication Engineers has always been at the forefront of promoting advancements in Electronics, Communication, Computer Science, and Information Technology by providing a vibrant platform for knowledge sharing, research collaboration, and professional development. The IETE Vijayawada Centre, with its strong base of corporate members, student forums, and active academic participation across the region, continues to contribute significantly to the dissemination of technical knowledge and the nurturing of young professionals.

ICIECS-2025 focuses on emerging and impactful domains such as Artificial Intelligence, Internet of Things, VLSI Design, Quantum Computing, Cyber Security, Machine Learning, Biomedical Engineering, Green Technologies, and advanced Communication Systems. These areas are transforming the way we live, work, and interact, and this conference provides an excellent opportunity for researchers to present innovative ideas, exchange technical expertise, and explore collaborative research avenues.

Dr. K. Gnaneshwar Rao, Zonal Mentor for their constant encouragement and visionary leadership. I extend my sincere thanks to the management, Principal and HoD of ECE department, P*rasad V. Potluri Siddhartha Institute of Technology* for their valuable support and excellent infrastructure in hosting this prestigious event.

I place on record my deep sense of gratitude to all the members of the Technical Committee, Organizing Committee, Coordinators, and the entire ECE Department team for their untiring efforts, commitment, and teamwork. Their attention to detail and enthusiasm have made this conference a grand success.

I also thank the authors, reviewers, session chairs, keynote speakers, delegates, and student volunteers whose active participation added great value to the technical deliberations and knowledge sharing.

I extend my best wishes to all the participants for a highly productive and enriching experience and congratulate the organizers for bringing out the conference proceedings successfully.

Dr. B. Surya Prasada Rao

Message by the Coordinator



I extend my heartfelt gratitude to all the participants, speakers, authors, and contributors of the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)** for making the event, held on **27th December 2025**, at **Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada**. a remarkable success.

The conference provided a valuable forum for academicians, researchers, industry professionals, and students to discuss recent advancements in intelligent electronics, communication systems, and emerging technologies.

The event witnessed active participation with quality research paper presentations across diverse areas such as IoT, Artificial Intelligence, Machine Learning, Communication Systems, VLSI, Biomedical Engineering, Cyber Security, Green Technologies, and smart applications. The keynote addresses, invited talks, and technical sessions facilitated effective knowledge exchange and encouraged research collaboration.

The organizing committee gratefully acknowledges the support of the **college management**, **Siddhartha Academy of General and Technical Education (SAGTE)**, **Dr. K. Sivaji Babu, Principal**, and **Dr. C. Subba Rao, Professor & Head, ECE**. Sincere thanks are extended to the **Institution of Electronics and Telecommunication Engineers (IETE), Vijayawada Centre**, for their association and support.

Overall, ICIECS-2025 successfully met its objectives by promoting technical interaction, innovation, and collaboration among participants.

Dr.T. Haritha

Coordinator

Message by the Coordinator



ICIECS-2025 has been envisioned as a dynamic platform to foster research, innovation, and collaboration in the rapidly evolving domains of Electronics and Communication Engineering. The conference brings together academicians, researchers, industry professionals, and students to deliberate on contemporary advancements in Internet of Things (IoT), Communication Systems, VLSI Design, Quantum Computing, Cyber Security, Artificial Intelligence, Machine Learning, Biomedical Engineering, and Green Technologies.

The overwhelming response to the call for papers reflects the growing research interest and the commitment of the academic community toward technological excellence. All manuscripts included in these proceedings have undergone a structured review process to ensure quality, originality, and technical relevance. The selected and presented papers, published as book chapters with ISBN, represent significant scholarly contributions addressing contemporary challenges through intelligent systems and innovative engineering practices.

We express our sincere gratitude to our Chief Patron, Patrons, Convener, Advisory Committee, Technical Committee, and Organizing Team for their visionary guidance and unwavering support. Their collective efforts have been instrumental in the successful organization of this international conference.

We also extend our heartfelt appreciation to all authors and participants whose research contributions form the cornerstone of these proceedings. It is our earnest hope that the work compiled in this volume will inspire continued research, meaningful collaboration, and impactful technological advancement.

May these proceedings serve as a valuable academic reference and a catalyst for future innovation.

Dr. A. Geetha Devi
Coordinator

Message by the Coordinator



It is my great honor and privilege to welcome you all to the **International Conference on Intelligent Electronics and Communication Systems – 2025 (ICIECS-2025)**, scheduled to be held on **27th December 2025**. At this crucial juncture of rapid technological evolution, the conference offers a timely and meaningful platform to explore recent advancements and innovations that are shaping the future of intelligent electronics and communication systems.

ICIECS-2025 features a rich blend of technical presentations, interactive discussions, and knowledge-sharing sessions that collectively contribute to a deeper understanding of emerging technologies. The conference serves not only as a forum for academic exchange but also as a catalyst for collaboration among academicians, researchers, industry professionals, and practitioners from diverse domains.

The conference proceedings stand as a testament to the valuable contributions made by the authors and presenters. The papers encompass a wide range of contemporary research areas, including artificial intelligence, machine learning, Internet of Things (IoT), VLSI, antennas, intelligent communication systems, advanced algorithms, system architectures, real-time data processing, and autonomous technologies. These domains hold immense potential in creating adaptive, efficient, and intelligent solutions for modern societal and industrial challenges.

On behalf of the organizing committee, I express my sincere gratitude to the college management, **Siddhartha Academy of General and Technical Education (SAGTE)**, our respected Principal **Dr. K. Sivaji Babu**, and **Dr. C. Subba Rao**, Head of the Department of Electronics and Communication Engineering, for their constant encouragement, guidance, and support in organizing this international conference.

I extend my special thanks to the **Institution of Electronics and Telecommunication Engineers (IETE) Vijayawada Centre**, for sponsoring ICIECS-2025. I also thank the distinguished keynote speakers, session chairs, reviewers, and the entire organizing team for their dedicated efforts in making this conference a success. My appreciation also goes to all the participants for their active involvement and valuable contributions to the advancement of intelligent electronics and communication systems.

Thank you for being a part of ICIECS-2025. I wish you a stimulating, insightful, and rewarding conference experience.

Dr.V.S.D. REKHA
coordinator

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Development of a Stable Drone Using SpeedyBee F405 V3 Flight Controller

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***Abstract*—**Unmanned aerial vehicles (UAVs), or drones, have already changed how many industries function, including surveil- lance, logistics, crop monitoring, environmental monitoring, inspection, delivery, and many others. The drone must have sufficient stability along with adequate controllability and adapt- ability to disturbances. During takeoff, landing (especially), and hovering, the drone must react quickly to disturbances such as wind or uneven terrain. Typically, either a standard drone development procedure or an Arduino-based sensor with an inertial measurement unit (IMU) like the MPU-6050 has been applied in drone development. These types of IMUs are cost-effective and widely available, and educational resources are abundant. However, standard IMU and Arduino setups can lead to costly, time-consuming, and inefficient prototypes as they are limited in processing, which often translates to the elimination of sensor fusion and delayed control systems, and precludes implementing advanced stability for more demanding applications.

In this paper, we present a drone platform that replaces the Arduino + MPU-6050 with a SpeedyBee F405 V3 flight controller and a 4-in-1 BLS 60A ESC (Electronic Speed Controller). Compared to Arduino, SpeedyBee offers faster processing speed, continuous firmware upgrades, and support for high-frequency control loops for better flight stability. Through expedient development and tuning in Betaflight, we were able to achieve significantly improved takeoff, hover, and landing behavior. The previous Arduino-based system was evaluated against our newly developed drone, demonstrating notable improvements.

***Keywords*—**Drone, UAV, Flight stability, SpeedyBee F405 V3, Arduino, MPU-6050, ESC, Betaflight.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have come a long way in relation to applications across various sectors as a prospective technology for surveillance, disaster management, logistics, agriculture, mapping, and environmental monitoring. Drones can perform autonomous missions, reach difficult locations, and provide real-time data before, during, and after the mission completes. Drones are extremely effective in assisting activities in both civilian and military applications. Even with UAVs continuous development, their flight stability still requires engineering attention to ensure more usable platforms including during take-off and landing.

Drones are most vulnerable during the take-off and landing phases of the flight and not to mention highly susceptible to disturbances from variable wind gusts, sudden shifts in payload, ground effect disturbances, and uneven surfaces/pad. These actions present a set of challenges to flight stability and can lead to oscillations, lack of control response, and possible crashes. Therefore, stable control systems that respond effectively are paramount for safety, overall user performance, and usability in real-world environments. Many drones as platforms still involve basic control structures that employ micro-controllers such as Arduino and Inertial Measurement Units (IMU) such as MPU-6050. These controllers and IMUs are reasonably priced and simple to program. These micro- controllers and IMUs make it easy for educational programs and design prototyping. Unfortunately, they cannot provide ad- equate computational capacity and sensor fidelity and feedback control for advanced stability control.

Recently, research has focused on algorithmic control strategies and hardware improvements in response to these limitations. Kaufmann et al. introduced a deep-learning based controller, “Neural Lander” which is robust in landing when aerodynamic disturbances are present [1]. Similarly, Rao et al. describe NMPC-Lander - a nonlinear model predictive controller using NMPC to account for dynamic changing conditions for trajectory planning and landing [2]. Both of these strategies are exciting, because they can be utilized under the aforementioned conditions, however they rely on high- performance processors, and a complex optimization process while computing in real-time which

may be out of reach for lightweight drones.

Other researchers have investigated vision-based guidance systems, including how to use IR markers and camera feed- back, such as the work by Springer et al. [3] and Liu et al.[4]. Although both studies demonstrated successful precision in landing accuracy under ideal circumstances, they are fully dependent on sufficient light and unobstructed visual input, both of which can be lacking in outdoor environments or mission-dependent scenarios. In efforts to address disturbances in control systems, Telli and Boumehraz suggested employing an adaptive sliding mode controller [5], while Sukmaningrum et al. propose a combination of PID control and kalman filtering estimators to achieve better control and disturbance estimation [6].

Environmental interactions are another important variable influencing landing stability. Jonauskas [7] and Marcinkevicius [8] have concluded, ground effect, which is a change in the lift force because of being closer to the surface, can change thrust behavior by around 13. This suggests that there is a need for precise control, based on the condition of the aircraft and its proximity to the surface. There also exist mechanical options (e.g. adaptive landing gear [9], and software optimization of the aircraft path [10]) that in the development of a controllable landing instance can provide landing stability, or enhanced controllability; but these potentially allow for more complexity and expense to the overall system.

Although there has been sufficient effort to provide information in the form of their findings that push the boundaries of landing stability, there remains a significant gap in the pursuit of a solution that evolves certain variables to create a low- cost, low-sensor, hardware efficient platform that can ensure smooth or high stability of landings as well as takeoffs, without complex calculations or exchange of vision sensor capabilities. This gap is being approached in this paper with the presented quadcopter platform as constructed from hardware that is an SpeedyBee F405 V3 flight controller along with a derived 4-in-1 BLS 60A ESC. This improved outcome can credit advanced firmware considerations, hybridization of high frequency control loops, PID tuning, and motor-ESC refinement.

Flight testing in the write-up describes the outcome of this hardware first protocol in term of actions produced in the stabilization time period, and directly significant improvement in response time improvements, drift in completed turns and stable levels of motor control during significant transitions for overall robustness and practical operation of quadcopter activities.

II. System Architecture

Hardware Components

A. SpeedyBee F405 V3 Flight Controller

The SpeedyBee F405 V3 controller is the brains of the drone, managing the acquisition of sensor data, operating the control loop and sending signals to the ESCs. It contains an F4 processor which is capable of gyro and PID loop frequencies up to 4 kHz, enabling flight dynamics that are rapid with high performance. The SpeedyBee F405 V3 has built-in barometer, built in black box, built in OSD (on-screen display) and Bluetooth functionality allowing for wireless configuration.

Using Betaflight firmware enables tuning and in-flight adjustments for flight characteristics. The flight controller also supports DShot ESC protocols and RPM filtering, allowing for precise motor control and stable attitude flying even during high speed flurries.

- Key features that enable improved stability
- PID loop running at high frequencies for rapid corrections
- Real-time tuning and diagnostic with SpeedyBee App
- Black box logging for review post flight
- Gyro noise filtering for pure IMU data

The SpeedyBee F405 V3 (from figure [1]) has performed well, demonstrating nearly every one of the great feature set I have described. Perhaps most importantly, the SpeedyBee F405 V3 has a great mix of performance and reliability for use in applications requiring consistent flight dynamics and hardware reliability.

Fig. 1. SpeedyBee F405 V3 Flight Controller

B. 4-in-1 BLS 50A ESC

The 4-in-1 BLS 50A ESC (from figure [2]) is important to the drone's propulsion system since it controls the

power sent to each brushless motor based on input signals from the flight controller. It accomplishes this task with a board that combines four independent ESCs into a single package; therefore, facilitating less wiring, reduced weight, improved heat dissipation, and overall electrical efficiency.
The important features and benefits are as follows:

- **High-Current Capability** - Continues to support motors with a maximum current to 50A each. If you have a lot of thrust for the quadcopter scenario, you can safely run it without risk of motor or ESC overheating.
- **Less Wiring** - All four ESC channels are combined into one PCB reducing cable wear and tear and improves electrical efficiency.

C. Brushless Motors (A2212 10T 1400KV)

The drone utilizes A2212 10T 1400KV brushless DC motors - these motors (from figure [3]) are commonly used in quadcopters and medium-lift drones because they are reliable, cost-effective, and offer an appropriate balance of performance characteristics. They offer smooth operation and can generate enough propulsion while consuming appropriate amounts of power.
The ”1400KV” rating indicates that, for each volt supplied to the motor, it will spin at approximately 1400 revolutions per minute (RPM). Too high a KV is not a concern for this type of installation as this value is a good compromise between torque and speed, so an appropriately balanced stable flight performance with standard 8–10 inch props can be achieved, whilst allowing longer endurance on higher propulsion efficiencies.

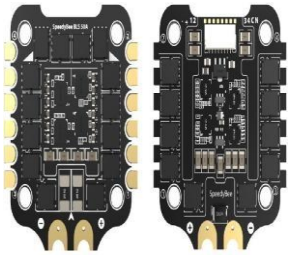


Fig. 2. 4-in-1 BLS 50A ESC



Fig. 3. Brushless Motors (A2212 10T 1400KV)



fig3a. *LiPo Battery (3S 1P 2200mAh, 35C)*

The drone is equipped with a 3S 1P 2200mAh 35C Lithium Polymer (LiPo) battery (from figure [4]) providing power to the motors, flight controller, and electronic speed controllers. In the drone market, this battery arrangement is somewhat typical of mid-sized drone applications because of its low weight, stable voltage and reliable current.
The 3S in the configuration means there are 3 cells in series for a nominal voltage of 11.1V with 3.7V per cell; in this case, a very efficient way to run A2212 1400KV brushless motors with low system weight and a reasonable power

consumption. The 1P in the configuration indicates that there is 1 parallel set of cells and therefore limits the size of the arrangement in the drone.



Fig. 4. LiPo Battery

D. Frame (F330 Glass Fiber, 330mm)

For the structural base of the drone, we are using the F330 Glass Fiber Mini Quadcopter Frame, which has a diagonal motor-to-motor dimension of 330mm. This frame size pro- vides the perfect compromise between being compact and stable for being able to test in an indoor location and for all outdoor uses that will be expected in light winds.

The F330 frame material is glass fiber (from figure [5]) reinforced composite material which provides a lightweight and durable structure that can withstand vibrations, light impacts and the twisting forces of the brushless motors. The overall length of the motor arms within the design, a central electronics plate and protected mounting points for the motors create improved flight dynamics and mechanical stability.



Fig. 5. Glass Fiber Frame

E. Transmitter and Receiver (FlySky FS-i6 + FS-iA6B)

The UAV is controlled using a FlySky FS-i6 transmitter and it an FS-iA6B 6-channel receiver (from figure [6]), which provides a reliable interference-resistant 2.4GHz radio control link. This is one of the more common and simplest methods for hobby-grade UAVs to transmit control links since it is easy, inexpensive, and has reliable protocols for communication.

The transmitter operates on AFHDS 2A (Automatic Fre- quency Hopping Digital System), which provides a reliable signal transmission path typically through most RF noisy environments. The FS-i6 transmitter is control with dual sticks, switch channels, multiple switch types, and an LCD screen that allows for configuration and real-time telemetry display.

The FS-iA6B receiver is mounted to the UAV and connects to the flight controller using either standard PWM or the iBUS protocol. The FS-iA6B receiver includes two antennas which improve reception diversity which increases the signal strength received, as well as, reduce the possibility of losing the control during more aggressive flight conditions or at greater ranges.

III. Results and Discussion

The drone equipped with the SpeedyBee F405 V3 flight control board and 4-in-1 BLS 60A ESC (from figure[7]) was tested in a real-world environment through a single set of controlled test flights. The main goal of the testing was to assess stability in flight (takeoff, hover, landing), as well as responsiveness to minor disturbances in external conditions.

The flight controller was set and tuned in Betaflight. Some of the advanced features in Betaflight included high-frequency control loop rates (up to 4 kHz), blackbox logging, and telemetry. These features offered a more flexible mapping of flight and the fly controller itself, resulting in a more stable and responsive flight experience.



Fig. 6. FlySky FS-i6 transmitter (left) and FS-iA6B receiver (right) used for drone communication.

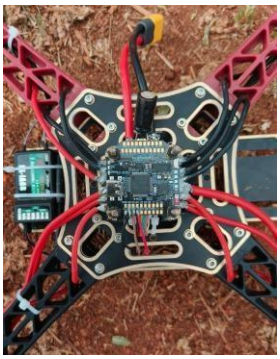


Fig. 7. Assembled drone

Takeoff Performance: The drone exhibited both smooth- ness and linearity during takeoff without excessive change in pitch or roll (from figure [8]). Because of how quickly the processing and the motors can respond, the drone was able to make immediate dynamic adjustments to minor disturbances at the ground during the initial lift phase.

Hovering Stability: The drone was able to maintain altitude and orientation from steady state during hover. The rapid PID loop and processing of gyro/accelerometer simultaneously, and the positioning movements of the drone and electronics stabilization, enabled firm position hold with little drift.

Landing Performance: The drone demonstrated stable con- trolled descent. Because the motors were executing the throttle changes accurately netting a steady and balanced landing. The wind was light speed during the entire landing operation and directional stability was observed.

Overall, the platform was reliable, consistent, and repeatable over many flights, providing the user a great experience with the system and some stability during key flight stages. The combination of real-time software, high frequency loop sampling, and modern ESCs greatly benefited the overall flight experience.



Fig. 8. Flight of the drone

IV. CONCLUSION

This paper has documented the development and evaluation of a stable drone platform based on the SpeedyBee F405 V3 flight controller and a 4-in-1 BLS 60A ESC. This drone platform has shown reliability during critical flight states including takeoff, hover, and landing. Achieving the correct smooth coordination of motors, where the motor rate provided optimal responsiveness of the drone controller, was the result of utilizing high frequency control loops, well-tuned PID gains, and deterministic filtering of sensor output in real time.

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Design of low noise amplifier at 1.9 GHz using 90nm CMOS Technology

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***Abstract*—** Low noise amplifier using a Source degeneration Cascode technique which contains of two NMOS transistors one is of common gate and other of common source. The LNA is designed at 90nm CMOS process, the input and output impedances were matched to 50 Ohm. The source degeneration in the LNA is used to increase the gain and to decrease the noise in the amplifier. The proposed LNA provides a gain of 20.4dB and Noise figure of 0.565dB at 1.9GHz frequency. Since the proposed low noise amplifier is designed in 90nm using CMOS, it operates at supply voltage of 1.8V which is given to the common source amplifier part of LNA and the S11 of the LNA is observed as -16.2dB.

Keywords—Amplifier, CMOS, Gain, S Parameters, Cascode

I. INTRODUCTION

Low noise amplifier is designed to amplify weak signals with little noise. LNA's are commonly used in communication system, such as in radio receivers, to boost the strength of incoming signal before processing. The important characteristics of a LNA is the ratio of output signal to the input signal amplitude which is nothing but gain parameter. A higher gain is generally desired in an LNA to amplify the weak signals, improving the output SNR.Noise figure quantifies how much the LNA contributes to the overall noise in the system. Lower noise figure indicates better performance, as it means the LNA introduces less additional noise to the signal. Bandwidth is another important parameter which is the frequency range over which the LNA can amplify signals. It is selected based on required application and the bandwidth has range that suits the application. A broader bandwidth is often desirable for versatile applications. Power consumption indicates the electrical power used by the LNA. Minimizing power consumption is crucial, especially in battery operated devices or applications with strict power constraints. Noise temperature is a parameter related to the performance of the LNA with noise. Lower noise and high SNR indicates better noise performance, especially in radio astronomy and other sensitive applications.

1.1. Types of Low Noise Amplifiers

There are various configurations for LNAs available in literature. Some common types of LNAs are as follows.

Cascode LNA: The cascode LNA is a two-stage amplifier comprising common emitter stage and common base stage. This configuration provides good gain and high noise performance, useful for giga hertz applications.
Structure of a cascode LNA:

Common Emitter stage (Transistor 1): First stage is usually a common emitter amplifier; CE is chosen for better gain. Input is connected to this which amplifies the weak signal. Common base stage (Transistor 2): A common-base, CB amplifier is connected at the output of common emitter stage in the second stage. Common base stage provides low input impedance which results in better matching with the previous stage and also decreases the miller effect.

High Gain: Usually, Cascode LNAs exhibit higher gains compared to single stage LNAs. The combination of the voltage gains and current gain from the common-emitter stage and the current gain of the common-base stage respectively which contributes to overall high gain.

Improved linearity: Inherent in the cascode configuration is a better linearity than the single-stage amplifier; this is of great importance in applications where signal distortion should be at its barest minimum. Enhanced input and output impedance matching: In the cascode LNA design, there is the possibility of much-enhanced impedance matching at the input and output, respectively, thus making easy interfacing with other components and ensuring continued efficient power transfer.

Lesser miller effect: The common-base stage reduces the Miller effect, which is a capacitance that exists between the input and the output terminal of a transistor. For maintaining bandwidth and ensuring stability, it is necessary to reduce the miller effect. Better noise figure: Even though cascode LNAs might not have the lowest noise figure, they provide great gain with an excellent noise figure. It therefore forms a good compromise for circuits that need both high gain and low noise.

Feedback LNA: Feedback LNAs use the technique of feedback to improve their performance. The feedback mechanism helps in controlling gain and bandwidth while keeping the noise low. These LNAs are often used when precise control over these parameters is required.

Differential LNA: It uses two identical transistors, which are in differential configuration. This configuration enables it to offer several advantages, such as common mode noise rejection, linearity enhancement, etc. Thus, differential LNAs are also a popular choice for communications that require noise immunity and rejection.

LNA Cryogenic: The cryogenic low noise amplifier is an amplifier that, at extremely low temperatures, works within a range usually occupied by liquid nitrogen, approximately -196 degrees Celsius or -321 degrees Fahrenheit, or even lower using liquid helium. This LNA is used where such reduction in thermal noise plays a crucial role in the attainment of high sensitivity, especially in areas involving radio astronomy and deep-space communication.

Inductive Source Degeneration (ISD): The approach mainly adopted in the design of LNAs that would improve their performance indices, especially the aspects of gain, linearity, and noise figure. It is the process of adding an inductor in series to the source terminal of the transistor in the amplifier stage. An inductor such as this, together with the source resistance of the transistor, comprises a degeneration network that is known to affect the operating characteristics of the transistor.

Advantages and trade-offs: Major advantages of ISD are associated with improvement in noise figure of the amplifier. The rise in source resistance due to degeneration serves to increase thermal noise from the transistor source resistance, thus increasing the noise figure. In most practical cases, this rise is outweighed by reduction in gain, thus presenting an overall gain in noise figure. ISD further improves the amplifier linearity by reducing its gain at large input signal levels. The reduction in gain effectively reduces the possibility of distortion and intermodulation products, hence making the amplifier more linear and suitable for high-performance applications. Like any design technique, ISD involves certain trade-offs. While ISD offers benefits against gain stability, noise figure, and linearity, there is also a reduction in gain.

II. LITERATURE REVIEW

[1] A low-noise amplifier for the sub-6 GHz band is proposed here with trans conductance enhancements to make it suitable for low-power applications. The proposed LNA exhibits high gain and low noise figures with a low power consumption. The LNA is fabricated in Global Foundries 0.18µm CMOS and exhibits 14.5 dB power gain at 5.8 GHz and minimum noise figure of 3.2dB. It employs a Gm-enhanced folded cascode topology and trans conductance enhancements to improve power gain and impedance matching while reducing chip area.

[2] This LNA is designed with degeneration using inductor works at low noise levels for an ultra-wide band receiver for biomedical implant, achieving minimum noise figure of 1.7 dB, maximum voltage gains of 15 dB, and CP1 of -10 dBm. LNA design involves the use of diode-connected load, degeneration source, and cascode design for improvising its features on 1.5 GHz frequency band.

The paper [3] presents the detailed analysis and design of a LNA implemented in 0.18-µm CMOS technology. It deals with circuit parameters such as frequency, S-parameters, noise figure, power consumption, and chip area. The LNA design incorporates on-chip and bond wire inductors to achieve a high effective Q in the input stage. Special attention has also been paid towards proper passive component selection and layout for noise performance improvement.

[4] This work shows the Multi-gain low noise amplifier which is useful fo wireless applications. The frequency of operation is around 2.4 GHz and also in ISM band Bluetooth. This design uses source generation using inductor and cascode multi configured differential structure. It also uses complementary structure for better output impedance matching. Cadence based simulations shows the focused gain and ripples are optimized using varactor based matching.

[5] Present the design procedure of a fully integrated LNA in 0.18µm CMOS technology, including transistor and RF inductor aspect ratios. Specify that Rb2 should be chosen greater than the input impedance at the gate of M 2 to ensure the maximum gain through the inter-stage network. The design will proceed with iterative steps to change the width of M 2 until the value of Ld1 is calculated and it satisfies equation (35) for matching at the gate of transistor M1.

[6] It talks about the role of LNA in wireless systems to amplify weak signals received from the antennas. It presents the design and simulation results of an inductive source degeneration-based LNA architecture using 0.35µm CMOS technology. The designed circuit shows an input impedance of 48.8 Ω, gain of 12.3 dB, with the power supply of 3.3 V and power consumption of 28.5 mW. The design of LNA is very critical because it needs to be optimized for gain, low noise figure, high linearity, input/output matching, and low power dissipation [7-9].

Some of the key findings from the literature survey conducted on source inductive degeneration LNAs are: Source inductive degeneration is a widely used technique to enhance the noise figure and gain of LNAs. Introducing inductance at the source terminal provides an appropriate matching of the input impedance of the LNA, which enhances the noise performance along with the gain. While source inductive degeneration has possible benefits in noise figure and gain, these approaches often involve performance trade-offs against power consumption, linearity, and bandwidth. The designers can make conscious choices towards optimization of the LNA parameters to obtain the correct balance. Simulation software such as Cadence, ADS, and Spectre are widely used to design and characterize source inductive degeneration LNAs [9-15]. These tools can be used to simulate different configurations with their performance in various operating conditions. Noise cancelling and impedance matching networks have been advanced techniques for further improvement of the performance of source inductive degeneration LNAs. These are meant to solve particular challenges and push the LNA performance limits.

III. PROPOSED METHOD AND RESULTS

The proposed Low noise amplifier will be designed using the latest CMOS technology to reduce the power consumption and the power dissipation done by the transistors and both NMOS and PMOS transistors will be utilized and the major performance criteria as noise figure and the gain of the Low noise amplifier will be much improved when compared with previous designs which were made and linearity of the amplifier will be increased by making the perfect design of the input output matching networks. The ideal performance criteria of the low noise amplifier were as follows,

Gain of the LNA:10- 30dB
Noise Figure of the LNA: <3dB
Power Consumption of the Low Noise amplifier will be varied by the application in which the Low noise amplifier is used but in major scenarios the power consumption should be in milli watts.

The Low Noise Amplifier in Fig.1 designed consists of two stages in which stage one is of common source and stage two is of common gate, the stage one has inductive source degeneration, the designed circuit is a s follows. The Circuit totally consists of two NMOS transistors which are taken from gpdk90 library of cadence virtuoso simulator and capacitors (C1, C2, C3 and C4) inductors (L1, L2 and Ls) along with single resistor R. The capacitors which are at the input and output of the circuit acts as the DC blockers to avoid the input and output noise interference, and the capacitors C2 and C4 were used to eliminate any other distortions present in the second and output stages of the circuit. Now coming to the inductors Ls is used for the source degeneration technique and L1 is used for the 50Ω impedance matching at the input whereas L2 is used for providing biasing to the circuit which is of 1.8V and at last the single resistor is used to provide biasing in CS (common source) stage the resistor value should always be high (50KΩ).
In the LNA circuit above the width of transistor in the second stage which is a common gate state is increased to get maximum amount of gain. The amount of gain we receive depends on the width of the transistor much gate area allows greater number of charges to pass through the gate results in high gains. The Width of the transistor is cannot be increased further because of increase in the size of the transistor.

The layout for the two transistors in Fig.2. was done using ASSURA tech library in the cadence virtuoso tool, in the layout only the connections between the two transistors were made and all other connections to the capacitors, inductors and resistor were neglected and the layout is as follows,

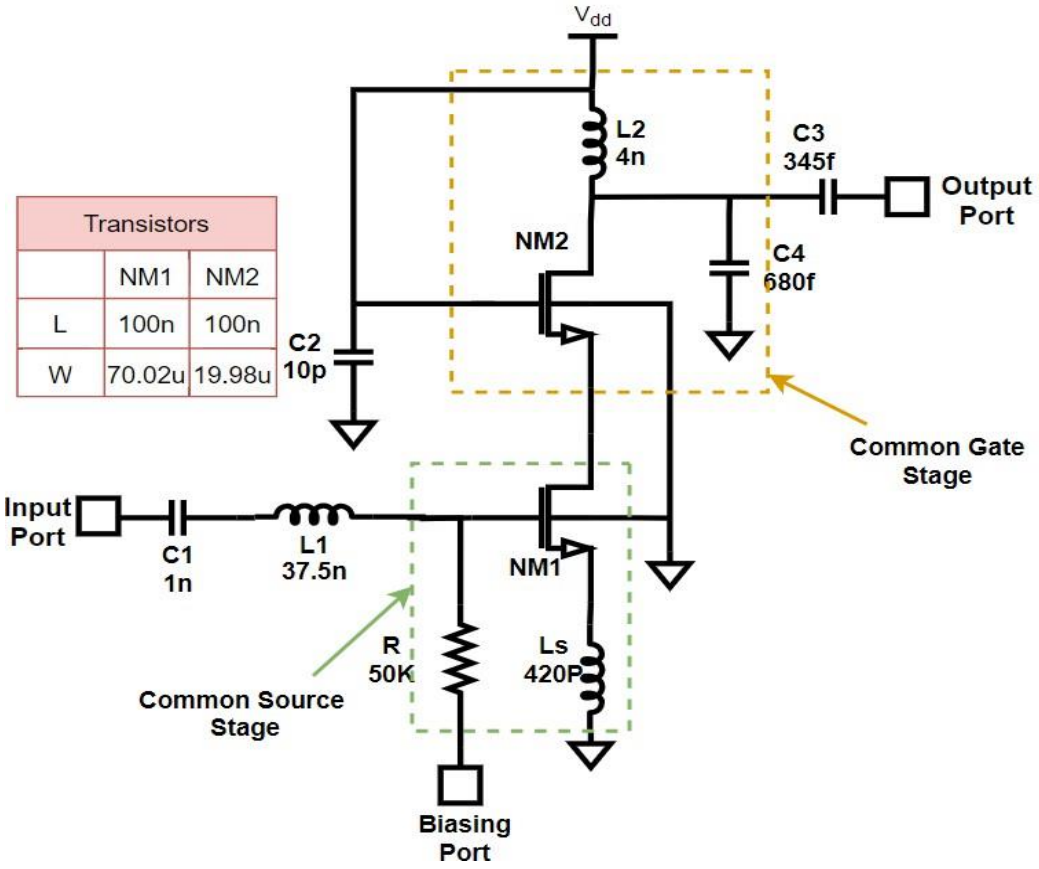


Fig 1. Implemented circuit diagram of LNA

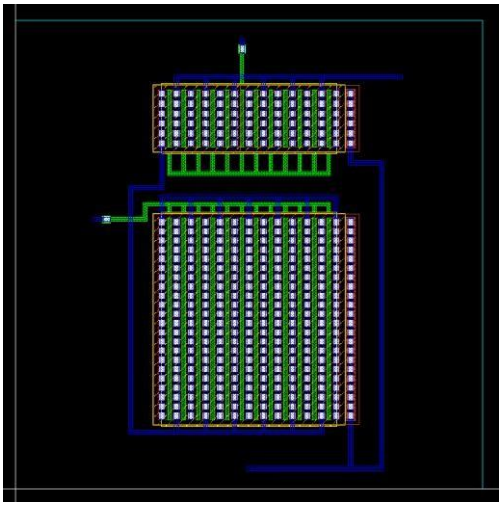


Fig 2. Layout of the transistors

4. *Experimental Results*

The LNA design will be done in the CADENCE Virtuoso software. Which includes different range of libraries as GPDK (Generic Process Design Kit) as gpdk180, gpdk90, gpdk45, etc. Cadence Virtuoso is a widely used electronic design automation (EDA) tool for designing integrated circuits (ICs) and other electronic systems. It provides a comprehensive platform for designing, simulating, and verifying complex analog, digital, and mixed-signal circuits. The software offers a range of features including schematic capture, layout editing, simulation, and physical verification. It is commonly used in the semiconductor industry for designing and testing ICs, and it

supports various semiconductor process technologies. Cadence Virtuoso is known for its advanced capabilities in custom IC design and is a key tool in the development of cutting-edge electronic devices and systems.

The outputs of the designed LNA are as follows the S11 parameter which defines the performance of the matching of the circuit is of -16.2dB.

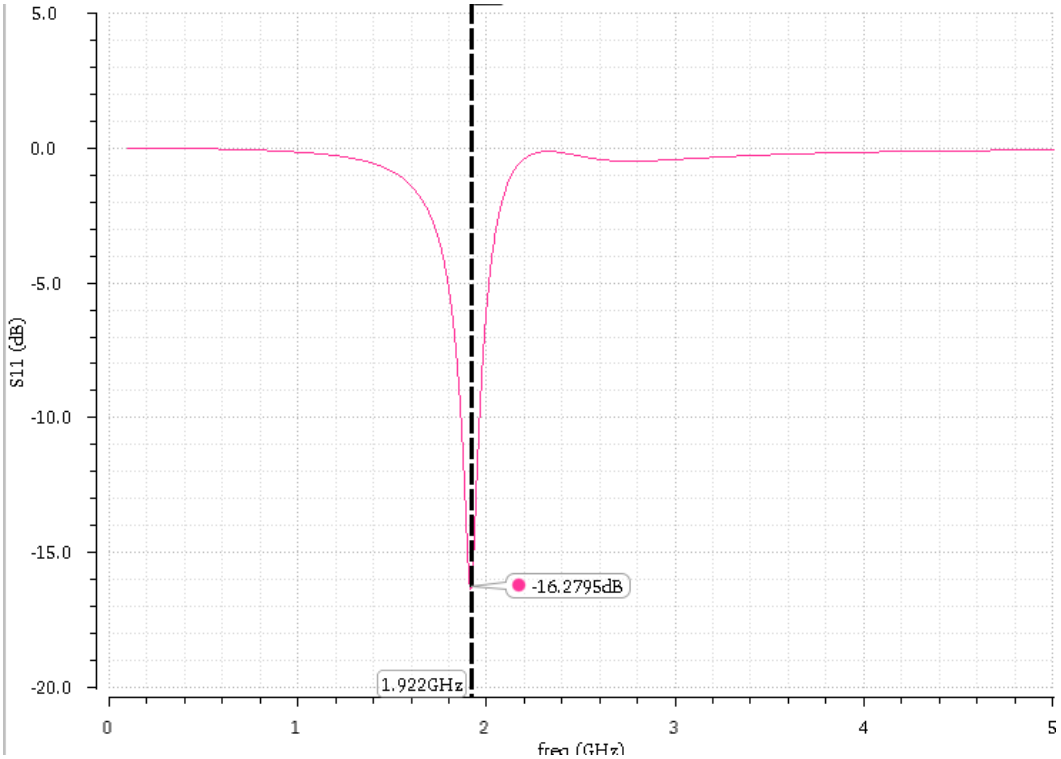


Fig 3. S-Parameter (S11)

The gain of the Low noise amplifier designed can be observed by plotting the graph of another S parameter which is S21 and the gain is of 19dB. The plot is as follows,

Parameter	**This Work**	**[6]**	**[5]**	**[4]**	**[3]**	**[2]**	**[1]**
CMOS Technology (nm)	90	180	130	180	180	180	180
Frequency (GHz)	1.9	5.5	2.4	2.3-2.4	1.5	5.8	2.4
Supply Voltage (V)	1.8	1.8	1.5	1.5	0.4	0.5	0.4
Gain (dB)	20.42	20.63	20/10	17.2-17.8	15	14.5	15
Noise Figure (dB)	0.565	3.12	2.6-7	2.52-2.54	1.7	3.2	2.6
S11(dB)	-16.2	-29.5	-31	-29.1	-10	--	-13

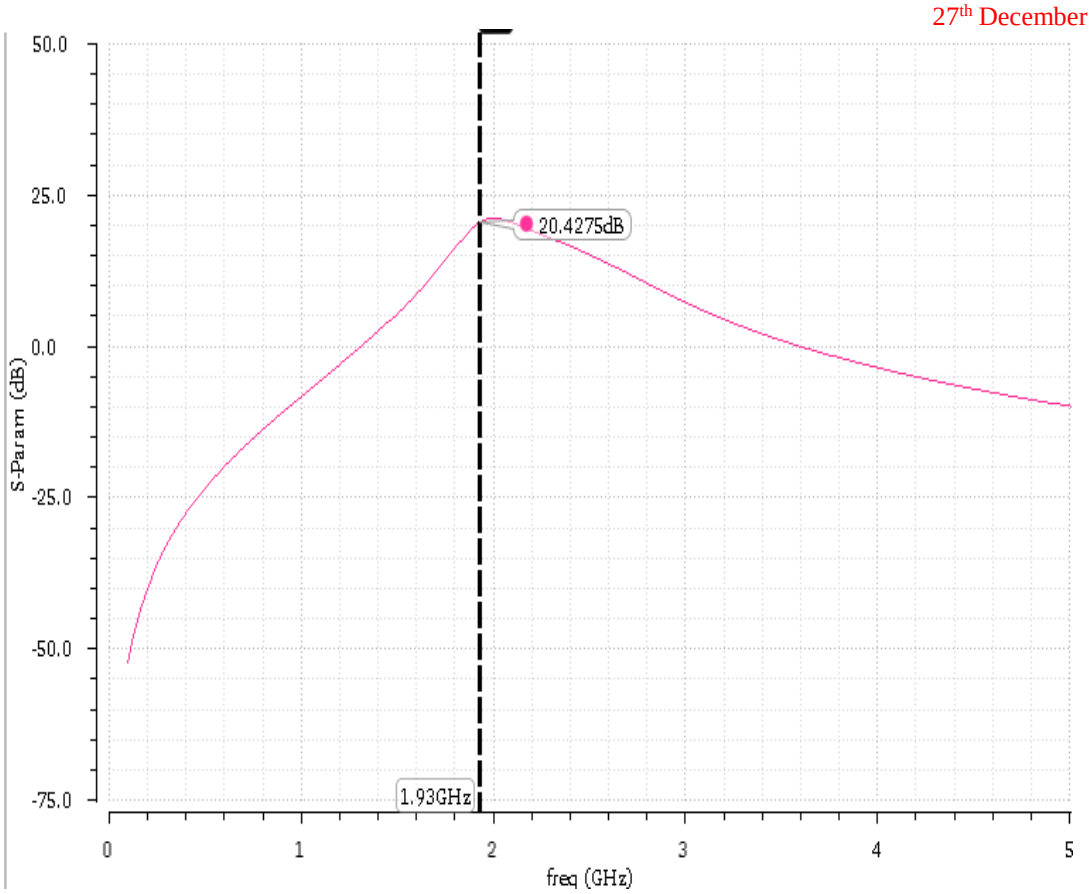


Fig 4. S-Parameter (S21)

And finally, the Noise Figure of the LNA is obtained very low and this is due to the usage of the inductive source degeneration technique used in the first stage which is common source stage, the observed noise figure is of 0.5dB and the plot is as shown below,

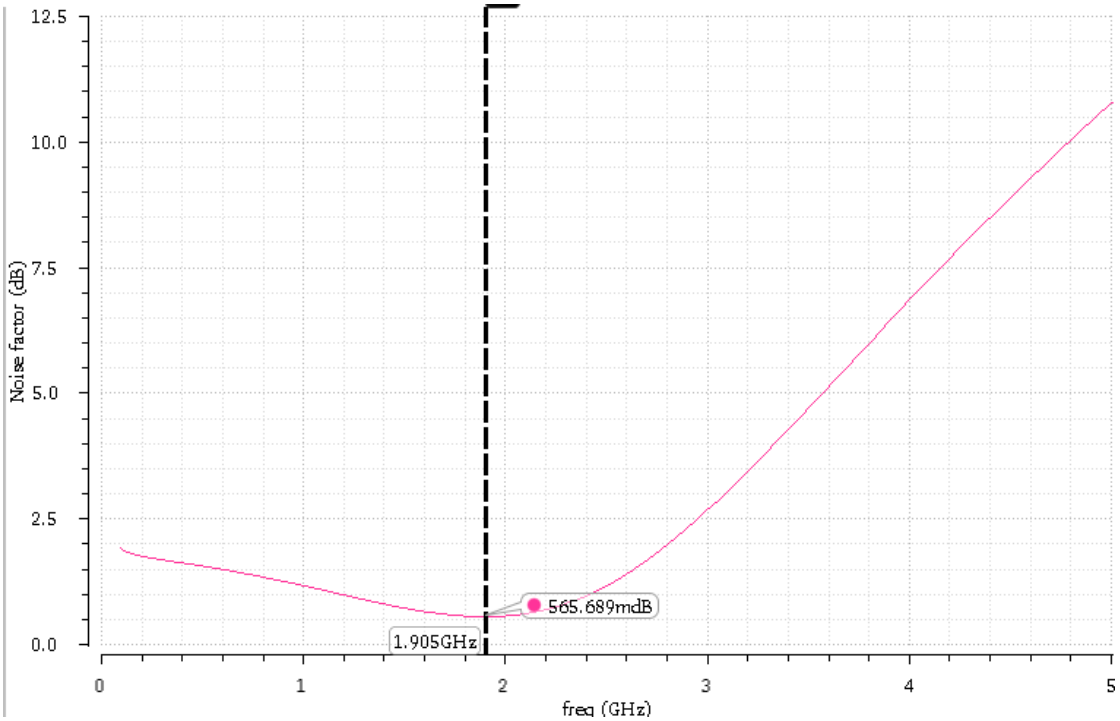


Fig 5. Noise Figure of Proposed Design.

IV. CONCLUSIONS

In this study we proposed a low noise amplifier using CMOS technologies. The final results of the designed topology provide 20.4 dB gain and 0.565 dB NF. So, the designed LNA can be effectively utilized where noise is considered as a major factor factor and also with a decent amount of gain. Proposed LNA outperforms the existed designs and provides better gain and S parameters.

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Innovative Multi-Agent Architectures for IoT-Driven Smart Vehicle Networks

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Abstract - The Internet of Things (IoT) is simplifying life of human in any way. It has incomprehensible applications. The Internet of Things (IoT) is a conceptual concept that links all computers, resources, and gadgets through the Internet to allow them to contact one another. Technologies that involve digitalization, networking, and embedding are also included. Sensing devices and monitoring systems are linked together to provide the desired result, making life simpler. IoT is used in a variety of ways, including intelligent cars and their protection, navigation, security, and fuel efficiency. The proposed Smart Vehicle Monitoring System (SVMS) for early identification of incidents and theft prevention is the subject of this paper. SVMS employs Internet of Things (IoT) technologies to constantly track the car as well as to view and manage it remotely. The SVMS is already familiar with the GPS platform. This will allow the SVMS to maintain a record of the vehicles' positions in real-time. This information would be used to locate the car in the event of a collision or robbery. The SVMS system's findings were positive in terms of accurately identifying collisions, determining the magnitude of the crash, and determining the position of the car. It is critical to incorporate the BDI (Beliefs, Desires, Intentions) characteristics of agencies in the autonomous agents that model them to completely exploit the capacity of agents in the software system. The BDI structure is also rooted in this paper's structured software structural specification of a Multi-agent framework (MAS).The framework introduced here supports multi-purpose machine learning solutions by deploying specialist learning assistants in every single domain in which the system gathers data.

Keywords: Multi-agent architecture (MAA), Internet of Things (IoT), smart vehicles monitoring system (SVMS), BDI (Beliefs, Desires, Intentions).

I. INTRODUCTION

A multi-agent architecture (MAA) is a decentralized open network of factors that communicate with one another via some protocols. The notion of speech actions is the conventional foundation for agent interaction in a MAA. Tools created in dispersed software and application engineering programs can manage the flexibility, autonomy, responsiveness, time-constrained activity, and interconnection of agents in a MAA. In contrast, the entire potential of well-formed agent theories must be integrated into software artifacts built using software engineering techniques as much as technologically possible. Some of the best techniques for addressing the varied, dynamical, and diverse character of a mobile sensing network appear to be multi-agent architecture (MAA) and the smart agent concept. Its dispersed context, as well as the intrinsic features of each agent, such as responsiveness, social capacities, and pro-activity, would seem to be suitable for controlling the dynamic and scaling of a huge metropolitan environment. Other benefits of MAAs for building a mobile monitoring device include human-specific qualities such as reason, connection with its surroundings, and entities of its kind. Furthermore, because of the decentralized character of these systems, they can create a changing system competent of changing its edifice to the ongoing changes that a huge metropolis produces.

Multivalent networks are a method for breaking a software challenge into several separate entities implanted in an environment to meet the system's operational and quality criteria. According to this viewpoint, MAAs is a method for solving a software problem. AMAA, in specific, is a precise deconstruction of interacting network pieces designed to meet the system's needs. Agents, assets, services, atmosphere, and other components make up a MAA software framework. The components' interactions are various, ranging from indirect engagement via virtual pheromones to complicated negotiation methods. In a nutshell, MAAs are a large family of design methods with distinct characteristics that can be applicable to a vast range of difficult implementation domains. The architect may not always choose a MAA-based result based on the analysis of the problem that yields the system's quality and functional attribute requirements. Robustness, openness, and flexibility, are some of the quality attributes that may influence the decision to use a MAA software design.

The Internet of Things (IoT) is a terminology that has gained attention in recent years to describe all of the linked

devices that make up smart environments. The quantity of data that IoT gadgets collect and with which, in many cases, none of it is done is amongst the primary concerns that IoT surroundings face. The data are typically sent to cloud-based servers that are central, whilst they are pondered to generate information that are derived or trigger specific events. As a result, conceptions like Computing of the Edge [1] and Fog [2,3] have become visible, aiming to change the IoT nodes' passive behavior and turn them into active members of the system. By equipping these machinations with analysis of data mechanisms, information can be processed closer to where it was created rather than being sent over long distances to data centers that are externally available. When expansion forecasts over the upcoming few years are considered in terms of the devices number linked to the Internet that data is generated, bringing processing of the data to local conditions makes even the most sense. As per the study [4,], it is anticipated that the devices number connected will exceed 50 billion, implying that each citizen will have nearly seven connected devices emission data.

To circumvent network density, inessential inefficiency, and more storing data costs, this information must be processed on the devices themselves. This processing locally will boost efficiency by avoiding the need to send all of this information to the cloud resulting in considerable cost savings and faster processing. For particular industries, such as industry, finance, telecommunications, transportation, and health, among others, real information analysis is a critical requirement that may be met by speedier data processing. The Internet of Things (IoT) is a communicating network of billions of complicated objects such as sensors, electronics, actuators, platform hubs, and gateways that are linked together. These physical devices communicate with one another over a wireless network. Smart devices communicate data and function without the need for human interaction. IoT is an internet- connected collection of embedded capabilities such as physical devices, sensing and actuation, computation, and networking.

The power of this innovation will be its potential to influence anything from ordinary decision-making to something as important as health monitoring, therefore improving endeavors and human life. The emergent significance of Internet of Things (IoT) technology in day-to-day life has changed people's lifestyle options. Numerous IoT-based services demand data about the node's position and location to enable communication efficiently across nodes. Wireless Sensor Network (WSN) communication is an important part of the Internet of Things, and it may be used in a variety of ways. WSNs are meant to be merged into the Internet of Things (IoT), with sensor nodes connecting to the internet and fulfilling their allocated tasks automatically. In many cases, combining WSNs with Socially Aware Networking (SAN) is desirable. In addition, merging WSN with the Internet of Vehicles (IoV) allows for a critical examination of the natural environment, enabling the prevention of potentially harmful events.

The Internet of Things (IoT) has brought up new opportunities for carmakers and purchasers all around the world. IoT in the automobile industry has become a key hotspot for a variety of multi-purpose solutions, with use at both a commercial and industrial level. The IoT applications have made a significant impact on the worldwide automobile business, from linked automobiles to automated transportation systems. Manufacturing businesses were the first to embrace IoT to achieve autonomy and lower production costs. Later on, its uses became more industrial and widespread. Nonetheless, the opportunities offered by the IoT for the automotive sector are enormous. Various Automotive IoT use scenarios have emerged, altering how people connect with their automobiles. By providing wireless standardized communication systems, the Internet of Things has revolutionized smart vehicle engineering. If the vehicle is traveling at a speed of more than 20 km/hr, it is considered a smart transportation system. Since this bandwidth of GPRS/GSM is in the region of 64 to 128 kilobytes per second, GPS connection will not be a viable option. A Wi-Fi communication method is a solid solution technique to apply. Wi-Fi's characteristics, particularly speed and adaptability, are critical. Automobile manufacturers began applying sophisticated applications and technology to ensure driver safety from the turn of the millennium [5]. Vehicle reversing assist, ensuring vehicle seats are worn, system of geo-tagging and geo-location systems for routing and position sharing, virtual door unlocking and locking anti-theft devices, and activation of airbags in the event of an accident are just a few of the many small elements that are closely monitored and are already used in cars. These warning systems have existed for over two decades, but they gained traction when Google launched autonomous cars for its Google Maps initiative in May 2012 [7]. Companies like Tesla quickly followed suit, doing various trials on the subject. Despite their growing popularity, there are still concerns concerning the carriage of employees in these vehicles [8]. This research focuses on developing an

intelligent system that provides protection against theft for automobiles by permitting initiation only after verifying the driver's biometrics data and guaranteeing that he or she is not inebriated. As part of autonomous driving, several parameters such as ambient and engine state, level of fuel, and distances between objects before and after the automobile are continuously monitored using inbuilt sensors. All of this data is shown on a tablet that is put in the vehicle. Wi-Fi and Bluetooth are used to make wireless communication between both the sensor and the tablet possible. The first half of the presentation included an overview of the project. All of the groundwork has been laid, including significant project modules like the implemented system's aims and objectives, as well as the rationale for selecting this project title. The second section of this project report looks at the surveys of the literature that were carried out to lay the groundwork for the present deployment. Equivalent and opposing techniques are researched, recorded, and compared to the methodology and processes employed in this study. These procedures are then double-checked for any potential dichotomies in their system. In addition, strategies are combined to close the gaps. The technical part of the project is discussed beginning in the third part. The fundamental structure and architecture of the methods are covered, which will be implemented in the development of intelligent automobile safety and protection systems This is demonstrated via text, images, and flow charts. This help in the step-by-step visualization and organization of the project. Section 4 discusses the findings, and Section 5 wraps up the research.

II. LITERATURE SURVEY

Even though automated automobiles were primarily introduced in 2010, driver support and protection technologies have been in use since the turn of the millennium. Hindrance detection systems that employed Ultrasonic, LIDAR, and SONAR, in the beginning, were subsequently joined by various types of cameras that employed image analysis and vision of the computer to achieve the same [9,10]. This segment highlights some recent developments in this area. Using the notion of vehicle ad hoc networks (VANETs), the researchers offer a deep learning system for displaying real-time navigation maps that adjusts to diversions in the road and environmental state in [11]. The authors of [12] use image analysis methods in combination with cameras to address the problem of driver fatigue. The authors of [13] offer an intelligent approach that focuses on road movement and safety while also utilizing "vehicle to infrastructure" communications to discover road impediments and difficulties. [14] explains a similar notion with an Advanced Driver Assistance System (ADAS). In [15], the authors present a way for ensuring automotive safety by avoiding theft. If the car bonnet or door is open, the enrolled driver receives an SMS or a phone call notifying that the door of the car has been unlocked with a spatial tag. A note is sent to friends, families, the police, and to the services like ambulance in the event of a major accident. In addition, if the driver needs to transmit an SOS signal to his friends or family, he may do it with a single touch or click on his electronic device. The major goal of the study discussed in [16] is to plan and create a web-based monitoring of weather and management system. The study [17] proposes a real-time privacy criterion that regulates speed of the vehicle when the driver is tired. The study [18] proposes a methodology for the construction of an intelligent automobile system using a fuzzy system. The intelligent automobile system concept, in particular, demonstrates how a car may go from point A to point B using the shortest way possible by identifying and avoiding impediments. The study [19] describes an Advanced Driving Monitoring Assistance System (ADMAS), which ensures safe driving depending on the driver's feelings. The driver's facial expressions are evaluated to assess his emotions, and his driving is continually monitored as a result. In the event of bad driving behavior, the driver is quickly informed by this system. The focus for Panna et al. [20] is on creating a pertaining perspective, self-contained auto model using the Raspberry Pi as a managing chip [21]. To look after basic information from the current world to the vehicle, a HD (high-definition) camera and an ultrasonic sensor were used. The car is designed to safely and completely complete the task at hand, avoiding the risk of human error. Several current computations, such as path identification and obstruction location, are combined to offer the auto critical control. The research focuses on the Raspberry Pi as a medium for implementing the system because of the processor's moral nature. The development and design of an accelerometer-based approach for driver safety were proposed by Kumar et al. [22]. The Raspberry Pi (ARM11) is used to obtain the control and the accelerometer is used to find events in this system. If an incident happens, a notification is delivered to authorized employees, allowing them to respond quickly and effectively to just save lives and minimize damage. The suggested model is ineffective and incomplete since it only contains one module and ignores the other catastrophic causes. Sumit et al. [23] suggested a persuasive technique for a vehicle's

collision avoidance arrangement to recognize the obstacles existing in the vehicle's front and blind zone. Mohamad et al. [24] suggested a reliable vehicle accident-avoidance system that includes alcohol detection. This device is capable of alerting the driver to the quantity of alcohol drank and displaying the information on an LCD screen. It also emits an alert through a buzzer to make the motorist aware of his or her position as well as to inform those in the surrounding zone [25]. In the current technological context, developing, managing, and integrating IoT systems in real-world situations, such as Smart Buildings or Smart Industries is a challenging issue for all parties engaged in their creation and use. That is why it is critical to create and implement models, techniques, technologies, and perspectives that will assist developers in addressing these new issues. To solve these issues, several solutions, tools, and software techniques have been created. It is feasible to categorize strategies based on various design methods, as explained by the authors of [26, 27], resulting in diverse categories such as service-based structure [28], event-based structure [28], and architectures-based on agents [29]. The latter are the ones that are covered in this paper and are based on software agents. An examination of the present state of the art on platforms accountable for supplying knowledge to the computing restricted devices that make up the present IoT has been conducted. The approach, according to the authors of [30], is to use mobile agents on hardware devices.

Working with devices that can run TinyOS, a fully accessible operating system designed specifically for wireless sensor networks, is the emphasis of this project (WSN). This operating system can only be run on a limited number of devices because it was designed specifically for them. The authors of [31] believe that using mobile agents as a way of delivering knowledge to the hardware nodes will be beneficial. The authors note that their programme may be delivered on TinyOS or a Java MV, as suggested by [30]. It may also be shown on Sun SPOT devices, which are compatible with programming languages like as Java but are expensive, thus they have been phased out. The pioneering work on BDI design and logic is becoming an important part of MAS research. In Agent Speak(L), the operative programming language, a new article officially establishes the BDI characteristics. The extraction of understanding from the data collected by the sensors is a crucial stage for a mobile sensor unit. The framework must be able to determine the user's current context and utilize that information to develop behavioral patterns or extract important information for subsequent decision-making. Machine learning (ML) and data mining methods particularly ensemble learning methods are commonly used in the literature for this aim.Due to its excellent performance (32), decision trees (DT) are commonly employed for object detection and user movement detection. In this line, the Jigsaw app takes information from the smartphone accelerometer and uses DTs to identify user behavior. Deep learning algorithms in the very same line as Human Activity Recognition (HAR) have been extensively embraced in recent years (33). For example, Deep Sense (34) blends recurrent and convolutional neural networks for three separate implementations: automobile tracking using sensors to capture motion, diverse activity of the human detection, and identification of the user using biometrics motion analytics all of which outperform the state-of-the-art. Gaussian Mixture Models (GMMs), but on the other side, are widely used in audio and speech recognition systems (35, 36). For example, Stress Sense (37), which uses GMMs with a covariance that is diagonal to identify pressure from human speech samples collected by the phone's microphone, uses GMMs with a covariance matrix that is diagonal. GMMs are used for automated speaker detection in Speaker Sense (36), a memory aid program. Other categorization methods are being investigated in this section. Dong et al. (38) present a device for extracting gasoline prices from digital camera photos of roadside billboards and classifying them using Artificial Neural Networks (ANNs).

III. SYSTEM MODEL

This research aims to resolve the problems that arise when designing a dynamic IoT environment by including software agents on computational restricted wireless hardware. When modeling IoT settings, the authors offer two basic concepts: Smart Objects (SOs) and Smart Environments (SEs). The key components of the Internet of Things (IoT) environments are so-called SOs, which refer to all ordinary items that are outfitted with hardware elements such as a CPU, a communications network, and actuators or sensors to manage, measure, and act on the surroundings. The idea of SE, but on the other side, is described as a cyber-physical environment in which many multimodal devices are employed to gather information from the surroundings and communicate with it. Hardware components are light-weight which can be incorporated into a variety of ‘things' and constitute the foundation of the cyber-physical networks engaged in the Internet of Things (IoT) play a crucial role. As a result, it is vital to specify what is designed by intellectually constrained devices or devices with restricted resources. In general, the devices are constrained by their size, data storage, source of energy, computation capability, and communication capability. As a result, the jobs that these gadgets do are generally highly

optimized. Fig. 1 depicts the primary components (hardware or software) of an IoT device. It is impossible to forecast all accidents with any available technology. As a result, we must at the very least be able to recognize mishaps as soon as feasible. Any human or animal that is harmed in an accident must receive medical attention as soon as possible. People who are wounded in accidents frequently do not seek early medical attention, either because they misjudge their injuries or due to the legal procedures involved in accidents. Even if a person appears to be in good health, it is always a good idea to have any injuries checked up. The major purpose of the SVMS presented in this research is to identify an accident as soon as possible, assess the driver's condition, and notify the authorities. The SVSM was not a robust mechanism, but rather a structure for detecting serious incidents quickly. SVMS also allows the customer to remotely disable the vehicle in the event of theft. It also allows users to track the whereabouts of the car anywhere on the planet.



Fig. 1 Internet of Things Basic Architecture.

The SVMS incorporates a Raspberry Pi, as well as several sensors, a GPS module, and a GSM/GPRS module, to accommodate all of these. Fig. 2 depicts the general structure of the SVMS platform as well as the inner design of the IoT network. Any shift in velocity in any direction may be detected by the IoT network, as can any tilt or spin. For a few years, the contact sensor is being used in automobiles to identify crashes and activate airbags. These two detectors are used by SVMS to detect any mishaps. The accelerometer data are continually watched and it will identify an accident if the deceleration or acceleration surpasses a threshold value or the detector is angled more than a particular degree.

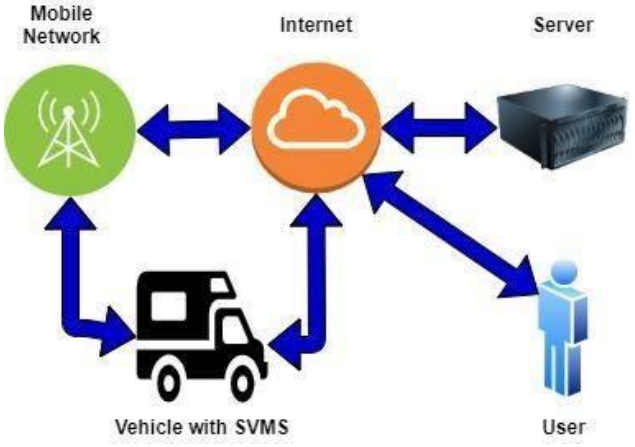


Fig. 2 SVMS framework's architectural overview.

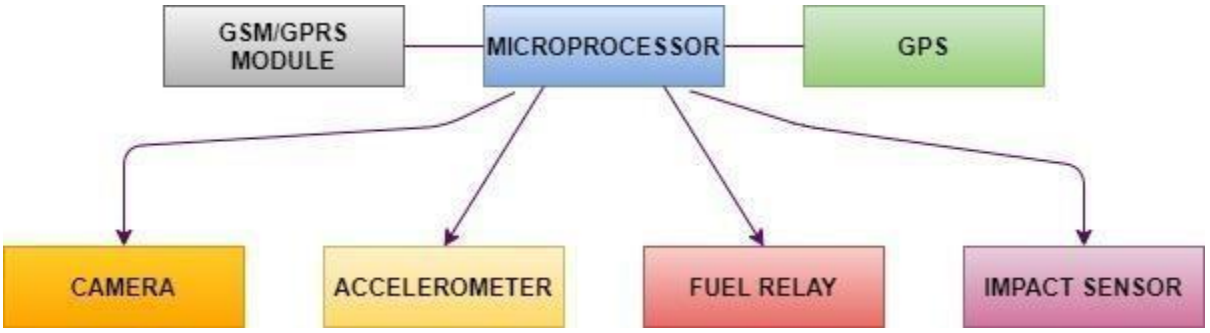


Fig. 3 Block Diagram of a vehicle equipped with SVMS framework.

The term "intelligent software agents" refers to a group of entities that attempt to mimic human thinking processes or behaviors. Agents targeted at assisting users, doing specific activities, conducting supervisory and security activities, or filtering data, among other things, can be found. It's possible to see how the agent senses its surroundings using several sensors and then gets involved in it with effectors. It's important to distinguish amongst a multi-agent network and an agent-based network. Systems dependent on agents will be those that use the notion of agents as an abstract technique when designing a system, but that may be implemented using regular software architecture. A multi-agent network, on the other hand, is created with the explicit intention of including a few agents that communicate with one another to accomplish a particular functionality [24]. When an issue requires more than one agent to solve, numerous agents can be combined into a MAS (Multi-Agent System), which offers a structure for agents to interact and collaborate to solve issues [25]. AMAS is defined as a system in which each agent has insufficient data or abilities to solve problems, has no universal control that has devolved data, and executes tasks metachronous. Inside a MAS, every single agent has their own goals and expertise, thus cooperation is essential to integrate their contributions and resolve the issue [26]. Because the malfunction of a solitary agent does not jeopardize the function of the whole system, a MAS is regarded as a durable system. A MAS's agents may educate and plan activities in a cooperative manner.

Algorithm of the proposed framework:

Step 1: Capture the image of the face and perform mean square error (MSE) of the image.
Step 2: Perform the mean square error (MSE) of the reference image and compare it with the previous result obtained.
Step 3: When the minimum threshold value is less than the threshold displays the result, otherwise display invalid and off the engine of the vehicle.
Step 4: Capture the fingerprint image from the sensor and compare it with the predefined entries. If the fingerprint matches display the result, otherwise display invalid and off the engine of the vehicle.
Step 5: Capture the value from the alcohol sensor and if the outcome is less than the minimal value, start the engine with a notification, others otherwise display invalid and off the engine of the vehicle.
Step 6: In case of an accident occurrence, then send awarning notification to the driver's emergency contact number.

Numerous data of the automobile, such as condition of engine's level of fuel, and the distance between the automobile and other cars both back and in front), are displayed on the HUD while the monitoring phase. The warmth of the surroundings is also captured and displayed. Aside from that, crash detectors are put on both sides of the automobile to detect crashes, and in the terrible case of a collision, a notification is sent to a predetermined number via a GSM module. An Arduino Mega microcontroller board is used to interconnect the sensors necessary for all of the above functions. The microcontroller's data are then relayed over Bluetooth to a Raspberry Pi, where they are shown on a HUD linked through a LAN (Local Area Network).
The Android software is critical to the Smart Vehicle Safety and Security System's output. The following are the hardware elements used in the Smart Vehicle Safety and Security System program. The microcontroller in this project is an Arduino Uno. All of the sensing elements are glued to this microcontroller circuit and the

microcontroller accepts the data and evaluates a suitable output. This project makes use of a vibration sensor to detect car accidents and crashes. The sensor's signal is sent to the microcontroller circuit, which processes it and produces a specified output. The alcohol/gas detector is used in this research to detect the presence of alcohol in breathing. The sensor's input is sent to the microcontroller circuit, which processes it and produces a specified output. This project uses an eye-blink detector to detect the driver's fatigue. The sensor's input is sent to the microcontroller board, which processes it and produces a specified output.\The buzzer is used in this application to indicate and warn the driver and the surrounding area. The no board sends the signal to the buzzer based on the calculations. The GPS module is used in this application to record the coordinates of the position where the project is taking place. The sensor's input is sent to the microcontroller board, which processes it and produces a specified output. The GSM module is used in this application to convey the position coordinates obtained by the GPS module. The sensor's output is sent to the Eye-blink Detector and the Circuit breaker. Module for GSM. The board is a microcontroller that uses the input to produce a certain output. This demonstration will show you how to connect a GSM modem to the module of Toradex. Numerous micro-switches are put all throughout the car's body for the objective of collision detection. If any of the switches light up, it means there has been an incident. Message is dispatched to the local agency in such a circumstance. A notification is also delivered to the driver's pre-defined emergency number. These notification messages are transmitted using a GSM module that is connected to the Arduino board via a sequential communication gateway.

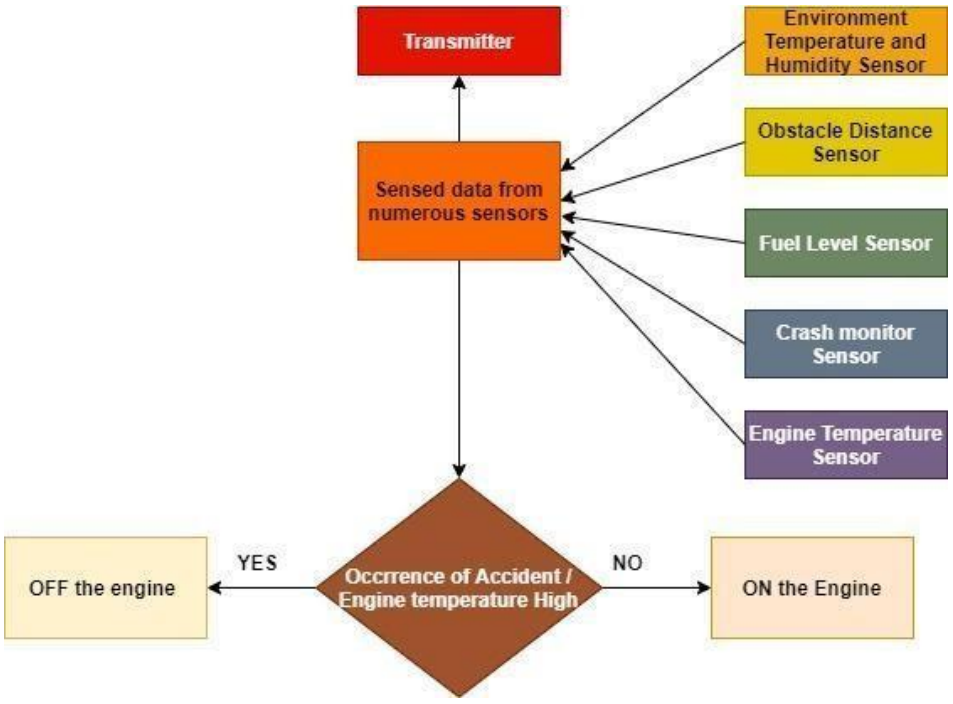


Fig. 4 Flowchart of the proposed SVMS Framework

IV. RESULT AND DISCUSSION

A traditional strategy based on detectors and a cloud processing system is compared to a novel technique based on embedded smart agents. The information-gathering platform for smart vehicles was built to conduct this analysis. This platform has over 5000 active users that contribute information on their intelligent vehicle routes regularly from all around the world. It is feasible to analyze the information of the routes received by people who have tried the technique suggested in this study with the data acquired using the traditional methodology. The information is analyzed in its whole in the normal system and as a continual transmission of data input/output inside the cloud system. However, in the proposed model, the data processing is dispersed among the many IoT devices installed. Similarly, communicating with the agent infrastructure entails more flexible and lighter information transmission than that provided by traditional cloud systems.

ACTIVE ROUTES WITH 3 ELEMENTS MEASURED	AVERAGE RESPONSE TIME OF REGULAR APPROACH (ms)	AVERAGE RESPONSE TIME FOR THE PROPOSED FRAMEWORK (ms)
5	750	500
10	830	554
15	1115	756
20	1870	987
25	2000	1056
30	2236	1079

Fig. 5 Average Response Time of the Regular Vs Proposed Framework for three elements.

The Raspberry Pi with Accelerometer and Impact Detector is used to create the IoT gadget. GSM/GPRS and GPS modules were also attached to the RPi. It also comes with a camera mounted directly on the board. The Raspbian operating system was installed on the RPi, which includes a Python interpreter. The Python program language was used to access and control all of the equipment connected to the Raspberry Pi. The SVMS system was installed and tested in a tiny automobile. The error value's example acquired for a contrast amongst an authorized or unauthorized photo and a reference picture to determine the efficiency of the face detection algorithm using mean square error.

ACTIVE ROUTESFOR 5 ELEMENTS MEASURED	AVERAGE RESPONSE TIME OF REGULAR APPROACH (ms)	AVERAGE RESPONSE TIME FOR THE PROPOSED FRAMEWORK (ms)
5	750	500
10	830	554
15	1115	756
20	1870	987
25	2000	1056
30	2236	1079

Fig. 6 Average Response Time of the Regular Vs Proposed Framework for five elements.

It is evident that if a match happens, the MSE is below 3500, and if no matching happens, the MSE is more than 5000. However, this method's total reliability was determined to be 92.7 percent. In circumstances when the user's face was only partially lighted, this approach proved unable to provide the intended results. In addition, the fingerprint detector had a 96.97% accuracy rate when there were no tiny sensor particles when it was being used. The notion of GPS and GSM has been used to construct a capable Smart Vehicle Safety and Security System that includes a pressure detector, eye-blink detector, alcohol detector, proximity detector and vibration detector. The Arduino board is connected to the detectors. Places with outreach issues and poor network connections, as well as isolated places with no network connectivity, might be problematic.

V. CONCLUSION

This technology is part of a multi-agent framework that will be in charge of handling the many wireless technologies that connect up the IoT environment in which it will be used. Wireless equipment capable of sharing data with the Internet and systems that make a gateway to operate as a bridge between the network and the Internet has been recognized as the two basic categories of wireless gadgets that may be implemented. Through all the deployment of MAS, the suggested architecture is aimed to reduce and address these open problems. Accidents will be recognized instantly with severity levels utilizing the SVMS and will be reported to officials without prejudice. Immediate medical care will help to limit the incidence of fatalities and serious injuries in car accidents. This might also assist traffic officials in diverting traffic, saving energy and resources. The frequency of car thefts will progressively decrease since this will assist the user in locating and controlling stolen automobiles. Because of the minimal cost and reduced complexity of the construction and components utilized in the suggested system, even low-end vehicles may be equipped with it. This would assure the safety and comfort of drivers in any sort of vehicle wherever on the planet. As a result, the incident notification text may not be delivered to the selected phone number. The suggested and thus constructed method may be improved and adjusted by incorporating technological ideas such as GPS (Global Positioning System) and big data to analyze and interpret the patterns related to the accidents. The same technique may be changed and implemented for two Wheelers at the same time. Furthermore, the geological position of the accident might be communicated to an ambulance for immediate medical care.

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Health Care Monitoring System

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***Abstract*—**Recent progress in Internet of Things (IoT) technology has transformed healthcare by making continuous, intelligent patient monitoring achievable. This work presents an IoT-enabled health monitoring solution that records key physiological parameters including oxygen saturation (SpO_2), heart rate, and body temperature in real time. The design employs sensors such as oximeters, accelerometers, and load cells to analyze muscular movements, detect paralysis symptoms, and monitor intravenous (IV) fluid usage. The system minimizes hospital visits, supports early diagnosis, and facilitates remote supervision. Due to its compactness, affordability, and ease of use, it is highly suitable for rural and resource-constrained environments. Continuous tracking and early warnings improve quality of care, patient well-being, and treatment efficiency.

***Index Terms*—Internet of Things (IoT), Health Monitoring, SpO_2, Accelerometer, Intravenous Fluid Tracking**

I. Introduction

Healthcare professionals around the world continuously strive to provide better and more reliable treatment to patients. The integration of modern technology into medical practice has made this goal increasingly achievable. Technologies such as Artificial Intelligence (AI) are transforming healthcare delivery, while the Internet of Things (IoT) allows medical devices to communicate and share data efficiently. In healthcare applications, IoT plays a crucial role in patient monitoring, disease prevention, and effective management of medical information [3]. However, conventional healthcare systems often require patients to visit hospitals or clinics in person, which can be difficult for individuals living in remote or underserved regions. To address this challenge, the present work concentrates on monitoring essential health parameters, including oxygen saturation, body temperature, and heart rate variations. Additionally, the rising incidence of conditions such as paralysis emphasizes the importance of continuous patient observation. By using accelerometer-based IoT systems, muscle movement can be monitored objectively, enabling the early detection of paralysis and supporting timely medical intervention [4].

II. Motivation and Inspiration

The increasing need for fast, dependable, and preventive healthcare services has encouraged the adoption of IoT-based monitoring technologies [6]. This project is driven by the real-world difficulties experienced by patients and medical professionals in areas where access to timely healthcare is restricted due to geographical distance or limited resources. In many cases, conventional healthcare systems do not provide continuous monitoring of vital signs, which can delay diagnosis and treatment. These limitations motivated the development of the proposed system. Moreover, medical conditions such as paralysis demand constant observation, and the idea of an automated solution capable of detecting early warning signs was introduced to reduce the workload on caregivers while improving patient safety and comfort.

In addition, the system was designed with portability and user convenience in mind. The inclusion of features such as automatic IV fluid level monitoring and continuous oxygen measurement helps eliminate frequent manual checks, making the system practical for both patients and healthcare providers.

III. Objectives

- Design a compact and easy-to-use health monitoring system suitable for regular patient use.
- Continuously measure essential physiological parameters such as SpO_2, heart rate, and body temperature.
- Integrate load cell sensors to automatically monitor intra- venous (IV) fluid levels.
- Analyze accelerometer data to identify abnormal body movements that may indicate paralysis.
- Enable remote access to patient health data for timely review by healthcare professionals.
- Develop a versatile monitoring solution that can be applied across various healthcare environments.

IV. Scope

This project focuses on the development of an IoT-enabled health monitoring system capable of remotely measuring key physiological parameters such as blood oxygen levels, heart rate, and body temperature. The system allows healthcare professionals to monitor patients, particularly those living in rural or remote areas, without the need for frequent hospital visits. In addition to basic vital sign monitoring, the solution incorporates IV fluid level measurement through load cells and movement analysis using accelerometers to support paralysis assessment. Owing to its compact and portable design, the pro- posed system is suitable for use in both clinical environments and home-based care settings [5].

V. Problem Statements

Delivering effective healthcare services to people in remote or underserved regions remains a major challenge, primarily due to the lack of continuous patient monitoring systems. Conventional healthcare methods often rely on periodic check- ups, which fail to capture vital health parameters in real time and can lead to delayed medical intervention. In addition, many existing techniques used for paralysis assessment depend on subjective clinical observation, which may slow down diagnosis and treatment [1].

Furthermore, the absence of automated intravenous (IV) fluid monitoring increases the risk of medical errors and patient discomfort. These limitations highlight the need for lightweight and reliable IoT-based solutions that support continuous monitoring, real-time supervision, and remote diagnostic capabilities.

VI. Proposed Solutions

The proposed system integrates IoT technology with biomedical sensors to address the identified healthcare chal- lenges. The key functionalities of the system include:

- Continuous monitoring of critical physiological parameters with timely alert mechanisms.
- Automatic measurement of intravenous (IV) fluid levels using load cell sensors.
- Detection of irregular or abnormal muscle movements through accelerometer-based analysis.
- Secure transmission of patient health data to healthcare professionals via IoT platforms for remote assessment [2].

VII. Methodology

Figure 1 presents the circuit architecture of the proposed health monitoring system. The hardware setup is built around an Arduino Mega 2560 microcontroller, which interfaces with multiple biomedical sensors, including an ECG module, an accelerometer, a DHT11 temperature sensor, and a SpO_2 sensor. These components work together to collect and process physiological data in real time.

To monitor intravenous (IV) fluid levels, a load cell is employed to measure the force exerted by the fluid container. The applied force is calculated using:

$$F = m \cdot g \qquad (1)$$

where m denotes the mass of the IV fluid and g represents gravitational acceleration. The resulting force is converted into an electrical signal, which is then processed by the Arduino to identify predefined threshold levels and trigger alerts when necessary.

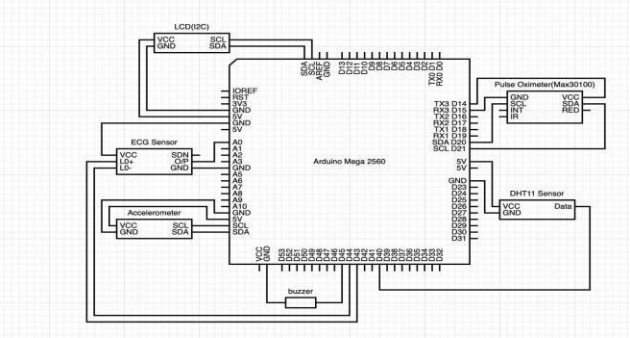


Fig. 1. Circuit diagram of the proposed IoT-based system

VIII. HARDWARE IMPLEMENTATION

Figure 2 shows the developed hardware prototype of the proposed health monitoring system. The figure highlights the integration of various sensors and modules within the setup. Table I summarizes and compares the measured physiological parameters, illustrating variations in key health indicators.

The core of the hardware system is an Arduino Mega 2560 microcontroller, selected for its sufficient input/output pins and reliable performance when interfacing with multiple sensors simultaneously. Biomedical sensors such as the ECG module, pulse oximeter, temperature sensor, accelerometer, and load cell are connected to the controller to acquire real- time physiological data. Each sensor operates independently while contributing to a unified monitoring framework.

Sensor readings are continuously processed by the micro- controller and transmitted through the IoT communication interface for remote access. Threshold values are predefined for each parameter, allowing the system to generate alerts when abnormal conditions are detected. The compact arrangement of components ensures low power consumption and enhances portability, making the device suitable for both hospital environments and home-based patient monitoring. Overall, the hardware implementation demonstrates a reliable and scalable design that supports continuous health supervision.

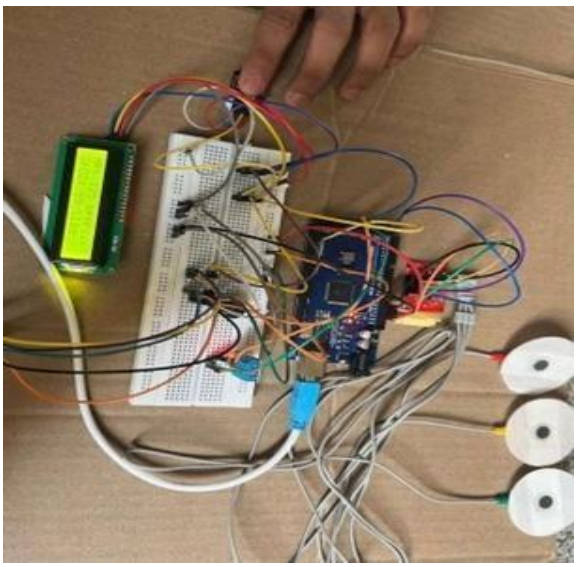


Fig. 2. Prototype of IoT health monitoring system

Table 1: Comparison of Vital Parameters

Parameter	Normal	Paralyzed
Heart Rate (bpm)	60–100	80–120
Blood Pressure (mmHg)	90/60–120/80	<90/60 or >120/80
Oxygen (PaO2)	75–100	70–95
SpO2 (%)	95–100	90–95
Temperature (°C)	36.5–37.5	35–38

IX. ECG MONITORING

Figure 3 illustrates the ECG monitoring configuration used in the proposed system. The ECG sensor captures the electrical signals generated by cardiac activity and forwards them to the Arduino controller, where the signals are processed and analyzed to assess heart function in real time.

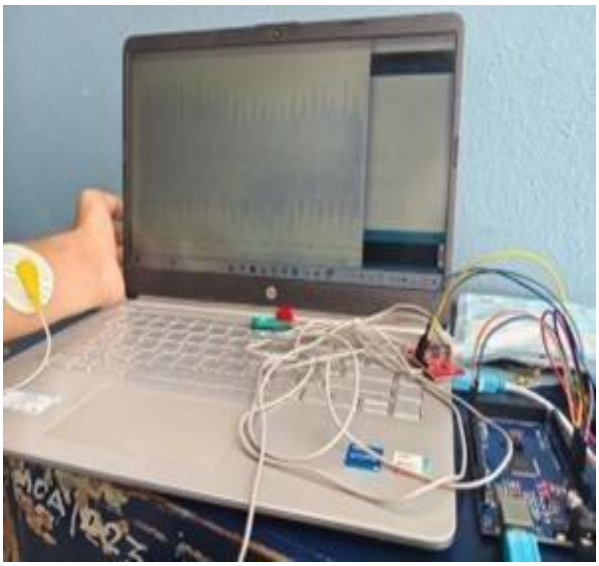


Fig. 3. ECG Monitoring Setup

X. TEMPERATURE MONITORING

Figure 4 illustrates the body temperature measurement process using the DHT11 sensor. The sensor continuously measures the patient's body temperature and transmits the data to the controller, enabling real-time monitoring and timely identification of abnormal temperature variations.



Fig. 4. Body temperature measurement using DHT11

XI. Movement Detection

Figure 5 demonstrates the movement detection mechanism implemented using an accelerometer. The sensor captures body motion data, which is analyzed to identify irregular or reduced movement patterns that may indicate motor impairment or paralysis-related conditions.



Fig. 5. Movement detection using an accelerometer

XII. SpO_2 Level Monitoring

Figure 6 illustrates the measurement of blood oxygen satu- ration using a pulse oximeter. The sensor continuously tracks SpO_2 levels and forwards the readings to the controller, allow- ing real-time assessment of the patient's respiratory condition and early detection of oxygen level abnormalities.



Fig. 6. Oxygen saturation measurement (SpO_2)

A. SpO_2 Monitoring

Oxygen saturation (SpO_2) is an essential physiological indicator used to assess respiratory health. In healthy individuals, SpO_2 levels typically range between 95% and 100%. Continuous monitoring of oxygen saturation enables early identification of hypoxemia, allowing timely medical intervention and reducing the risk of serious complications [12].

XIII. Conclusion and Future Work

This study presented an IoT-enabled health monitoring system designed to continuously measure vital parameters such as oxygen saturation, body temperature, heart rate, IV fluid levels, and body movement. By enabling real-time data collection and remote access for healthcare professionals, the system reduces the need for frequent hospital visits and is particularly beneficial for patients in remote or underserved regions. Its compact design, affordability, and multi-functional capability make it suitable for both clinical and home-based healthcare applications. Despite these advantages, certain challenges remain, including sensor calibration accuracy, environmental influences on measurements, and the need for stable network connectivity. Ensuring the security and privacy of patient data during transmission is also a critical concern. Future work will focus on incorporating SIM-based direct communication between patients and doctors, integrating machine learning techniques for predictive health analysis, and further miniaturizing the hardware to enhance user comfort. Additionally, improving compatibility with telemedicine platforms and electronic health record systems will support wider adoption. Overall, the proposed system contributes to the advancement of connected healthcare by promoting proactive monitoring, personalized treatment, and improved patient outcomes through IoT-driven solutions.

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Design and Analysis of a PCB MEMS Gyroscope

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Abstract: An operational Microelectromechanical Systems (MEMS) gyroscope based on ICM-42605 sensor and ATmega328P microcontroller has been designed and analyzed. A printed circuit board (PCB) has been designed using Altium CAD software and manufactured that houses ICM-42605 sensor, 3 Chip Resistors of 1KOhm each, 4 capacitors and Linear voltage regulator (IC REG LINEAR 3.3V 600MA SOT25). Inter-Integrated Circuit bus (I^2C) which is also known as Two Wire Interface (TWI) bus was utilized as the connection between the ICM-42605 and ATmega328P. 0 offset calibration has been done to ensure the accuracy of the readings. The angular rotation was done using a robotic arm rotating for a maximum of 90° at the angular rate of 81.36°/s. This has been done based on a similar setup on the MPU6050 sensor and ATmega328 Microcontroller setup to determine the consistency of this type of Microelectromechanical Systems and reduce the noise level. It was observed that the ICM-42605 is very sensitive and has variation of sensitivity in the different gyroscope axes.

Keywords: *Gyroscope, MEMS, ICM-42605, ATmega328P, PCB.*

I. INTRODUCTION

A gyroscope is an instrument used to measure angular rotation. Gyroscopes have many applications for example in space, drones, aircrafts, automobiles. Gyroscopes are basically used for inertial navigation purposes.

Different types of gyroscopes exist which vary based on their working principle. This includes Optical Gyroscopes such as Fiber based ring laser gyroscope, monolithic integrated ring laser gyroscope, He-Ne ring laser gyroscope. The ring laser gyroscopes suffer the locking effect where the gyroscope becomes insensitive at a low angular rotation [1-9], research is still going on to mitigate the issue. MEMS gyroscopes on the other side are a type of gyroscopes that have received much attention recently due to their local cost, very small size etc. In this research we designed an MEMS gyroscope based on ICM-42605 sensor and ATmega328P microcontroller.

Several MEMS gyroscopes still face the issue of low sensitivity, mutual coupling for a small coupling network structure was proposed as a viable solution and also an optimization of gyroscope coupling on the design is more effective [10,11]. Also an appointed time control method was proposed to compensate for sampling constraints and inconsistencies that occur during data collection [12]. Sage-Husa Adaptive Kalman Filter (SHAKF) method was utilized to improve the gyroscope performance without changing the hardware, this is by random error modelling and utilizing a virtual gyroscope for measurement [13]. There is also a design of a displacement mechanism that is chevron shaped in order to increase the performance of MEMS Tuning fork gyroscope [14]. Negating self-induced parametric excitation can also improve the performance of an MEMS gyroscope under specified conditions by ensuring nonlinear frequency matching [15]. For accurate approximation of uncertainties and disturbances which results from a dynamic environment, a time-vary independent on initial condition barrier function is modelled [16].

II. COMPONENTS OF A PCB BASED GYROSCOPE

2.1 ICM-42605

The ICM-42605 has the least gyro and accel sensor noise as compared to other IMU sensors. It also has immunity against out-of-band vibration-induced noise. It is also recommended for use in drones [17]. The device operates at a voltage range of 1.71V to 3.6V. In this case, a stable 3.3V input voltage was supplied. The standard Gyroscope noise according to the manufacturer is 3.8 mdps/$\sqrt{Hz}$ and it has a full scale range of ± 15.2/31.2/62.5/125/250/500/1000/2000 in terms of dps. It also contains digital filters which can be programmed by the user. The device supports several interfaces which include 1 MHz I^2C, 12.5 MHz I3CSM,24 MHz SPI.

The gyroscope part of the IMU in this device contains a proof mass, the drive and sense mechanism. . The drive system and the sense element are supported by the spring-like system.

The proof mass is supported by the suspended beam. In the constant working conditions, the proof mass reciprocates along x directions because of the function of the driving system. Its motion equation can be expressed as Eq. 1

$$x = A_x cos(\omega_x t) \quad (1)$$

where x denotes the proof mass displacement; A_x is the amplitude of the movement; ω_x is the angular speed of the driving system.

When an angular force is applied in Z direction, a Coriolis force will be initiated along Y direction because of the Coriolis effect. It is expressed as:

$$F_y = 2m\Omega \times v = -2m\Omega A_x \omega_x sin(\omega_x t) \quad (2)$$

where F_y denotes the Coriolis force; Ω denotes is the applied angular speed; v is the linear motion of the proof mass's displacement.

By detecting F_y applied on the sensitive mechanism of the sensor, the applied angular displacement can be determined by the use of Eq. 2 [18].

III. METHODOLOGY

In this research an ICM-42605 and ATmega328P were used. This configuration has been selected due to its inexpensiveness and practicality which is ideal for academic research purposes. The configuration was done in accordance with a similar setup of MPU-6050 sensor and ATmega328 Microcontroller [19].

3.1 Schematic

The circuits were designed using the Altium software. The schematic as shown in **Fig. 1** consists of a Linear Voltage Regulator which outputs constant 3.3V from variations of inputs. In our case, the input was 5V from the arduino uno (which houses the ATmega328P) development board. It also contains supporting components such as 4.7 kΩ resistors which are actually pull up resistors to maintain the high state of the I^2C communication, Decoupling-Capacitors (C1, C2, C3 having 0.1 µf and C4 having 47µf) which maintain the voltage across the circuits. The Connector enables the transmission of power and signals between the microcontroller and the PCB.

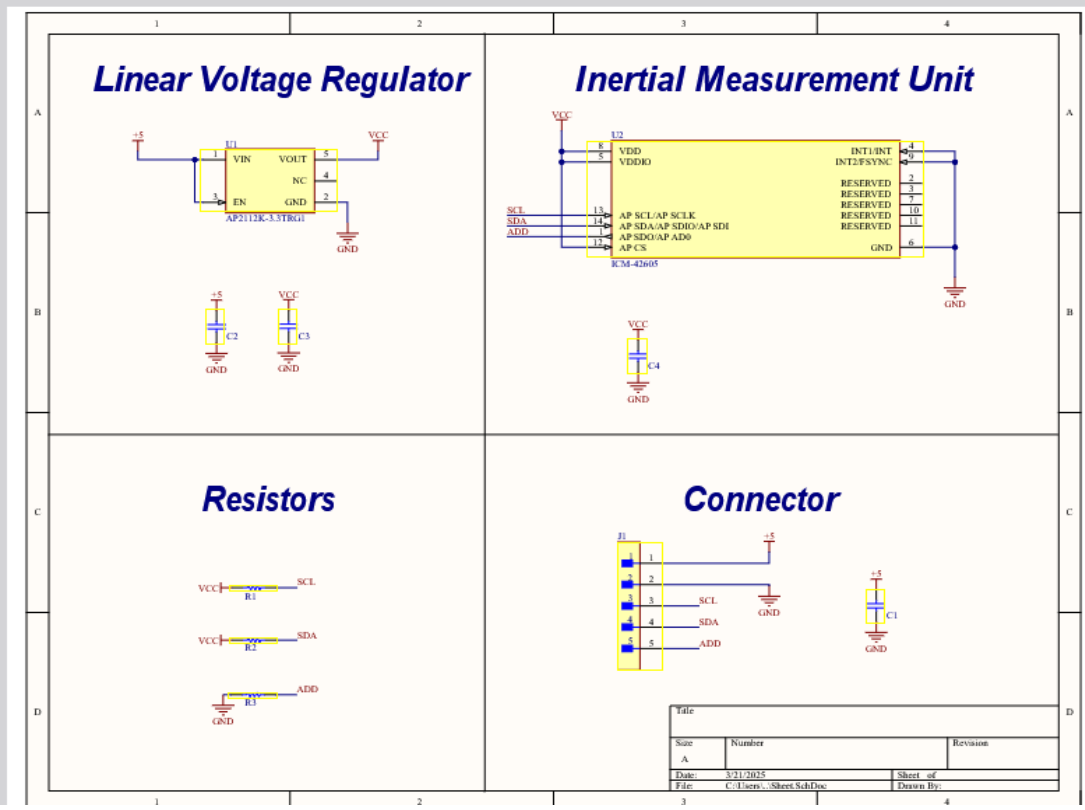


Fig. 1. Schematic of the ICM-42605 with its supporting components

3.2 Printed Circuit board design, manufacture and assembly

In this project, a two layer design with dimensions of 20mm x 18mm. The top layer consists of ICM-42605, 3 Chip Resistor, 1 KOhm, 4 capacitors and a Linear voltage regulator (SPX3819M5-L-3-3/TR). And the bottom part consists of only 1 pcb board connector with 5 pins.

Altium software was used in this project to design the Schematic and PCB. After designing, the PCB was manufactured using a PowerPCB. The designed PCB in Altium can be illustrated in Fig. 2 and 3.

The PCB was designed in such a way that the copper signals as shown in Fig. 4 and 5 have a power and signal transmitter and also a heat sink for the supporting components. This to ensure the optimum temperature condition for the linear voltage regulator and the ICM-42605. This was also done to make everything compact. After completion of the design, Gerber files were extracted from the Altium software and sent to a manufacturing company; in our case our Powerpcb. The PCB was manufactured as shown in Fig. 6. During the assembly; firstly thin soldering wire and a soldering iron were used to solder the resistors, capacitor, the linear voltage regulator and the connectors. Secondly, the ICM-42605 was solder by putting melted soldering wire on the copper surfaces, using the desoldering wick to remove excess solder, an SMD station was used to blow hot air on the solder paste at a constant temperature of 350°C and an ICM-42605 was mounted on top of the solder paste and left to solidify. The whole PCB was mounted on a desk using double sided tape. The final assembled PCB is as shown in Fig. 7 and 8.

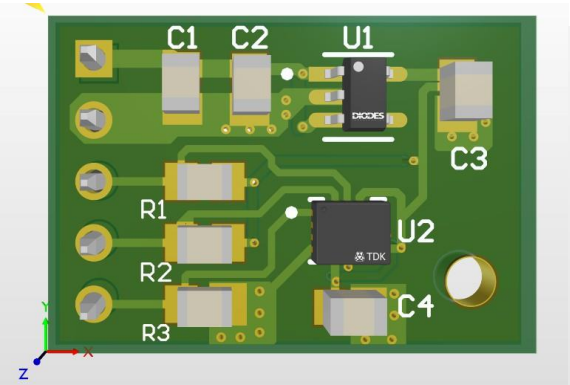


Fig. 2. Designed pcb top view

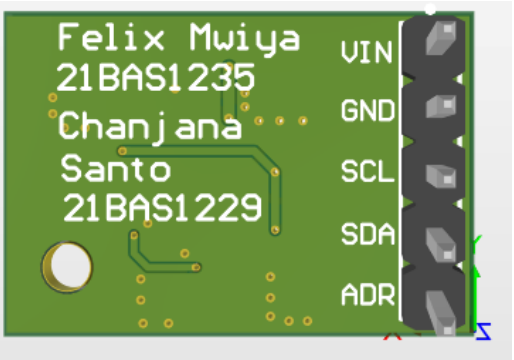


Fig. 3. Designed PCB bottom view

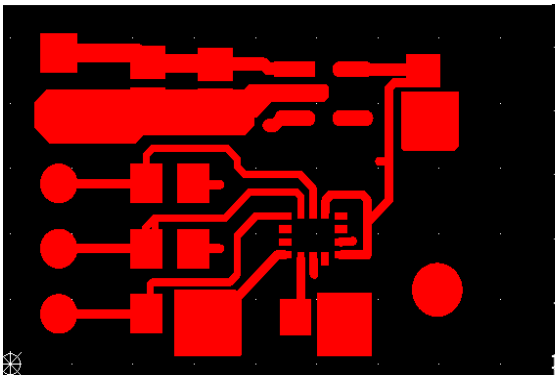


Fig. 4. Board copper signal top

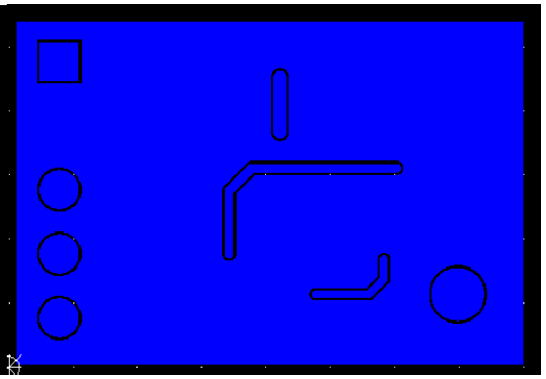


Fig. 5. Board copper signal bottom

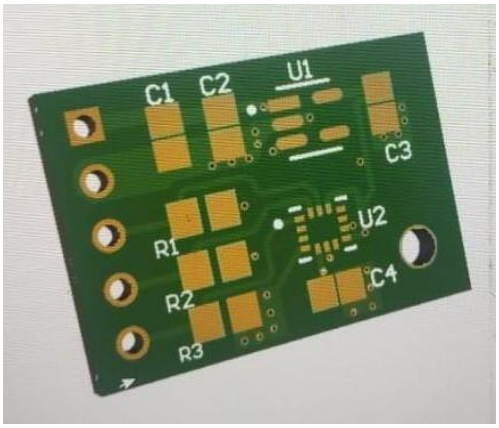


Fig. 6. PCB design without the assembled components.

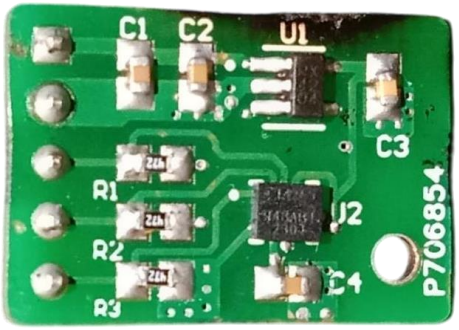


Fig. 7. Assembled PCB top view



Fig. 8. Assembled PCB bottom view

3.3 Data logger

The data logger was designed using python and compiled into an exe file, was extracted and installed on the windows operating system. The data logger was solemnly designed for the experimental part of this research. The GUI for the data logger (see **Fig. 9**) consists of the COMport for selecting the port for USB communication between the arduino uno and the PC. Baud rate, in our case we used 115200. It indicates Maximum points and has a CSV logging interface for extracting data from the data logger into a CSV file. In order to start and stop the sensor from transmitting data a connect and disconnect button was used.

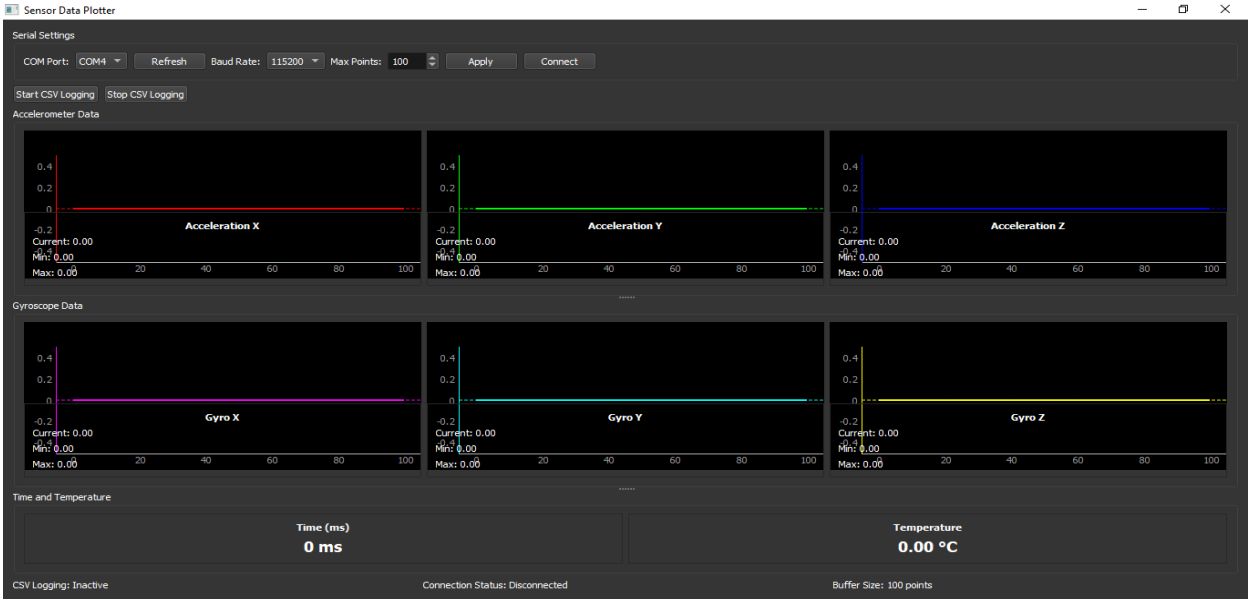


Fig. 9. Data logger

3.4 Configuration of ICM-42605 and ATmega328P

Inter-Integrated Circuit bus (I^2C) which is also known as Two Wire Interface (TWI) bus was utilised as the connection between the ICM-42605 and ATmega328P. I^2C is widely used when connecting sensors and other external devices with the microcontroller board since it is simple and user friendly. Data transmission is done via two wires i.e *the data line* (SDA) and *clock line* (SCL). SCLATmega328P acted as the master while ICM-42605 acted as a slave. The slave device possesses a hexadecimal number which permits the microcontroller to address and communicate [33]. Table 1 shows the pin connections between the sensor and the microcontroller.

Table 1. Pin connections between ICM-42605 and ATmega328P

PCB (ICM-42605)	**Arduino Uno R3 (ATmega328P)**
SDA	SDA
SCL	SCL
GND	GND
VCC	5V

Avanced_I2C example code from ICM42605 by Inhwan Wee library was taken and modified; the time clock was added for our experimentation purposes. After the code was uploaded into the ATmega328P, we disconnected the Arduino Uno from the Arduino IDE and connected it to the data logger. The data logger was configured and it was able to plot the data from the sensor and the ATmega328P acting as the intermediate.

IV. Results and Discussion

The experiment of the PCB based gyroscope was done in the Robotics Lab at Chandigarh University where a robotic arm was used to rotate the PCB based IMU at 81.36°/s. **Fig. 10-12** shows the sensitivity of the gyroscopes for each axis i.e. X,Y and Z. The variation in the axes is due to the experimental error such variation of the motor speed in terms of torque delivery, system stability and control etc.
The graphs are showing rotation in X, Y, Z axis. The data was collected using the data logger into a CSV file. The raw data was analysed using Microsoft Excel and **Fig. 13** shows the analysed data. According to the graph, it shows that the gyroscope is very sensitive and minimum deviation is there as compared to the theoretical values. It was also observed that the curve in the Z axis measured in terms of sensitivity deviated from the theoretical curve. In the overall design of the PCB, ports not required for instance INT2 / FSYNC (Interrupt/Frame sync input) were removed from the final model to the make the design compact and also increased the space for copper layer which also performed as a heat sink.

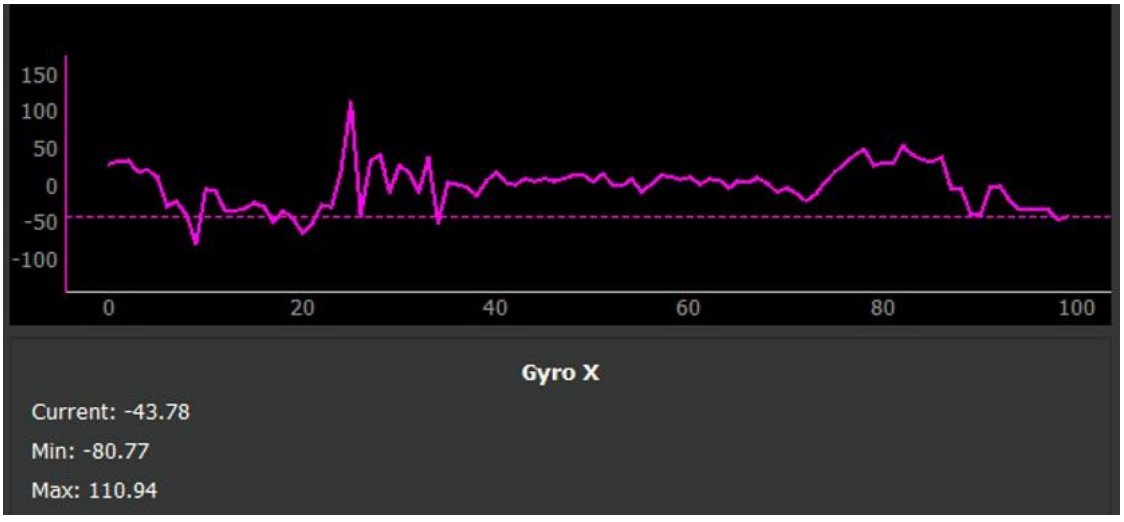


Fig. 10. Gyroscope test in the X axis

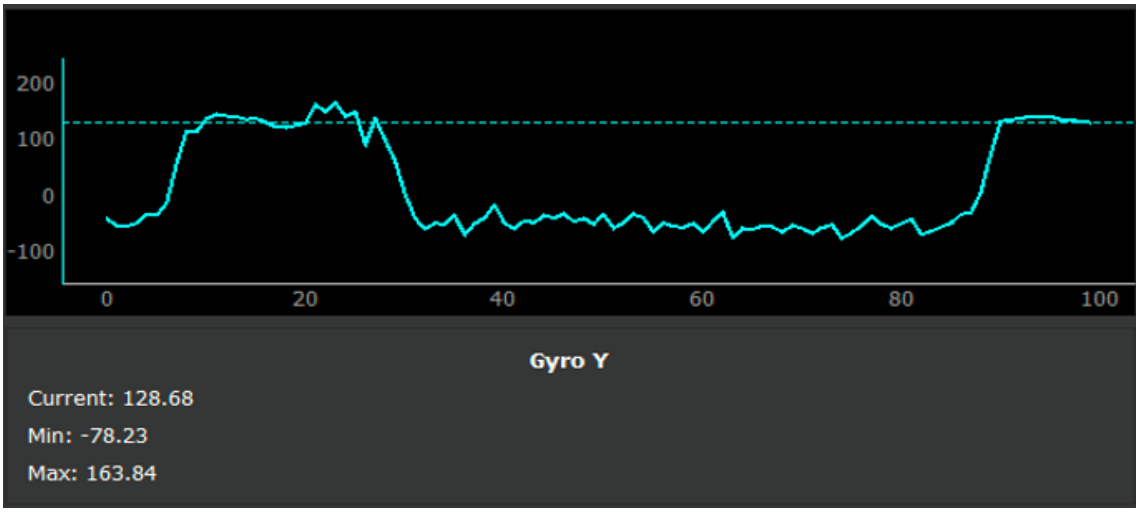


Fig. 11. Gyroscope test in the Y axis

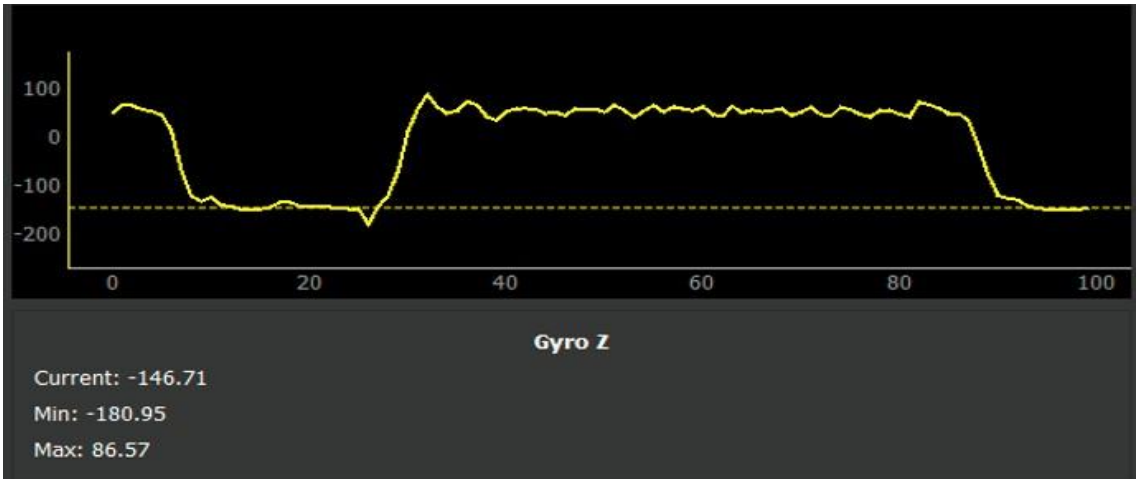


Fig. 12. Gyroscope test in the Z axis

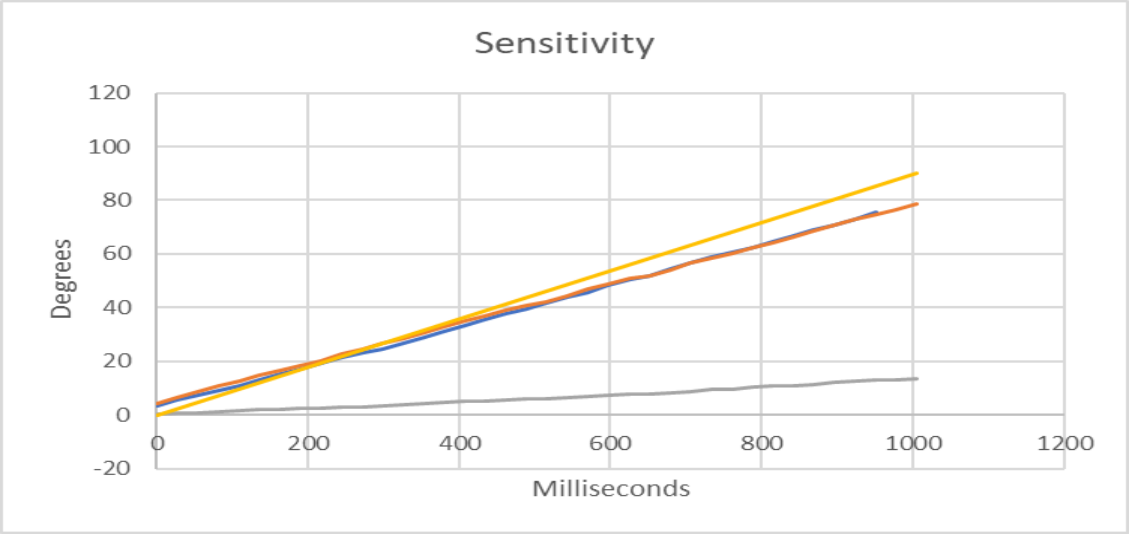


Fig. 12. Shows the sensitivity of the gyroscope in the X, Y and Z axes with comparison to the theoretical sensitivity. The Yellow line shows theoretical sensitivity, the red line shows sensitivity in the X axis, the blue line shows sensitivity in the Y axis and the grey line shows sensitivity in the Z axis.

CONCLUSION

The PCB based Gyroscope was designed and its sensitivity was analysed. Based on the results, it shows that the gyroscope is highly sensitive and therefore it is recommended for drone use. It was also observed that there is some inconsistency of the gyroscope sensitivity in different axes.
Further research can be done in the design and use of the ICM-42605 and high speed microcontroller on the same PCB design and materials in order to make the gyroscope more compatible and more efficient in terms of data transmission.

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A Comprehensive Review on Reconfigurable MIMO Antenna Systems

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***Abstract*—**Wearable antennas Reconfigurable Multiple-Input Multiple-Output (MIMO) antennas have emerged as a transformative technology in modern wireless communication systems, enabling enhanced adaptability, robustness, and spectral efficiency. With the rapid evolution of 5G and the forthcoming 6G networks, wireless channels demand high data rates, low latency, and efficient utilization of spectrum all of which rely heavily on intelligent antenna architectures. Reconfigurable MIMO antennas address these requirements by dynamically altering key antenna parameters, including operating frequency, radiation pattern, and polarization states. Such adaptability not only improves link reliability but also mitigates challenges such as mutual coupling, channel fading, and spatial correlation between antenna elements. This paper presents a comprehensive review of reconfiguration mechanisms—frequency, pattern, and polarization—and examines established and emerging switching technologies such as PIN diodes, RF MEMS, varactors, liquid metals, and tunable materials like graphene and phase-change compounds. Furthermore, key MIMO performance indicators, including envelope correlation coefficient (ECC), diversity gain (DG), total active reflection coefficient (TARC), and channel capacity, are analyzed to provide a deeper understanding of system behaviour under reconfiguration. Mutual coupling reduction techniques, including metamaterial-inspired structures, decoupling networks, defected ground structures (DGS), parasitic elements, and electromagnetic bandgap (EBG) surfaces, are also reviewed in detail. The paper highlights applications across 5G/6G communication, wearable electronics, Internet of Things (IoT), vehicular communication systems, and reconfigurable intelligent surfaces (RIS). Finally, major research gaps and future opportunities are identified, emphasizing the need for low-loss materials, compact configurations, AI-driven reconfigurability, and fully programmable antenna platforms. This review aims to guide future advancements in adaptive and intelligent MIMO antenna systems.

I. INTRODUCTION

Modern wireless communication systems are evolving rapidly to accommodate unprecedented demands for high data rates, robust connectivity, and efficient use of the radio spectrum. As 5G networks mature and 6G technologies emerge, wireless devices are expected to support ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), extended reality (XR), high-speed vehicular links, and dense Internet of Things (IoT) ecosystems. In such environments, antenna systems play a critical role in determining overall communication performance, particularly in terms of throughput, interference mitigation, spatial reuse, and link stability. Multiple-Input Multiple-Output (MIMO) antenna technology has long been recognized as an effective solution to improve channel capacity and link reliability by exploiting spatial diversity and multiplexing gains. However, conventional MIMO antennas suffer from inherent limitations arising from their fixed operating characteristics and strong mutual coupling when placed in compact platforms such as smartphones, wearables, sensor nodes, or automotive modules.

Reconfigurable antennas have emerged as a promising solution to overcome these constraints. By dynamically modifying key operating parameters such as frequency band, radiation pattern, and polarization state, reconfigurable antennas can adapt to varying channel and environmental conditions in real time [1]. This adaptability enables functions such as interference avoidance, multi-band operation, adaptive beam shaping, and polarization diversity, thereby enhancing the versatility and robustness of wireless communication systems. When such reconfigurability is integrated into a MIMO architecture, the resulting Reconfigurable MIMO Antenna (R-MIMO) system inherits the advantages of both technologies—spatial diversity from MIMO and dynamic adaptability from reconfigurable antennas—leading to significant improvements in overall system performance.

The synergy between reconfigurability and MIMO operation leads to several key benefits. First, dynamically switching between radiation states helps reduce spatial correlation among antenna elements, which is crucial for achieving high MIMO efficiency and channel capacity. Second, reconfigurable frequency or pattern modes allow the antenna elements to decouple in specific operating conditions, thereby reducing mutual coupling—a major challenge in compact MIMO designs. Third, reconfigurable MIMO antennas enable multi-standard compatibility, allowing a single antenna system to operate across diverse wireless protocols such as 4G LTE, 5G NR, Wi-Fi, Bluetooth, UWB, and emerging sub-THz standards for 6G [2]. Fourth, adaptive polarization switching enhances link reliability in multipath environments, especially in mobile, vehicular, and satellite communication scenarios.

Reconfigurable MIMO antennas are particularly valuable in applications where size, efficiency, and performance are tightly constrained. For example, IoT nodes benefit from multi-band reconfigurability to support multiple protocols while maintaining low power consumption. Wearable and biomedical devices require flexible and compact reconfigurable MIMO structures that can maintain reliable links despite body-induced detuning. In vehicular and drone communication systems, pattern reconfigurable MIMO antennas support beam steering for enhanced connectivity in dynamic environments. Cognitive radio systems benefit from frequency-agile MIMO antennas capable of spectrum sensing and rapid band switching.

Despite significant advancements, several challenges remain in achieving optimal reconfigurable MIMO performance. Integrating switching elements—such as PIN diodes, varactors, RF MEMS, graphene sheets, or liquid-metal actuators—often introduces additional losses, biasing complexity, and structural constraints. Furthermore, real-time optimization of reconfigurable states requires intelligent control algorithms, potentially using AI or machine learning. As wireless systems move toward higher frequencies, compactness and low correlation become even more challenging.

Overall, reconfigurable MIMO antennas represent a key enabling technology for next-generation wireless systems, ensuring adaptability, efficiency, and high performance across diverse communication scenarios.

II. FUNDAMENTALS OF RECONFIGURABLE MIMO ANTENNAS

Reconfigurable MIMO antennas support three primary modes of reconfiguration:

2.1 Frequency Reconfigurability

These antennas tune or switch their resonant band to support multi-band and wideband applications. Techniques such as PIN diodes, varactor diodes, RF MEMS, and graphene-based tunable elements modify the electrical length of the radiator [3].

2.2 *Pattern Reconfigurability*

Pattern reconfiguration enables steering of the radiation beam to improve coverage, reduce interference, and enhance SNR. Methods include parasitic switches, reconfigurable reflect arrays, and metamaterial structures [4].

2.3 *Polarization Reconfigurability*

Polarization switching improves link robustness under fading and mobility. PIN-controlled slots, tunable feeding networks, and dielectric rotation enable polarization agility [5].

III. RECONFIGURATION MECHANISMS AND SWITCHING TECHNOLOGIES

Reconfigurable MIMO antennas rely on various mechanisms and switching technologies to dynamically modify their operating characteristics, such as frequency, radiation pattern, and polarization. The selection of a suitable mechanism depends on application requirements including switching speed, linearity, power consumption, complexity, and frequency range. The following section provides an in-depth analysis of the major switching approaches used in modern reconfigurable antenna systems.

3.1 PIN Diodes

PIN diodes are widely used in reconfigurable antennas because they offer fast switching speed, low cost, and easy integration on PCB structures. When forward-biased, they act as a low-resistance conductor to activate antenna segments, enabling quick changes in frequency or radiation pattern. However, incorporating PIN diodes requires biasing networks (bias lines, RF chokes, capacitors), which can disturb the antenna's current distribution. This may reduce radiation efficiency, increase insertion loss**,** and affect impedance matching, especially in compact MIMO layouts. Despite these drawbacks, PIN diodes remain preferred for sub-6 GHz reconfigurable MIMO antennas due to their speed, simplicity, and reliability [6].

3.2 Varactor Diodes

Varactor diodes provide continuous and smooth frequency tuning by varying their capacitance through a reverse-bias voltage, making them ideal for fine frequency control in reconfigurable antennas. They are especially useful in compact IoT and portable devices where small size and tunability are required. However, varactors have limited power-handling capability, exhibit nonlinear behavior at high RF power, and require careful biasing to avoid distortion. Despite these limitations, they remain popular for low-power, frequency-agile antenna designs.

3.3 RF-MEMS

RF-MEMS switches provide very low insertion loss**,** high isolation, and excellent linearity, making them ideal for mmWave and THz reconfigurable antenna systems. They enable precise control of frequency, phase, and radiation characteristics with minimal signal distortion. However, RF-MEMS suffer from slow switching speeds**,** higher fabrication cost, and reliability issues such as stiction, fatigue, and sensitivity to environmental conditions. Despite these challenges, they remain a key technology for high-frequency reconfigurable MIMO designs.

3.4 Tunable Materials

Graphene provides tunability in THz bands due to variable surface conductivity. Liquid metal structures enable shape reconfiguration for flexible and wearable antennas [9].

3.5 Optical and Mechanical Reconfiguration

Optical switching offers ultra-fast actuation for photonics-integrated antennas, while mechanical rotation is used in satellite-grade reconfigurable arrays [10].

TABLE 1: Reconfiguration Mechanisms and Switching Technologies

Reconfiguration Mechanism	Switching Technology	Advantages	Limitations	Typical Applications
Frequency Reconfiguration	PIN Diode Switching [16], [17]	Fast switching, low cost, compact	Requires biasing network, introduces nonlinearity, limited high-power handling	Multiband MIMO antennas, WLAN/LTE tunable antennas
	RF MEMS [18], [19]	Very low loss, high isolation, excellent linearity	Slower switching (µs), reliability concerns, expensive	Satellite tunable filters, high-Q tunable antennas
	Varactor Diodes [20], [21]	Continuous tuning, compact size	Nonlinear behavior, lower power handling	Frequency-agile MIMO antennas
Pattern Reconfiguration	RF MEMS [22], [23]	High precision, low loss	Reliability issues over cycles	Beam-steering arrays, adaptive coverage antennas
	Mechanical Actuators [24]	Very wide tuning range, excellent isolation	Slow response time, bulky	Deployable antennas, large reflector systems
	Liquid Metal Channels [25]	Flexible tuning, reconfigurable shape	Limited speed, fluid control required	Flexible and wearable MIMO antennas
Polarization Reconfiguration	PIN Diodes [17]	Fast switching between polarizations	Nonlinearity, biasing complexity	Dual-polarized MIMO systems, diversity systems
	RF MEMS [23]	Low loss, precise polarization control	Higher cost	Polarization-agile arrays
	Graphene / Smart Materials [26]	Ultra-wide tunability, low profile	Early-stage technology	Future 6G reconfigurable intelligent surfaces

IV. MIMO PERFORMANCE PARAMETERS

MIMO antennas are evaluated using several key performance parameters:

4.1 Envelope Correlation Coefficient (ECC)

ECC measures the similarity of radiation patterns between antenna elements. Lower ECC (<0.5) indicates better diversity performance [11].

4.2 Diversity Gain (DG)

Indicates improvement in signal reliability due to multiple antennas. Typically DG ≈ 10 dB for efficient MIMO systems [12].

4.3 Channel Capacity

Shows the maximum achievable data rate of the MIMO system and increases with more independent radiation patterns and lower ECC [13].

4.4 Total Active Reflection Coefficient (TARC)

TARC quantifies reflection when the MIMO system is excited simultaneously. Lower TARC corresponds to better overall radiation efficiency [14].

4.5 Mutual Coupling

High coupling deteriorates MIMO performance. Reconfigurability helps tune operating bands and reduce coupling dynamically [15].

V. MIMO PERFORMANCE PARAMETERS

Despite significant advancements in reconfigurable MIMO antennas, several research gaps remain unaddressed. First, there is a lack of ultra-low-power switching technologies suitable for IoT-scale MIMO nodes, where energy efficiency and miniaturization are critical. Additionally, reconfiguration techniques at THz frequencies essential for future 6G systems—are still in their early stages, with limited experimental validation. Another major gap is the absence of AI/ML-based real-time optimization frameworks that can intelligently select reconfigurable states based on channel conditions. Further, integrating reconfigurable MIMO antennas into

flexible, wearable, and bio-compatible platforms poses mechanical, electromagnetic, and material challenges. Finally, although RF-MEMS offer excellent high-frequency performance, concerns regarding their long-term reliability, switching fatigue, and environmental sensitivity continue to hinder large-scale deployment. These gaps highlight the need for multidisciplinary research to realize fully adaptive, efficient, and robust reconfigurable MIMO systems.

VI. RESEARCH GAPS

i) Lack of compact, low-power reconfigurable arrays for 6G.
ii) Need for flexible, textile-based reconfigurable MIMO systems.
iii) High-speed switch integration without performance degradation.
iv) Limited studies on AI-driven state selection for reconfigurable antennas.
v) THz reconfigurable MIMO antennas remain largely uncharted.

CONCLUSIONS

Reconfigurable MIMO antennas are essential for future wireless systems due to their ability to dynamically adapt performance parameters such as frequency, pattern, and polarization. They significantly enhance spectral efficiency, channel capacity, and reliability while enabling compact multiband devices. Advancements in tunable materials, AI-driven reconfiguration, and flexible electronics will drive the next generation of intelligent and energy-efficient MIMO systems.

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A Low Power and High Accuracy Approximate Multiplier using 2x1 Multiplexer with Reconfigurable Truncation

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***Abstract*—**Reconfigurable Truncation is a technique that allows for dynamic adjustment of accuracy and power consumption. In multipliers, Reconfigurable Truncation is used to dynamically reduce the number of bits in the output by truncating less significant bits, with the ability to adapt the truncation level based on application requirements, there by optimizing power consumption, area, and processing speed while maintaining acceptable accuracy through techniques like error compensation and control logic. The aim of this project is to design an approximate multiplier with reconfigurable truncation. It evaluates the parameters of Power and Accuracy using VHDL/Verilog Simulation.

Keywords- *Reconfigurable Truncation, Low Power Multiplier, Power Optimization, Area Efficient.*

I. INTRODUCTION

With the increasing demand for high-performance and energy-efficient digital systems, arithmetic units such as multipliers play a critical role in applications ranging from image processing and digital signal processing to machine learning [1],[4]. Traditional exact multipliers, while precise, often incur high power consumption, silicon area, and delay, making them unsuitable for energy-constrained or error-tolerant applications [7], [4]. To address these challenges, approximate computing has emerged as a promising approach, where controlled inaccuracies are introduced in computations to achieve significant power, area, and speed improvements without substantially compromising output quality [2], [5].

Several techniques have been explored for implementing approximate multipliers, including partial product modification, approximate compressors, truncated adders, and hardware-level perforation, each offering different trade-offs between accuracy and efficiency [1],[3], [5], [6]. In particular, Akbari et al. [3] introduced dual-quality 4:2 compressors with switchable exact and approximate modes, enabling dynamic accuracy-configurable multipliers that reduce power and delay while maintaining acceptable output quality. These designs let you change the accuracy at runtime, which is very helpful for applications that can handle errors, like processing images and signals. Even with these improvements, we still need modular, scalable, and tunable approximate multiplier architectures that strike a good balance between power, area, and computational precision. The current study fills this gap by suggesting a straightforward, modular, and energy-efficient approximate multiplier design, fully validated through simulation, aimed at practical uses in image and signal processing.

II. LITERATURE SURVEY

Approximate computing enhances performance and energy efficiency by reducing design complexity for applications that need to be error-resistant. This study presents an approximate multiplier that adjusts partial products according to variations in probability.[1] Two 16-bit approximate multipliers use 72% and 38% less power than an exact design. They are more accurate, with mean relative errors as low as 7.6% and 0.02%. One multiplier in image processing gets the highest PSNR, which shows that it works better.[2]. We suggest a new approximate multiplier that can be adjusted for accuracy modes and uses an inaccurate 4×4 multiplier. With a maximum absolute relative error of 22.2%, it cuts power use by 17.98% to 34.15%.[3] A Gaussian filter that sharpens images increases SNR by 5 to 22 dB and lowers power and area. An error detection and correction (EDC) circuit makes things more accurate for applications that don't need to be error-resistant.[4] Compared to other error-correcting multipliers, the design uses the least amount of space.

The 4:2 compressors have two modes: exact and approximate, which can be switched on and off for dynamic accuracy control. In approximate mode, a 32-bit Dadda multiplier can run faster, use 68% less power, and have 46% less delay. [5]Their usefulness has been proven in image processing applications, which shows that they work. These compressors let you change the accuracy of the runtime to make it more efficient. [6]. Low-power methods for portable multimedia devices that use approximate computing in DSP. A transistor-level logic reduction makes full adders easier to understand, which cuts down on switched capacitance and critical path delays.[7] When used for video and image compression, it can save up to 69% of power. Error and power models

confirm the effectiveness of DSP architectures such as DCT and FIR filters. "Block-based carry speculative [8]. Approximate computing speeds things up and uses less power by not requiring exact calculations. This paper presents innovative approximate compressors and an algorithm for the design of efficient approximate multipliers.[9] These multipliers, which were made using a 40-nm library, are better than other designs in terms of power or speed for a given level of accuracy. Their usefulness is shown in applications for image filtering and adaptive least mean squares filtering. [10]. Partial product perforation as a hardware-level method for making multipliers that use less energy. The method guarantees limited and foreseeable errors contingent upon input distribution. A lot of testing shows that these designs use 50% less power, take up 45% less space, and have a 35% shorter critical delay. The method works best for different types of architectures with different error limits. It works better than truncation, voltage over scaling, and logic approximation when it comes to power dissipation and error performance. This makes it a good choice for applications that need to be able to handle errors. [11].

III. PROPOSED METHOD

The proposed design suggestion involves a low-power, high-accuracy approximate multiplier that employs a 2x1 multiplexer with truncation which may be varied. The multiplexer makes use of the maths easier because it can choose only the products required for calculation. This reduces the number of switches that should be made. This, in its turn, implies that the system requires less power when running. Adaptive truncation of bits is one of the best with this architecture. This implies that the amount of bits to be truncated is adjustable anytime and one is still able to use the error-correction techniques to maintain the accuracy. This balance is fast, consumes less energy and preserves accuracy of calculations. The multiplier is simple and very compact to use and can be applied in digital signal processing, embedded systems, and low-powered computers. Overall, the design seems to be mainly a satisfactory balance of power, performance, and accuracy that makes it a superior design compared to traditional multiplier architectures.

3.1. *Block Diagram*

•Truncated Partial Product Generation (Stage 1): The inputs are truncated using several truncation blocks (Trunc$_0$ to Trunc$_3$) to make things less complicated before generating partial products.

• Accurate and Approximate Regions (Stage 2): The partial products are split into two areas: the accurate area (left, blue and grey blocks) for exact calculations and the approximate area (right, green and black symbols) to make the most of power and space.

• Use of Compressors and Adders (Stage 3): The architecture uses proposed 4-2 compressors, EDC compressors, full adders, and half adders to quickly add up the partial products while using less power and time.

• The 2x1 mux is used to find errors in the output in the second stage.

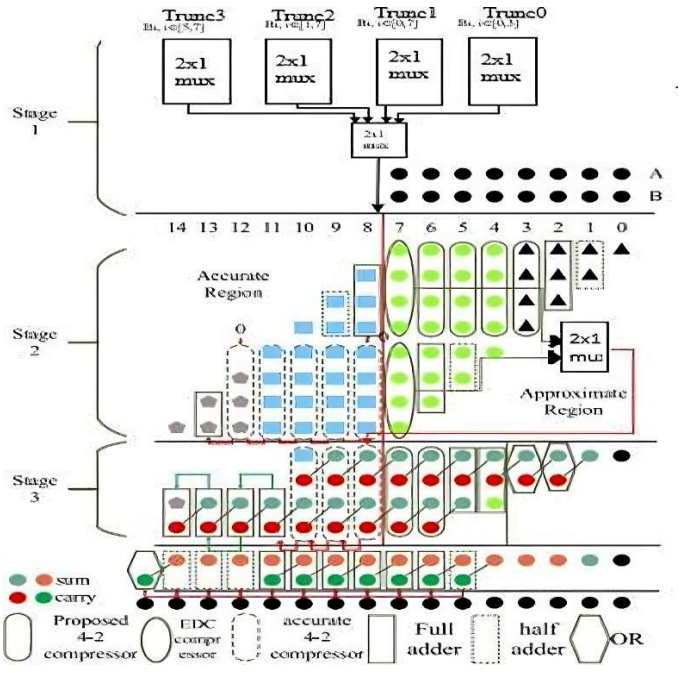


Fig. 1 Block diagram of the proposed approximate multiplier.

3.2 Truncation:

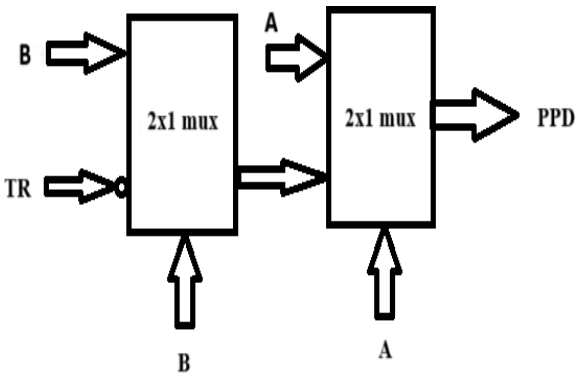


Fig. 2 Block diagram of Truncation.

Truncation is the process of removing or discarding a part of a numerical value, typically the least significant bits or digits, to reduce the precision of a computation. In the context of multiplication, truncation involves cutting off a portion of the result to reduce the bit-width or decimal precision.

IV. RESULTS

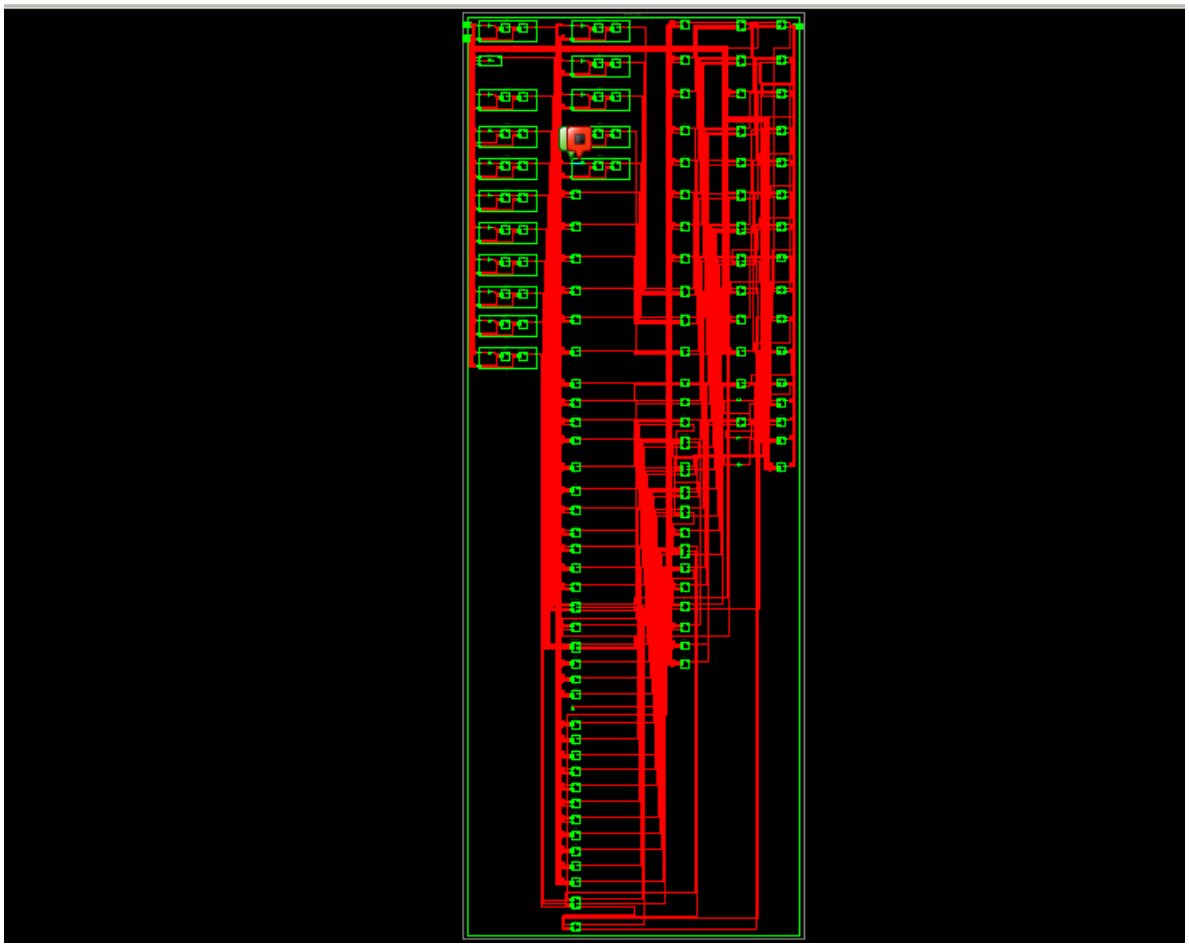


Fig. 3 RTL Design of the proposed approximate multiplier

The layout has an approximate multiplier that uses a multiplexer and makes the best use of space to cut down on power and delay. Red signal paths show how well routing works, but interconnect congestion needs to be fixed. Improvements can make performance even better by cutting down on wire congestion and improving the design of transistors at the level of individual transistors.

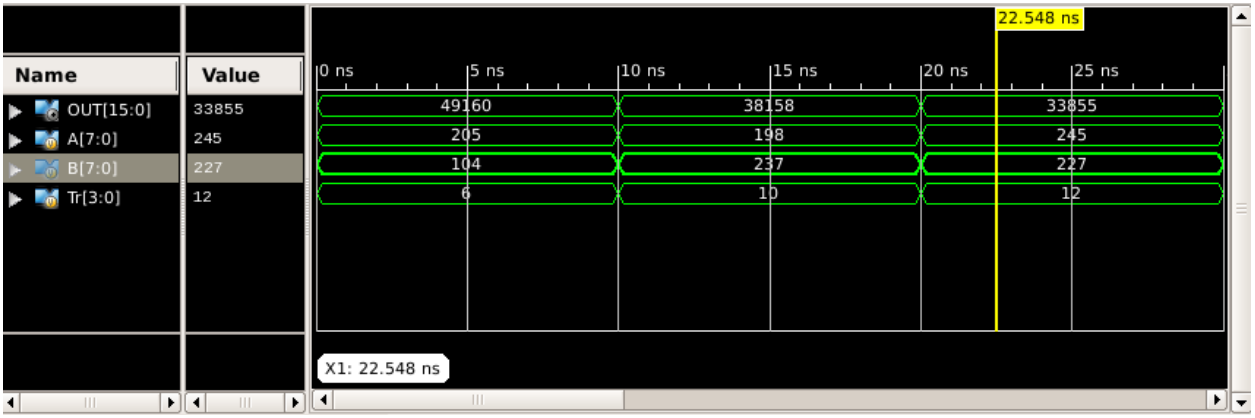


Fig. 4 Simulation result of the proposed approximate multiplier.

The layout has an approximate multiplier that uses a multiplexer and makes the best use of space to cut down on power and delay. Red signal paths show how well routing works, but interconnect congestion needs to be fixed. Improvements can make performance even better by cutting down on wire congestion and improving the design of transistors at the level of individual transistors.

TABLE I: PERFORMANCE METRICS OF PROPOSED METHOD

	Area (LUT's)	**Delay(ns)**	**Power(W)**
Proposed Method	125	15.870	0.00648

V. CONCLUSION

The piece outlined here examines one method of creating a rough multiplier which reduces its power consumption without reducing its precision to a level which is useless. It is based on a small 2×1 multiplexer and a crude form of truncation rather than a full and heavy multiplier. Through the jettison of the pieces which add little or nothing to the final value, some parts of the circuit may be idle and this, in its turn, keeps the errors within reach of most application. The 2×1 multiplexer behaviour is one of the reasons why it uses less power in the design. It transitions state much less frequently compared to a standard CMOS structure and cannot conduct much current through it therefore the overall activity is kept low. When simulations are run and followed by verification with Verilog models, it was revealed that the circuit is capable of saving a significant sum of energy, and the results obtained are still close to the actual multiplication. This kind of design is appropriate in systems where every mill watt counts like mini-wearable gadgets, mini IoT boards, and lightweight signal-processing units. An advantageous feature of the design is that the level of truncation can be changed. Tighter accuracy can be decreased when it is necessary, and the reverse is also true. The multiplier, in that regard, does not confine the user to a single mode of operations but provides an opportunity to shift the balance between accuracy and power to appropriate the situation.

VI. ACKNOWLEDGMENT

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Intelligent Flood Monitoring and Early Alert System using IoT

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Abstract— India's monsoon-driven climate often produces intense rainfall that can trigger sudden flooding, highlighting the need for continuous river surveillance and rapid warning systems. This work presents a compact, sensor-based platform that measures real-time water level and flow conditions in riverbeds using an Arduino-controlled module with wireless communication capability. When monitored parameters exceed predefined safety limits, the system automatically issues early-warning email notifications to multiple recipients. The proposed design enables timely dissemination of flood-related alerts, supporting improved preparedness and response in vulnerable regions.

Keywords: Wi-Fi, Flooding, Water Level, Monitor, Emergency Alerts, Arduino, Email Alerts, Sensors.

I. INTRODUCTION

Flood events continue to pose a major threat across numerous regions worldwide, and several studies have explored different approaches for establishing reliable alarm infrastructures to protect residential communities [1]. Many countries have repeatedly experienced severe flood-related losses, including casualties, large-scale displacement, destruction of agricultural land, and damage to essential infrastructure such as roads, homes, and bridges [2]. India, in particular, is highly vulnerable due to its sub-tropical monsoon climate, where intense rainfall frequently leads to extensive inundation. To reduce the impact of such events, it is essential to have systems capable of continuously observing river conditions and issuing timely alerts about variations in water levels and flow characteristics [3].

Similar challenges are evident in other flood-prone regions, such as the Philippines, where outdated flood monitoring mechanisms often delay the dissemination of critical warnings. To address these limitations, recent research has proposed pressure-sensor-based platforms equipped with long-range wireless communication (LoRaWAN) for remote and continuous flood detection [4]. Parallel to these developments, the present work focuses on designing a flood-alert mechanism that employs advanced sensing modules integrated with a Wi-Fi-enabled controller. The system monitors riverbed water levels and flow rates, and upon detecting conditions that exceed predefined thresholds, it automatically issues email notifications to designated recipients to warn them of potential flood risks [5].

Flood disasters not only lead to psychological distress among affected populations but also result in significant damage to property, infrastructure, and livestock [6]. Modern solutions increasingly rely on wireless sensor networks, enabling real-time detection and rapid transmission of alerts to relevant authorities and stakeholders via IoT-based communication modules such as the ESP32 [7], [8]. Additional work has explored coastal flood detection using wireless sensor networks to monitor abnormal sea-wave activity and rising tide intensities, which are often influenced by persistent depressions in the ocean [9]. Floods also routinely damage residential and commercial structures located within floodplains, reinforcing the need for automated water-level control mechanisms that employ IoT technology for remote monitoring and system regulation [10].

Recent research has also demonstrated the benefits of using multiple sensing components simultaneously to improve the reliability of flood detection. For instance, ultrasonic, rain, and humidity sensors have been combined to capture comprehensive hydrological data in advanced monitoring systems [11]. Natural disasters often occur

without warning, leading to substantial human, economic, and environmental losses [12], and flooding in particular can be especially destructive when water levels rise beyond safe limits [13]. Automated systems that notify communities before such thresholds are reached can significantly reduce damage [14]. Reviews of IoT-based flood detection frameworks indicate a growing trend toward multi-sensor data acquisition and intelligent decision-making for disaster management [15]. One such example is an IoT-driven early-flood prediction system that continuously monitors environmental parameters to anticipate hazardous conditions [16]. In addition, climate change has intensified the frequency and severity of urban flooding, making remote sensing technologies increasingly important for prediction and monitoring [17].

Given the recurrent flood incidents across numerous Indian states, the need for real-time sensing and automated notification becomes even more critical. The system examined in this work incorporates several environmental sensors—including humidity, temperature, water-level, and flow-rate modules—to track conditions that contribute to flooding. The rain sensor measures precipitation, while the flow sensor detects changes in water movement using a rotor-based mechanism and Hall-effect interface. The HC-SR04 ultrasonic sensor continuously measures the water level, and when the detected value surpasses the specified limit, automated email alerts are issued. Some existing systems also employ multiple sensors in combination, as demonstrated by Bande & Shete [18], to strengthen flood prediction accuracy.

II. Literature Review

Flood warning technologies have attracted sustained academic interest due to their critical role in disaster-risk reduction, particularly in countries such as India where monsoon-driven flooding is recurrent. Conventional flood alert systems depended heavily on human monitoring and centralized reporting, which often caused significant delays and limited the overall responsiveness of authorities. With the emergence of the Internet of Things (IoT), however, flood monitoring has shifted toward autonomous, real-time systems capable of delivering rapid warnings with minimal human intervention.

The present work is informed by research efforts that utilize wireless sensor networks for the prediction of tidal activity and cyclone behavior, integrating intelligent techniques such as fuzzy inference mechanisms and neural-network-based models. Contemporary studies increasingly highlight the importance of multi-parameter sensing, noting that relying on a single environmental variable rarely yields timely or reliable predictions. Rain sensors, for instance, are widely recognized for their robustness in diverse climatic conditions and are therefore frequently incorporated into monitoring architectures. Similarly, the HC-SR04 ultrasonic sensor has become a preferred choice for measuring water-level variations due to its high distance-measurement accuracy. Configurations that combine multiple sensors are commonly adopted in recent systems, as they improve environmental validation and help suppress false alarms.

Another notable trend in current literature is the integration of remote alerting capabilities through cloud services and mobile platforms. Applications such as ThingsViewFree illustrate this shift by enabling users to remotely observe field conditions through smartphone interfaces. Additionally, the practice of using Python scripts to automate email notifications from microcontroller-based platforms is gaining prominence because of its ease of use and dependable performance. Such advancements align with ongoing research advocating decentralized, intelligent alert frameworks that can operate with minimal latency during emergency situations.

The adoption of low-cost microcontrollers—including Arduino UNO and ESP8266—reflects the broader goal of creating flood-monitoring systems that can be deployed affordably across large geographic areas, including economically constrained regions. Literature consistently emphasizes the necessity for scalable, accessible, and low-maintenance systems to support vulnerable communities. The system developed in this project contributes to this expanding domain of IoT-driven flood mitigation, promoting an architecture that blends real-time sensing, cost-effective hardware, and rapid communication pathways to help reduce the socio-economic consequences of severe flooding.

III. Methodology

Following an extensive review of the literature and relevant research contributions, the hardware platform and software tools for the proposed system were finalized. The designed prototype identifies potential flood conditions by monitoring multiple environmental variables, specifically rainfall intensity, river water level, and water flow rate. To capture these parameters, distinct sensing modules are employed for each quantity. Rainfall is measured using a rain sensor, which provides continuous feedback on the presence and magnitude of precipitation. Water level is monitored in real time using an ultrasonic sensor that repeatedly measures the distance to the water surface as the level rises and falls. When the measured height surpasses a preconfigured threshold, the system interprets

this condition as critical and initiates an automatic trigger that results in an email notification being sent to the designated recipients, warning them about the elevated water level and the increased likelihood of flooding. The flow sensor complements this measurement by tracking the rate of water movement. It operates by detecting changes in the rotational speed of a rotor subjected to flowing water, from which the flow rate is inferred.

Once the hardware components were successfully assembled and validated, the software environment was configured using the Arduino IDE and Visual Studio Code. A dedicated email account was created for the purpose of dispatching automated alerts. Python scripts were then developed to interface with the Arduino output, enabling sensor readings to be captured and processed on a host system. A threshold value was assigned to the water-level parameter, and when this value was exceeded, the Python program was triggered to execute the alert routine. At that instant, an email is automatically generated and transmitted, informing users of the critical rise in water level and the associated risk of flooding.

IV. BLOCK DIGRAM

The proposed IoT-enabled Flood Monitoring and Alerting System functions through continuous acquisition of environmental data, embedded processing at the microcontroller level, and automated dissemination of remote warnings. By integrating real-time sensing with intelligent decision logic, the system is capable of detecting early indications of flooding and issuing timely notifications to users or responsible authorities, thereby supporting proactive response measures.

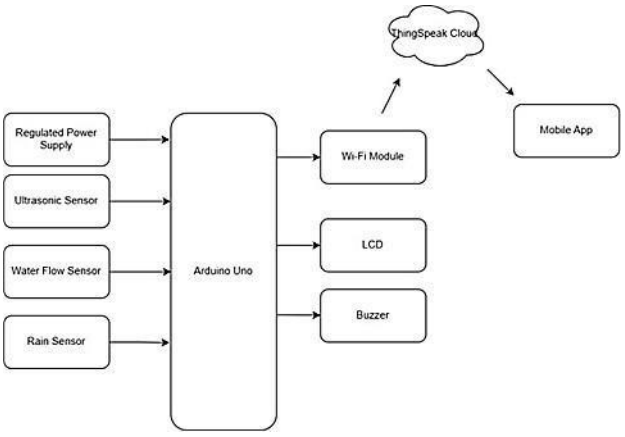


Fig: 1 Block diagram of proposed system.

The overall working of the IoT-based flood monitoring and alerting system can be understood from its functional sequence and the corresponding block representation. The block diagram captures the primary hardware and software elements, as well as the direction of data flow within the system. The major components are summarized below.

3.1 Sensing Layer

Rain Sensor: This module is responsible for detecting and quantifying rainfall. It provides a direct indication of precipitation intensity, which is one of the key precursors to flooding.

HC-SR04 Ultrasonic Sensor: The ultrasonic sensor continuously determines the distance between the sensor and the water surface. These distance readings are translated into water-level values, enabling the system to track how the water height changes over time.

Flow Sensor: This unit measures the rate at which water is moving through a river channel or drainage path. Variations in flow rate support the assessment of rapidly changing flood conditions.

3.2 Processing and Control Layer

Arduino UNO: The Arduino UNO acts as the core processing unit of the system. It acquires measurements from all the connected analog and digital sensors and compares these readings against predefined threshold values stored in the microcontroller. Based on this decision logic, it determines whether a potential flood condition exists.

ESP8266 Wi-Fi Module
Interfaced with the Arduino UNO, the ESP8266 module provides wireless connectivity. It enables the transmission of real-time sensor data and status information to external devices over the Internet.

3.3 *Communication and User Interface*

Layer Python-Based Application

(PC/Cloud)
A Python script running on a computer or cloud platform receives serial data forwarded by the Arduino. When one or more sensor readings exceed the critical threshold, the script automatically generates and sends email alerts to a set of predefined recipients, informing them of the elevated risk.

Things ViewFree Mobile Application

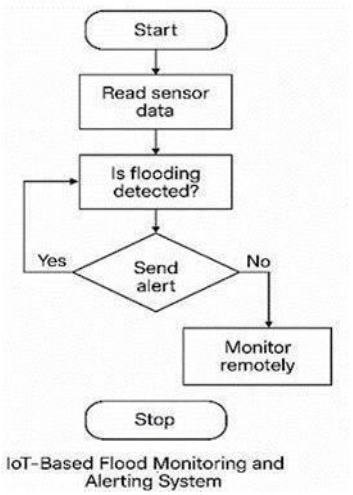


Fig: 2 Flow chart of proposed system

The mobile application serves as a remote visualization and monitoring tool. It displays live sensor values and system status on any smartphone with Internet access, allowing users to observe flood-related parameters from any location. Through the coordinated operation of these sensing, processing, and communication modules, the system continuously monitors environmental conditions and issues timely notifications whenever potential flood scenarios are detected.

V. RESULTS

The IoT-enabled Flood Monitoring and Alerting System was developed and evaluated under controlled, simulated environmental conditions to assess its operational reliability. The integration of the rain sensor, HC-SR04 ultrasonic module, and flow sensor with the Arduino UNO facilitated continuous acquisition of environmental variables, including rainfall intensity, water height, and flow velocity. All sensing modules exhibited stable data-collection behavior, and the system successfully captured changes across all test scenarios with minimal delay. The ultrasonic sensor consistently registered variations in water level with accurate distance measurements and dependable response intervals, while the flow sensor effectively detected changes in water movement, demonstrating suitability for early-stage flood detection applications.

To examine responsiveness, deliberate fluctuations in water level were introduced during testing. Whenever the measured water height exceeded the predefined safety threshold, the Python-based backend—linked to the Arduino through a serial interface—automatically generated an email alert. The timely arrival of these notifications verified the correct functioning of the automated alerting mechanism.

In addition, the ESP8266 Wi-Fi module provided a stable wireless communication link for real-time data transmission to the Things View Free mobile application. Live readings were displayed seamlessly on the smartphone interface, confirming the system's capability to support remote monitoring through an IoT dashboard. This demonstrated the practicality of enabling users to observe hydrological parameters from any location with network connectivity.

Overall, the experimental results confirmed that the system is dependable in tracking environmental indicators, issuing timely warnings, and enabling remote data access. The performance outcomes indicate that the design is not only operationally sound but can also be scaled and adapted for deployment in real flood-prone environments. This underscores its potential to enhance community preparedness by providing early warnings and facilitating continuous monitoring as part of broader disaster-risk-reduction strategies.

The completed prototype incorporates the Arduino UNO, ESP8266 Wi-Fi module, rain sensor, HC-SR04 ultrasonic sensor, flow sensor, and an LCD display. Email alert functionality and real-time visualization through the Things View Free mobile application were also successfully implemented, enabling comprehensive remote oversight of the system's behavior.

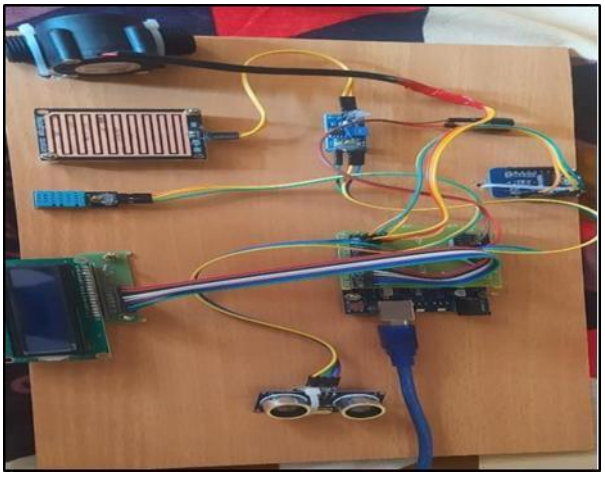


Fig: 3 Hardware Setup.

The figure illustrates the prototype configuration of the IoT-based Flood Monitoring and Alerting System. At the center of the setup is the Arduino UNO microcontroller, attached to a customized PCB, which serves as the primary platform for acquiring and processing data from all sensing modules. Positioned at the upper right is the HC-SR04 ultrasonic unit responsible for measuring the height of the water surface, while the rain sensor located at the lower right detects and quantifies rainfall. A flow sensor placed toward the bottom section of the prototype monitors variations in water-flow velocity.

An LCD panel provides real-time visibility of the measured parameters, enabling on-site observation of system status. The ESP8266 Wi-Fi module mounted on the left side offers wireless connectivity, allowing sensor readings to be transmitted remotely for continuous monitoring. A red indicator LED confirms that the system is operational and that power is being supplied to the circuitry.

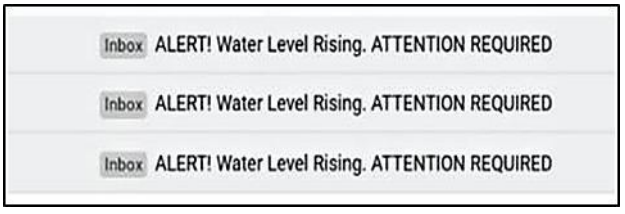


Fig: 4 Email Alerts.

The figure. 4 displays a series of automated email notifications generated by the IoT-based Flood Monitoring and Alerting System. Each alert originates from the sender ID "kiranproject9999" and carries the subject line "ALERT! Water Level Rising. ATTENTION REQUIRED," indicating that the measured water level has exceeded the predefined safety limit. The presence of multiple successive messages confirms that the Python-driven alert mechanism is functioning correctly, continuously monitoring sensor readings and issuing notifications in real time whenever critical conditions are detected.



Fig: 5 LCD Display

The figure shows an LCD module integrated into the IoT-based Flood Monitoring and Alerting System, presenting live readings from the connected sensors. The display indicates measured values for rainfall status, water-level distance (D: 13 cm), and water-flow rate (F: 0 L/min), demonstrating that the sensing units are actively capturing and reporting environmental parameters. Providing this information directly on the device enables rapid on-site assessment without the need for a mobile interface. The clear and structured layout of the displayed data supports easy interpretation, allowing users to maintain awareness of current conditions and respond promptly when necessary.

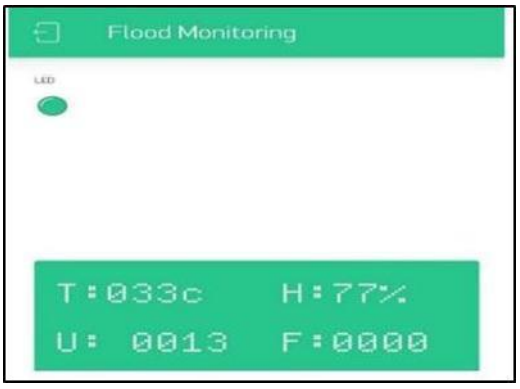


Fig: 6 Things View Free App (Real time Display)

The figure illustrates the interface of the Things View Free mobile application used for real-time visualization of data collected by the IoT-based Flood Monitoring and Alerting System. The dashboard displays the latest sensor measurements, including rainfall status, ultrasonic water-level readings (U: 0013 cm), and flow-rate values (F: 0000 L/m). At the top of the interface, a vertically arranged LED control element is shown, allowing users to either toggle the indicator remotely or view its current operational state. This layout enhances user interaction by offering immediate insight into environmental conditions that may signal potential flooding. Accessing this information through a mobile device significantly improves convenience, enabling users to review system status and critical measurements from any location at any time.



Fig. 7 (a).Water flow sensor



Fig. 7 (b). Ultrasonic sensor



Fig. 7(c). Rain sensor.

Fig. 7. Presents the time-series plots of rainfall, water-flow rate, and water-depth measurements, illustrating aligned peak values recorded on March 13 and April 15, with all parameters remaining at baseline (zero) during the intervals between these events.

CONCLUSION

The developed IoT-based Flood Monitoring and Alerting System effectively demonstrated its ability to track key environmental parameters and issue timely warnings. By integrating rain, water-level, and flow sensors with an Arduino UNO and ESP8266 communication module, the system provided continuous monitoring and rapid detection of threshold breaches. Automated email alerts and real-time visualization through the Things View Free mobile application confirmed the reliability of the alert mechanism and remote-access capability. Its low cost, scalability, and fast response time make the system a practical solution for deployment in flood-prone regions, contributing to improved preparedness and early risk mitigation.

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Smart IoT-Based Medicine Reminder and Automated Dispenser Using Raspberry Pi

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***Abstract*—**Crappy medication use hits those with long-term diseases, the old, and individuals with sight issues. To top it all, missing meds is very hurtful to caregivers and most of the times, it leads to poor health consequences. This paper proposes an internet of things device that reminds individuals, has a tracker on the web, automatically dispenses medicine and alerts when it is time to take them. It runs on a Raspberry Pi Pico, and has a IR pill-check, motor-controlled dispenser, a real time clock and cloud-linked data upload. The pre-established schedules are available online so that you do not get into trouble accidentally. At the time of delivery, the alarms work by releasing the correct dose of medicine by using light and sound; the IR will still monitor whether the tablets have been swallowed or not. Each step will be logged automatically to allow its review by helpers in the future. The outcomes are improved dosage adherence, reduced human effort and it functions on and off at home and in clinics even in remote locations. It is an inexpensive, flexible method of handling connected equipment meds.

***Keywords*—** IoT, Medication Adherence, Raspberry Pi Pico, Smart Healthcare, Automated Dispenser.

I. INTRODUCTION

In the case of the chronically ill or the aging population who undergo surgery or have to contend with aging, a medication regimen is necessary. But forgetfulness, mixing up drugs, brain fog or lack of a hand at home screws that up a lot. Such slip-ups have the potential to worsen symptoms, increase hospitalization and inflate medical bills [1].

Many households depend on caregivers to administer medication to newborns or elderly people at predetermined times. When moms and dads let grandparents watch kids, mistakes can happen more easily. Likewise, seniors living by themselves often face dangers due to missed or wrong doses. Common alert methods like phone sounds, scribbled messages, or pill boxes sorted by hand tend to fail without proof they were used correctly. These tools also lack accuracy and consistent performance.

The use of IoT helps automate medical tasks while enabling distant oversight. By using small computers, live data detectors, and online networks, medicine distribution can become precise and monitored. In order to reduce human involvement and improve consistency, the proposed system merges self-operated releasing, scheduled alerts, with confirmation checks through one connected platform[2]. This project intends to build a cost-efficient, user-friendly smart dispenser capable of working in rural as well as urban contexts.

A patient's daily routine may be easily incorporated with the IoT-based Real-Time Medicine Reminder and Dispenser. It can connect to that user's smart devices utilizing Wi-Fi and alert the patient about their impending prescription schedule in real-time. By doing so, it becomes a indispensable tool in guaranteeing timely and correct medicine administration. The primary feature of this gadget is its capacity to provide immediate reminders utilizing three means, speaker, display, smartphone notification, and administer the correct drug out of its allocated box. This would assist the patient remember their medication regimen very simply even if they are far away from the gadget since it will send alerts to their phone. Additionally, it will assist users who take various drugs in determining which one to take.

Problem Statement:

Self-medication is not easy with elderly patients and long-term patients, blurry eyed patients or those who are not independent (this is particularly true at home or in rural areas where there is no one around all the time). Miss taking pills, confusing schedules, and lack of a good method of checking whether the doses have been taken actually lead to avoidable health issues in the event of the plan being off track. The existing devices would have you enter the time manually, push buttons to indicate usage, and run simple features locally only, thus you can easily make a mistake and cannot connect to online medical trackers [3]. There is no automatic device at the moment that does the exact dosing, makes sure the person swallowed and keeps a safe electronic record-something that is so very much needed in the current care system. And hence we require internet-enabled

intelligent dispensers that minimise human effort, provide precise timing and allow family members or nurses to monitor consumption remotely.

Objectives:

The main aim of this study is designing a smart IoT medicine dispenser that handles full dose control automatically. Instead it pulls prescription plans from a cloud source, aligns them with live time tracking, then delivers pills precisely - no setup needed by users. One focus involves adding sensor checks so every portion taken gets confirmed mechanically, increasing trust beyond hand-entered notes. Also, records update instantly when meds are used, viewable remotely by health workers or family members for better monitoring. The overall goal is to create something that is accessible, inexpensive, and adaptable in many contexts while increasing compliance rates, relieving the burden on caregivers, and encouraging safer self-care among those who are at risk.

II. EXISTING MODELS

When searching the literature, I have located a few articles that have delved into automated drug dispensers, and narrowed down to the primary patient-compliance attributes, like tracking and remote monitoring. The initial prototypes, the type that ran on Arduino and basic clock chips, in fact demonstrated that it was possible to deliver pills on schedule, but was restricted by low computing capability and could not connect to the internet to get real-time updates. In 2023 Tiwari and crew later improved those rigs with phone notification features via web-connected tools, but the system continued to require users to schedule themselves and press buttons following doses, which would be easy to do carelessly.

In 2016, Shih and co-workers released a smart dispenser that was connected to phones and shot out alerts in case you forgot to take a dose. However, in reality, it was largely a reminder app instead of the one that would regulate the release of the pill and it was not able to confirm whether you had swallowed the pill or not. Mitra and colleagues went even further by streaming real-time information to the cloud in 2025, although their model was still heavily reliant on user input and failed to provide the sensors necessary to prove the use of medicine. Although badge-based technology can also be useful to reduce missed doses - studies in technology-aided elderly care, such as those by Alwan and colleagues, reported encouraging results - automatic dispensing or intake monitoring is still unattainable.

Lee et al., together with Park et al., studied rotating dispensers that deliver several doses daily [8]. Although such designs helped sort medications better, users had to set them by hand - also, there was no way to know if patients took pills from the tray. In contrast, work led by Karthikeyan added GSM tech to alert caretakers when a dose was skipped; however, alerts relied on people pressing response buttons. Devices introduced later by Niazi and Rahman used Wi-Fi along with MQTT protocols to boost connectivity across networks - but their circuit boards couldn't handle fast sensor updates or sophisticated confirmation methods [9].

The IoT-powered medicine reminder and dispenser helps tackle missed doses, improving health results and daily living. Later versions could include extra features through ongoing testing. Most seniors - about 9 out of 10 - take at least one prescription; more than four-fifths use two or more; and roughly a third take five different medications regularly. Skipping pills or incorrect usage can lead to worse conditions, increased hospital visits, along with higher treatment costs. An IoT-driven medicine reminder device with a dispensing mechanism helps tackle these problems effectively. Various aspects regarding the development of such smart dispensers have already been explored.

According to recent research, medical orders directly from clinics can be synchronized by connecting low-energy chips with online data storage. However, many existing designs prioritize distant tracking over self-operated, sensor-guided release [10], including those examined by Abir's team (2025) and Gupta's group (2024). A few experimental models attempted to track tablet motion using mass or nearness detectors, but performance accuracy was compromised by erratic setup procedures and slow response times in devices like the Arduino Uno. One problem that keeps coming up in published research is that the tools that are currently available only provide parts of the solution, such as alerts, straightforward distribution, or record-keeping, rather than an integrated, user-friendly system that guarantees accurate timing, automatically verifies ingestion, and seamlessly connects to web platforms all at once [11].

III. SYSTEM TOPOLOGY/METHODOLOGY

The My current project is based on a Raspberry Pi Pico and it relies on the IoT capabilities to remind and deliver medication automatically. It connects physical components to a web-based prescription database that provides accurate timing, real-time notification, and trend monitoring to be used remotely. This design unlike the previous models where users had to manually enter or verify pills, this design directs dose plans directly off an online platform

and adjusts intake times according to medical standards. At the right moment, doors that are powered by servo motors will open to display the correct pill, there will be a blinking light, a beep will sound and an infrared sensor will check whether the patient has swallowed the pill or not, and this will automatically send the data to cloud.

When the device is boiled until Wi-Fi, it uses an NTP server to adjust the clock to maintain the timing. It communicates to a cloud service, such as think ThingSpeak, the most recent dose schedule which was specified by a caregiver or a doctor. The measurements are then converted into a regular format and stored temporarily to be compared with real-time measurements. The dispenser release mechanism activates when the time matches one of the alarms that are set: an LED lights, a buzzer sounds, and a servo opens the container with a set dishavant and closes it. This IR sensor in turn measures any movement around the tray at that specific moment allowing the system to verify that a pill was taken or skipped or overridden without any human intervention.

All the compliance data is directly forwarded to ThingSpeak, which provides med staff with immediate access to pickup rates. The entire system is automated, whereby it polls new schedules every few seconds and records alerts to ensure each reminder is only triggered once in the interval. It makes it a good affordable medical aid that is reliable and will remain online, which is good in the case of older people, individuals with vision impairments, children under their care, or anyone who requires to have a good time with pill-taking.

3.1 System Architecture Diagram:

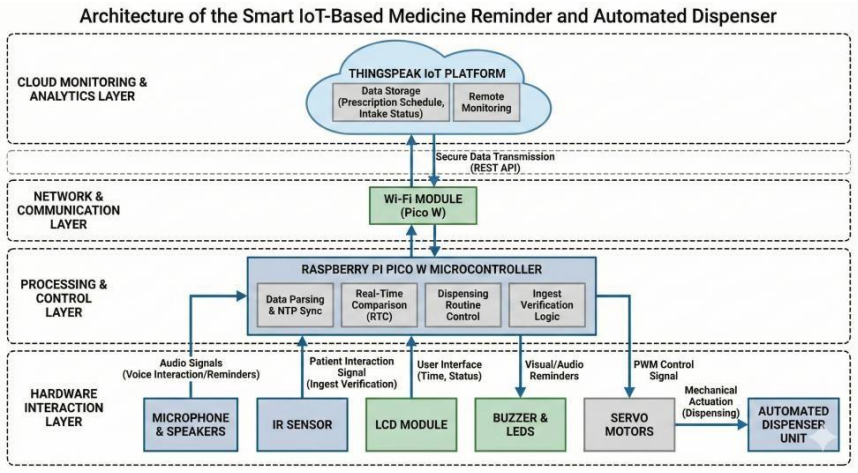


Fig. 1 System Architecture of Smart IoT-Based Medicine Reminder and Automated Dispenser Using Raspberry Pi Pico

Figure 1 illustrates the four primary components of the proposed IoT medication dispenser setup: the cloud level, connection layer, control section, and device interface. These elements work together to facilitate automated release, seamless dosage planning, and real-time usage pattern tracking.

Table 1– Components Used in the Medicine Dispenser Prototype

Component	*Specification*
Microcontroller	*Raspberry Pi Pico W (RP2040, onboard Wi-Fi)*
DC Motors	*3× SG90 Micro Servos (PWM controlled)*
IR Sensor	*Digital Infrared Proximity Sensor*
Display	*16×2 Alphanumeric LCD (GPIO interface)*
Connectivity	*Wi-Fi 802.11 b/g/n (ThingSpeak Cloud Integration)*
Buzzer	*5V Piezoelectric Buzzer (digital ON/OFF control)*
LEDs	*3× Indicator LEDs with current-limiting resistors*

Component	*Specification*
RTC Synchronization	*NTP over Wi-Fi (Network Time Protocol)*
Power Module	*5V DC supply (≥1A for servo load stability)*
Supporting Components	*Jumper wires, resistors, breadboard/module connectors*

Table 1 lists the hardware components of the prototype. While each component carries out a specific task, such as movement, detection, alarms, or data transfer, when combined, they provide automatic management of medicine scheduling and usage confirmation.

The Cloud Layer in our architecture is composed of the ThingSpeak IoT system. It maintains a record of the medications that are taken and their timings of taking them. The Pico can fetch the changes made by the remote doctors and caregivers with the timing scheduled slots and makes the adjustments by calling the REST API at predefined intervals.

The Network Communication Layer is based on the inbuilt Wi-Fi component of the Raspberry Pi Pico W. It is TCP/IP-aware, to fetch reminders and push adherence data to it and not to hang on disconnects; it can auto-reconnect if there is a temporary outage to ensure our time is not lost.

The brain of the system is a Raspberry Pi Pico microcontroller. The heart that reads fetched data downloaded by the cloud, crunches the data, corrects timestamps, synchronizes time using NTP, and continues to compare real-time clocks to the schedules. Upon arrival of the match, the Pico triggers the release of the pills: LEDs flash, there is a buzzer that notifies, and an IR sensor is used to test whether the pills were actually taken in.

The Hardware Interaction Layer contains all the hardware - servos, IR sensor, LCD, buzzer and lights. The pill rack is flipped on by a mechanically driven servo, the IR unit detects patient contact and the screen displays the current time, dosage schedule and status. There are visual and auditory signals provided by lamps and music. Everything is held together by a simple microcontroller with on/off signals of alarms, LEDs and detection, and pulse signals to control the motor.

That system fits well in at-home care or support-oriented health facilities and allows the layers to function as a single system that administers the meds on its own, changes settings through the cloud, and tracks all doses.

Table 2 – Communication & Safety Protocol Parameters

Parameter	System Handling / Standard Used	Purpose in Medical Device Context
Cloud Security	ThingSpeak HTTPS (API Key Based Access)	Ensures authenticated prescription updates and prevents unauthorized schedule modification
Time Synchronization	NTP over Wi-Fi (“pool.ntp.org”)	Guarantees reminder accuracy and eliminates RTC drift
Upload Control	Single-slot log update with retry handling (send_status)	Avoids duplication of intake logs and prevents multi-write errors
Trigger Lockout	One-minute slot lock via last_triggered[]	Prevents repeated dispensing if minute matches repeatedly
IR Intake Validation	Single-state read on dispensing window	Avoids false intake confirmation from external motion
Cloud Status Isolation	Dedicated fields for each slot (Field 4–6)	Separates time-specific adherence logs for clarity
Local Alert Fail-Safe	LED + Buzzer dual alert	Ensures user notification even if audio/visual alone fails
Handling Missed Dose	Cloud entry = 0 when IR not detected	Enables caregiver intervention via remote monitoring

To guarantee that medical dispensing cannot be tampered with locally or remotely, the system incorporates time-locked dispensing, authenticated synchronization, and restricted cloud writing activities, as shown in Table 2.

3.2 System Components:

3.2.1 Raspberry Pi Pico (Microcontroller Unit – MCU):

The Raspberry Pi Pico (Fig. 2) is fundamentally the core computer that manages the exchange of data with web services, time stamps and the coordination of the devices. The two ARM CortexM0+ cores of the RP2040 chip and its energy-efficient design are capable of maintaining real-time applications such as web polling, sensor reading and servo control all in MicroPython.

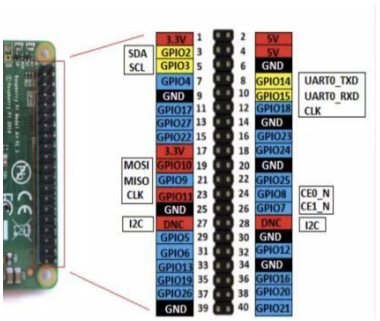


Fig. 2 Raspberry Pi Pico (Microcontroller Unit – MCU)

It has native MicroPython support, which provides us with cleaner scripts and faster prototyping, as well as a nice 26-pin I/O, which can power motors, LEDs, and sensors at the same time without messy wiring (compared to old 8-bit boards such as the Arduino Uno). External components can easily be connected by internal clocks, PWM units and serial interfaces. To enable the motor to be controlled smoothly, the special hardware of the board produces accurate pulse signals rather than software-generated pulse signals.

Network chores are made easier by pre-installed code packages that manage data exchange protocols. Additionally, reduced heat generation and cheap energy utilization allow healthcare equipment that requires a lengthy runtime without failure to run continuously.

3.2.2 Wi-Fi Communication Module:

To exchange data with the Thing Speak cloud platform, the setup needs a Wi-Fi connection, which is present in gadgets like the Pico W. Because it connects to the cloud, users may change settings from a distance while monitoring performance in real time or automatically storing information. The wireless component controls safe transfers using WPA2 security and transforms incoming HTTP GET signals into a straightforward JSON format that the main chip can understand.

Wi-Fi eliminates the need to manually enter schedules or set up Bluetooth. Rather, caregivers can remotely, even internationally, modify medication schedules. People who live far away from assistance or are unable to go around quickly therefore have better access. In the meantime, the microcontroller maintains network connections and quickly reestablishes them following disruptions, ensuring that medication alerts remain on schedule.

3.2.3. Thing Speak Cloud Platform:

Thing Speak is used as both a **data source** and a **data sink**.

- Fields 1–3 store the scheduled dosage times.
- Fields 4–6 store the status confirming whether the patient collected their medicine.

Thing Speak's simplicity, low battery consumption, and JSON data transmission make it ideal for healthcare IoT devices. Its free API hosting helps small clinics reduce expenses while providing family members with easy-to-understand visual updates on patient statistics via simple charts. REST APIs facilitate communication by enabling small computers to check new schedules now and give back status reports later with little energy consumption. These network exchanges don't require any sophisticated software on either end.

Its time-stamped records, which are useful for adhering to rules, monitoring therapy, or researching patient behavior, maintain note of any modification made to the schedule and preserve them indefinitely.

3.2.4 Real-Time Clock (RTC) and NTP Synchronization:

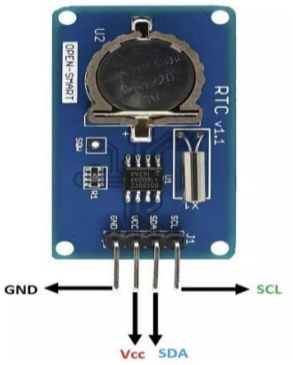


Fig. 3 Real Time Clock (DS1307)

Despite having an integrated RTC, as shown in Figure 3, the RP2040 cannot maintain precise time unless it is routinely synchronized. Timing is crucial for medical dosage; even little discrepancies might result in inaccurate dose plans. Consequently:

- On every boot, the RTC is synchronized with an NTP server ("pool.ntp.org").
- This eliminates drift, ensuring consistent alignment with the prescription schedule.
- The system also performs UTC → IST conversion for Indian time zone formatting.

By combining RTC with periodic remote synchronization, the system ensures reliable scheduling even during long-term operation.

3.2.5. LCD Display (16×2 Alphanumeric):

The LCD module provides continuous real-time feedback to the user. It displays:

- Current clock time
- Last updated schedule from the cloud
- Active dispensing messages
- Wi-Fi connection status

For those who have trouble remembering things or find cellphones difficult, especially those who are not tech-savvy, utilizing an LCD makes things easier. While some rely on sophisticated technologies, this alternative accommodates people who want more straightforward methods of communication.

Text is sent over GPIO-managed channels using a MicroPython-friendly LCD module, which reduces processing requirements and increases signal dependability. Using.goto(), it enables accurate cursor positioning, allowing several message lines to be produced in a neat manner.

3.2.6. Servo Motors (for Automatic Dispensing):



Fig. 4 DC Motor

Each of the three standard microservos (SG90 or similar) is allocated to a different medicament compartment. The Pico precisely provides PWM-controlled duty cycles, which are used by servos.

- Position 0° → compartment closed
- Position 90° → compartment open

Servo motors are preferred over DC motors because:

- Servos offer precise angular control.
- No additional motor driver IC is required.
- They consume less current during idle states.

The timed rotation makes sure the compartment stays open long enough for the patient to receive the dose and prevents pills from being dropped too soon.

3.2.7 Infrared (IR) Sensor (Pickup Verification):

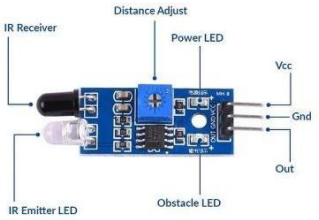


Fig. 5 Infrared (IR) Sensor

The infrared sensor functions similarly to a distance sensor. It emits infrared light, so when a hand approaches, the photodiode detects the bounce-back and modifies its signal. As a result, the device can detect presence.

Whether the patient collected the medicine

- Whether the compartment was ignored or unattended

Caregivers receive a timestamped proof of adherence when each reading is submitted to the cloud.
Weight sensors were rejected in favor of IR sensors due to:

- They do not require platform calibration
- They are not affected by humidity or pill size variations
- This simplifies verification logic while still ensuring high reliability.

3.2.8. LEDs (Visual Indicators):

Each pharmaceutical container features a separate LED that illuminates when the pills are released. Visual cues are crucial in situations when aural messages could be missed. Doses for morning, evening, and nighttime may be distinguished more easily with the help of these lights. Resistors restrict the electrical flow to each diode in order to protect the microcontroller's output ports.

3.2.9. Buzzer (Auditory Alert System):

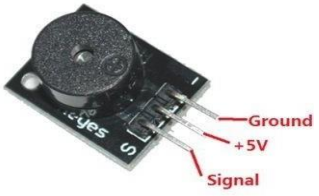


Fig. 6 Buzzer for Auditory alert system

The buzzer produces a loud audio alert during the dispensing window. The alert ensures:

- Patients are immediately notified
- Caregivers nearby can hear the signal
- Missed reminders are minimized

It remains active only during the prescribed drop window to reduce noise pollution and power consumption. The system uses a simple digital ON/OFF control rather than PWM tones, which conserves processing time.

3.2.10. Speaker Module (Audio Prompting & Alert Assistance):

The notifications of the device are much improved when you compare it to a simple buzzer when you load a speaker. Although a buzzer is simply a brief sharp sound, a speaker allows the addition of audio prompts, which is monumental when it comes to seniors or people with visual impairment. The device does not have to play a beep, it can play a recorded or synthetic reminder of It is time to take your medicine or it can speak Kindly get the tablet out of Slot 1. In such a manner, dose reminders help users to be not confused and become more understanding.

The Pi Pico W connects to the speaker using a low-power amp, which does not consume the GPIO line to

maintain the sound quality. Being not a passive buzzer, the speaker can speak in numerous languages about the missed intakes, medication schedule and warnings. The device is not a buzzer but a complete health messaging platform, which will prompt individuals to adhere to their care practices. It is particularly important in health-support situations in which the simplest cues of sight can be prevented by mental effort or sensory constriction.

3.2.11. Microphone Module (Voice Interaction & Intake Confirmation Assist):

Instead than using their hands, patients may answer with their voices thanks to the microphone. The gadget can identify simple verbal cues like "Dose taken" or "Remind later" when clicking buttons isn't practical.

Sound input increases user attention even if the primary check is based on infrared detection. This reduces the requirement for hands-on activation for those who are blind, bedridden, or have mobility problems. In addition, it assists in verifying delivery in situations when infrared signals are ambiguous, such as when a portion of the route is blocked or retrieval takes longer than anticipated.

Additionally, in future upgrades, the microphone will allow variable care features that use dynamic modifications through growing capabilities.

- Pain/discomfort voice reporting (“I need help” alerts uploaded to cloud)
- Voice-triggered schedule query (“When is my next dose?”)
- Remote caregiver communication

The module uses quiet ADC channels, incorporating built-in filters that block misfires caused by ambient noise. It increases reliability by verifying user activities through numerous inputs while permitting more seamless access ways, but it is not a replacement for sensor checks.

3.2.12. Power Supply System:

The whole system runs using a stable 5V supply. Key factors involve:

- Servo motors need consistent current flow; otherwise, performance drops.
- A voltage stabilizer - or a separate servo supply - can prevent MCU restarts by keeping power steady.
- Low-energy parts like LEDs or an IR sensor use almost no power. The LCD also consumes little current.

The system runs nonstop, staying cool while keeping power steady throughout the week.

Table 3 – Operational Specifications of the Prototype

Requirement	Specification
Reminder Frequency	Configurable (up to 3 daily reminders)
Reminder Duration	5 seconds servo action + alert window
Reminder Sound Level	~80–85 dB buzzer output
Reminder Display	16×2 LCD Module
Timing Accuracy	±1 minute (NTP-synchronized RTC)
Status Logging	Cloud upload via ThingSpeak (Fields 4–6)
Network Requirement	2.4 GHz Wi-Fi, WPA2 secured
Power Source	5V DC regulated supply

Table 3 displays the test model's performance characteristics, including timing accuracy, reminder duration, and alert functionality. Such information supports consistent, reliable dosage release that satisfies clinical requirements.

Table 4 – Device Power, Load & Control Distribution

Module	Peak Current Draw	Functional Notes
Servo Motor (per slot)	650–800 mA (peak on rotation)	Requires stable 5V rail during dispensing; idle draw negligible
Raspberry Pi Pico W	250–320 mA during Wi-Fi bursts	Cloud read/write + NTP sync increases transient consumption
LCD Display (16×2)	30–35 mA	Constant draw during continuous visibility

Module	Peak Current Draw	Functional Notes
IR Sensor	15–20 mA	Continuous polling during dosing windows only
Buzzer	25–30 mA on alert	Intermittent power, active only on alarm state
Indicator LEDs (3)	8–12 mA each with resistor	Short activation window during slot alert
5V Regulation Rail	1A recommended minimum	Handles servo surge + Wi-Fi transmit spikes without brownout

The choice of a stabilized 5V rail is guided by the power distribution analysis in Table 4, which emphasizes the transient peaks during servo actuation and Wi-Fi transmission states.

IV. IMPLEMENTATION

The code creates a completely automated drug management process by integrating all system components.

4.1 Wi-Fi Initialization:

connect_wifi()

The device uses its saved SSID and password to connect to the local Wi-Fi network. Throughout the procedure, the LCD ensures that the user is aware of the connection status by providing feedback.

4.2. NTP Time Synchronization:

sync_time()

To guarantee precise scheduling, the system synchronizes time with an NTP server. By doing this, RTC drift-related dosage problems are avoided.

4.3. Fetching Reminders from Thing Speak:

reminders, upload time = get reminders ()

This program collects three fields that describe dosage timings after sending a GET call to Thing Speak to get the most recent data input. Format reminder () is used to clean and format the timings into HH: MM.

4.4. Time Comparison Logic:

Every loop checks:

if reminders[i] and reminders[i] == current time:

When the cloud-specified time matches the current RTC time, the system triggers the dispensing sequence.

4.5. Dispensing and Alert Sequence:

Once a slot matches:

- LCD displays the specific medicine slot
- LED for that slot turns ON
- Buzzer activates
- Servo rotates to release medicine
- After a fixed window, servo resets and buzzer turns OFF

This ensures predictable and safe dispensing behavior.

4.6. IR-Based Verification:

status = 1 if ir_sensor.value() == 1 else 0

If the IR sensor detects hand presence, the system marks the dose as "taken". Otherwise, it marks it as "not taken."

4.7. Uploading Status Back to Cloud:

send_status(i, status)

Every slot uploads to the correct field on ThingSpeak since the field number is immediately mapped. This enables real-time remote monitoring of adherence by physicians or caregivers.

4.8. Preventing Double Triggering:

last_triggered[i] = current_time

The system stores the last triggered time to ensure the same dose isn’t delivered twice in the same minute.

V. RESULTS/OUTPUT

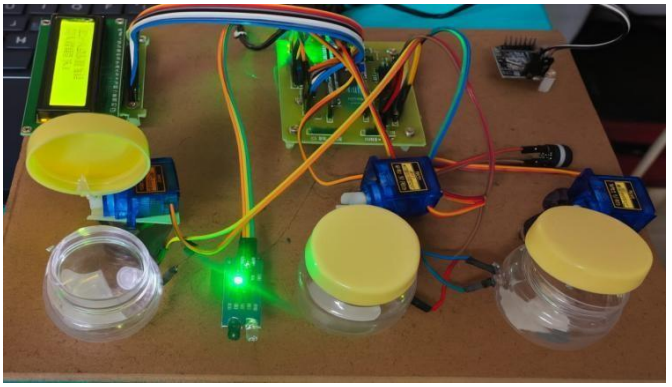


Fig. 7 Smart IoT-Based Medicine Reminder setup.

The prototype was proved in terms of its functionality with the help of integrated hardware and MicroPython logic. Trial output screen shots reveal that it retrieves medication schedules in cloud repositories and still maintains time at the appropriate spot. The display displays real-time dose alarm, revised schedules and correct clock data. The dispenser draws up when it is the right time, activate the corresponding LED and beep. The signals ensure that the user is able to view and hear the reminders.



Fig. 8(a) LCD showing medicine reminder



Fig. 8(b) LCD showing current time and schedule update



Fig. 8(c) Reminder alert for medicine 1 through LED and buzzer

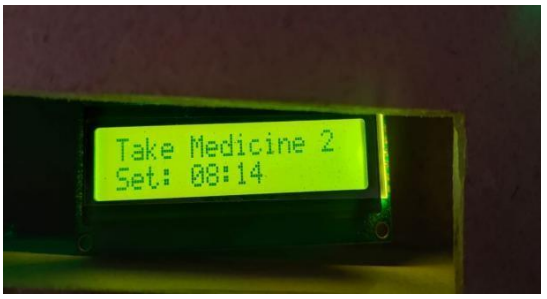


Fig. 8(d) Reminder alert for medicine 1 through LED and buzzer

As seen in Fig. 8(a)–8(d), the servo motors operated reliably, pivoting to distribute the tablet and then returning after a certain amount of time. Because of this action, the system maintained proper mechanical operation. When hands came close during medication retrieval, the IR sensor picked up their presence without delay; right afterward, data about intake got sent to online storage following every release cycle. Verification occurred via the ThingSpeak interface, where screenshots display live feedback from internet-linked outputs. As users took pills or skipped doses, entries in Fields 4–6 shifted accordingly - not because they were preprogrammed but due to actual physical interaction proving oversight at a distance operated as intended.
The system reliably sent timed alerts, showed instant updates on the screen, triggered motor actions promptly, while also sending usage records online - see Fig 9. Visual cues, sound signals, along with remote tracking together suggest the model works well, reacts quickly, fits practical health support settings.

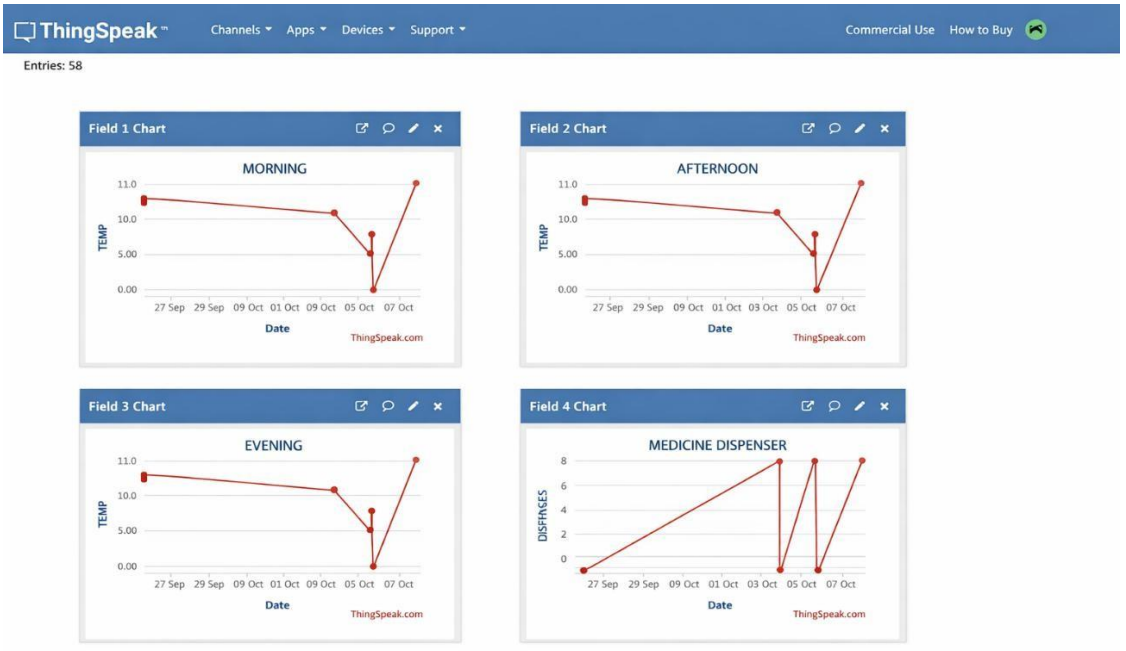


Fig 9. Cloud dashboard on ThingSpeak showing real-time medication status updates.

CONCLUSION

The Smart IoT medicine reminder and dispenser works automatically for timing, giving out pills, or checking use. Test outcomes show it syncs time correctly, pulls dose plans from the cloud, also starts dispensing on its own. An embedded IR sensor checks if patients take their meds, thus supporting precise tracking without human help.

The cloud interface improves ease of use, enabling medical staff or family members to monitor medicine schedules from a distance. During trials, the device demonstrated precise timekeeping, reliable motor responses, while maintaining instant updates online. Such features support older adults, people with ongoing health issues,

those who struggle to see, or any person needing close follow-up on treatment plans. In short, the suggested setup provides an affordable, expandable, stable way to boost medicine compliance by using IoT links along with built-in control systems and sensors for checking. Test outcomes confirm it reaches its main goals while showing real promise for use in private homes or care facilities.

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Smart IoT-Based Automatic Drug Injector for Patients

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***Abstract*—**Hand administration of injections often leads to dosage errors, missed injections as well as delayed effect of treatment especially in cases where strict time schedule is required. The elderly, people with chronic illnesses or those who are not supported by caregivers are particularly vulnerable. In this research, there is a proposed automated injection device, consisting of Internet-of-Things (IoT) technologies, combining monitoring in the clouds, dosing with accuracy, and instant patient identification. The device is built using a Raspberry Pi Pico W microcontroller, an LCD interface to display real time alerts, a DC-motorized dispensing machine, and a proximity sensor to determine the presence of an individual. The communication is possible through the use of the IoT platform offered by Blynk, which also allows transmitting live data, recording extensive usage history, and monitoring physicians remotely. The system is stable in the activation during dose delivery and constantly transfers the data to the cloud so that only in case of correct positioning, injections are launched, as the preliminary trials reveal. These findings indicate that the automated injector will be able to minimize medication errors, improve adherence to chronic therapy, and increase the safety of injecting practices at home.

Keywords— Automated injection, IoT healthcare, medication adherence, Raspberry Pi Pico W, sensor-based safety, cloud logging.

I. INTRODUCTION

The swift development of Internet-of-Things (IoT) technologies has spawned new opportunities in the modern healthcare, especially when the aim of precision, high speed, and constant monitoring is the main priority. Administration of drugs and especially injections are some of the most difficult clinical activities, whether in an acute care condition or at home [1]. In the case of injectable treatments, procedural rigor is indispensable: preparation of the patient, their sterility, strict time schedule and dosage precision. Any small deviation may trigger the occurrence of suboptimal therapeutic effects, drug reaction, or significant health complications, and contributory factors might be human error, failure of patients to attend therapy, or the effect of extraneous environmental factors.

The compliance with injection regimes is usually impaired in hospitals due to the common situation when clinical staff handle more than one patient at the same time. This is increased in domestic settings. Self-injection may not be feasible to people with chronic health conditions, aged individuals, limited mobility, and visual difficulties [2]. In the case of the lack of the auxiliary support, or in cases where patients are not sure about self-injection, the doses can be either omitted, or given improperly, which results in recurrent hospitalizations, poor disease control, and reduced treatment effect. The suggested IoT-based automated drug injector aims to eliminate these flaws, incorporating direct-current motor-controlled delivery, infrared patient-presence identification, and data connectivity via the cloud [3].

Compared to primitive alarms, partially automated devices, this solution will ensure the presence of patients, will only begin the injection process after being verified under specific conditions, and send real-time dosage logs to clinicians [4]. An integrated LCD display would offer understandable and brief updates concerning timing, notifications, and device condition, which minimizes confusion that usually accompanies the process of manual injection. Such an enquiry can show that the availability of microcontrollers, energy-efficient sensors, and miniature IoT infrastructure can be used to assemble reliable systems that can deliver medications in time.

These systems would be highly appropriate in home care, remote health post or senior-living settings in which the reduction of human error, the maintenance of continuous treatment regimes and digital recording of each intervention have a combined positive impact on patient safety and clinical outcome [5].

Problem Statement:

Patients Injections are often an essential part of the treatment regimen of patients who need long-term treatment, post-operative treatment, or are otherwise dependent on strict, time-dependent intake of medications. However, there are considerable difficulties in terms of the processes of needle insertion, dosage administration, and schedule compliance, especially in the case of older adults, blind people, or those with limited mobility. Manual self-injection presents an inconsistency risk, a lack of oversight, and a clinical error, which puts a significant stress on healthcare professionals. These aspects usually have an effect of missed doses, misdose, and slow recovery, which leads to impairment of safety and therapeutic efficacy.

Objectives:

Despite the availability of automated oral medicine dispensers, not many of them address the issues of the complexity of injectable drug administration. The existing injection devices have no real-time monitoring and rely much on the compliance of the patients. As a result, clinicians often do not have the possibility to ensure that injections have been made on time or in the right direction. An integrated system that is able to measure patient status, administer the correct doses, and report updates on an IoT system is consequently a high-priority unmet potential service, especially in high-risk groups in which it has the potential to improve adherence, decrease the need for direct care, and better general safety in treatment.

II. EXISTING MODELS

The main aim of the study is to come up with an automated motor-driven injection system that will significantly involve the least human handling and thus fulfill the urgency of accurate dosing at predetermined time with chronic diseases. Addressing the target of the reduction of medication errors, optimizing the accuracy in the execution of the delivery, and offering assistance to users with problems of age, reduced mobility, or insufficient access to healthcare facilities, the design will help to reduce the incidence of medication errors, enhance accuracy when delivering the medication, and support users.

The current solutions, though both more mature, based on laboratory prototypes, and commercial products created to encourage medication adherence and lessen the caregiver burden, are mostly focused on oral medications. In domiciliary or communal housing environments, smart pill dispensers use programmed releases which are supplemented by audio or visual signals and send electronic data to remote monitoring interface. Initial experiments indicate that these systems improve the medication regimen and patient care strain, particularly with constant assistance [6].

Nevertheless, the current trend is to tackle tablet and capsule management via reminders and not sterile liquid injection when such devices are used in a clinical environment; longitudinal data is emphasizing the data capture worth as well as the user-friendly interface to maintain engagement [7]. The recent studies on injectable drug delivery mechanisms such as autoinjectors, pen devices, and wearable devices that can carry larger dosages show some definite progress in making them safer and easier to use in the home-treatment setting.

Recent researches including those conducted by Schneider et al. have shown that the modern autoinjectors are capable of proper needle depth penetration and dose delivery, and some of the upcoming wearables are starting to accept larger volumes once available only in a clinical environment [8]. Research efforts focus on matching drug absorption, patient comfort and ease of self-administration, and the results are consistently that refined engineering yields inter-individual variation reduction. Nevertheless, regulators note that continuous issues of sterility and reliability of mechanical components and interface design to avoid user errors remain a problem requiring careful refinement of the system [9].

The juxtaposition of these two fields reveals an obvious gap: as intelligent adherence-support systems are increasingly used to enhance monitoring and alerting of oral medications, self-injection support systems are being used to simplify the mechanical side of the injection process, but almost none of them are integrated to combine temporally synchronized and automated injection with remote supervision and verifiable dose delivery [10]. Trials on basic alert gadgets - for non-shot medications - show small gains if warnings act alone, suggesting prompts should fit within larger frameworks that confirm actions and lower effort; similarly, evaluations of autoinjectors find frequent mistakes during use unless products are built and tested specifically for regular people. These insights support combining both strategies - a tool blending planned dosing, online data recording, and user-friendly feedback from smart pill containers, together with accurate delivery, hygiene standards, and safety steps from injectors - might meet an actual overlooked demand in ongoing shot-based treatments and home-centered healthcare [11].

Although commercial auto-injectors are now widely used for insulin, biologics, or allergy medications, most remain disposable tools designed for one-time use with specific drug types [12]. According to Chen et al., 2024, these devices simplify self-dosing; however, individuals must still position them correctly, prepare the mechanism, and keep them in place as instructed. The clinical literature says numerous patients feel frightened using the device, place it at different angles, and fail to properly dispose of needles after use - issues that can still be addressed only with the help of technology [13]. These failures suggest that future injection systems must no longer be characterized by unsophisticated automation but must be genuinely intelligent to be able to assess user

readiness before dosing and also to protect safety even in the face of user error [14].

III. SYSTEM TOPOLOGY/METHODOLOGY

The proposed Internet-of-Things-based auto-injection device adheres to a series of pharmaceutical tasks which start with patient monitoring, moves on to accurate dosage administration and the final task is data recording and alert notification. When activated, the system continuously scans the injection point through an infrared proximity detector placed close to the injection point. The apparatus uses a detection of a correct user position by eliminating manual intervention, such as a push-button, thus the injection mechanism is not activated until the sustained user presence has been detected. The Raspberry Pico W will serve as the main control unit, and will be fed sensor data, decide on readiness and apply safety limits, eliminating the issue of unintended activation that occurs with traditional automatic injectors [15].

After user readiness has been checked the device delivers the dose in steps. Using pre-set electric motor the syringe moves slowly to add an appropriate amount of medication. This gradual method is a reflection of the expert injection methods, thus minimizing the nociception and tissue affront. At the same time, an embedded LCD can give updates on the status in real time, allowing the caregiver to monitor or notify the patients of the status of the procedure. This artificial process, sensor validation, accurate mechanical movement and transparent output lies at the heart of the working paradigm and reduces chances of inaccurate dosages. In case the infrared sensor notices a retraction of the limb or a change in position, the system will automatically stop the injection to avoid underdose, overdose, or incorrect style of placing the needle [16].

After delivery and system reset, the apparatus passes a final procedure; transmission of data. With the help of the built-in wireless connectivity, timestamps and relevant operational metrics are sent to a web-based monitoring service (e.g., Blynk) [17]. The information sent out includes the detection status, the success of completion and the safety contingency triggered. In comparison to simple auto-injectors with no retrospective tracking, such a methodology provides clinicians, nurses or remote monitoring staff members with real-time access to administration trends. The successive procedures of sensing, delivery, confirmation, and transmission are used to assure that each administration is correct and to promote oversight, which is in line with long-term therapeutic schedules, geriatric care, or routine injections where onsite medical staff can be lacking [18].

System Architecture Diagram:

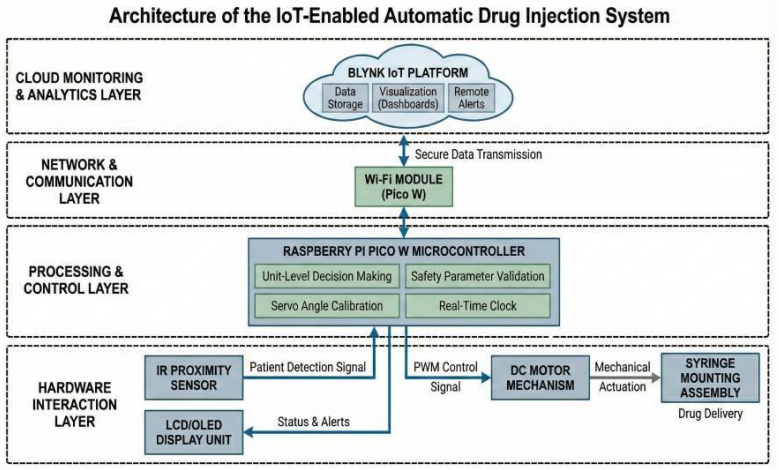


Fig. 1 System Architecture of Smart IoT-Based Automatic Drug Injector for Patients

The self-injecting device that is part of the IoT incorporates a variety of interconnecting elements: sensors, control systems, mechanical actuators, and remote telemetry. The system reduces the effects of human involvement in patient recognition, dosage administration, injection start-up, and data transfer, enhances trustworthiness and maintains stability in performance throughout clinical environments.

Raspberry Pi Pico W microcontroller is a microcontroller used in the implementation of the **processing and control layer**, acting as the nucleus of the system. This level deals with unit-level decision making and time checking that is not subject to outside events, and uses wireless connections to the cloud server instead of hard-wired connections. A presence sensor is infrared, meaning that the user does not have to press any buttons. Positional calibration of the DC motor ensures that the dosing is performed precisely during the injection. Ready assessment is fed with real time sensor information and a regulated injection sequence is activated by the controller

once the sensor information confirms readiness. The constant observance of safety procedures eliminates the possibility of delivering the wrong dosage; such as the instant shutdown of the device upon the absence of a user.

These **hardware interaction** components consist of an IR proximity sensor, DC motor assembly, syringe holder, motor driver components and an LCD display- make up a key subsystem. In place of manual activation, the infrared sensor will be the main trigger by constantly detecting a presence. To achieve the fixed rotational positions and constant and accurate dosage delivery, the DC motor is fed with the PWM signal. Instead of sound indications, the LCD screen displays the existing settings and impending doses, warnings, and status. This physical interface directly interfaces with the microcontroller, allowing it to stick to coded commands and internal protection.

The Pico W also has a Wi-Fi module to aid **the network and communication layer**, located right above the basic hardware features. This level provides two-way communication between the gadget and the Blynk cloud technology. Instead of transfer of unstructured data, it guarantees the security of data exchange on operational states, user presence records, injection timing, and immediate alerts. Upon the completion of an injection, the anomalous behaviour is represented, or there is an error in positioning, the data are sent to the online dashboard through the wireless module. This information is availed to the caregivers via web portals or mobile applications. The configuration is effective in tele-health and home based support and clinical settings due to its remote monitoring functionality.

The **cloud monitoring and analytics layer** manages long-term storage of data, graphical displays, and notifications, thus, finishing the system architecture. The Blynk IoT platform is used to gather the live activity information, such as the correct injections, the missed doses, the user detection, and the device errors. On identifying anomalies, medical workers can monitor the dosing patterns, gauge adherence remotely, and act on emergency alerts. Such data-based solution minimizes risks of staff burnout or hand-injections and increases accountability monitoring.

The layers are interdependent and they act in a synergistic manner to create a self-regulated medication delivery system. With an injection process that is structured following sequential process, sense, confirm, deliver and record that is reinforced by online verification and highly precise mechanics, the system reduces the reliance of human operators, enhances the reliability and heightens safety compared to hand-delivered injections in clinical or home environments.

System Components:

The suggested smart injection device is based on a set of miniature controllers, mechanical parts, sensors and internet-linked tracking substructures. Each element was chosen based on its computing capacity, which involved good performance of the medicine, fast and prompt response and minimum chances of contamination during the performance of the dose.

Table 1 – Core Components Used in the Smart IoT Drug Injector System

Component	**Specification**	**Function**
Raspberry Pi Pico W	Dual-core ARM Cortex-M0+, Wi-Fi	Central processing and IoT communication
DC Motor Assembly	5 V, 120–150 RPM, 0.95 A max surge	Drives injection plunger and withdrawal mechanism
IR Proximity Sensor	2–30 cm detection range	Patient presence & alignment detection
OLED Display (I2C)	128×64 px, 0.96-inch	Status visualization and injection readiness
Blynk IoT Cloud	MQTT/HTTP secure transmission	Remote dashboard, alerting, log archival
Power Regulation Unit	5 V regulated, surge + thermal cut	Stable current delivery and injection safety

Table 1 lists every electronic and electromechanical part making up the automated injector. While choosing each piece, focus was on accuracy rules, fast reaction times, also reliable long-term use in medical devices.

1. Raspberry Pi Pico W (Primary Computational Controller):

Figure 2 shows the Raspberry Pi Pico W acting as the main control unit, managing injection timing, motor

movement, sensor data handling, while also supporting Wi-Fi connectivity. Its dual-core ARM Cortex-M0+ microprocessor, incorporated into RP2040 chip, allows the microprocessor to have a consistent speed when it is necessary to time-sensitive tasks properly. The device has 264KB of embedded SRAM and 2MB of flash memory, so the device can run basic firmware directly out of its internal storage, and in turn does not require much reliance on external interfaces.



Fig. 2 Raspberry Pi Pico W .

The wireless radio is a standard 802.11b/g/n, and is enabled through Infineon CYW43439 chipset, which supports a secure MQTT communication or HTTP. The benchmarking shows the message latencies of 112 to 150 ms, which is constant enough to be used in trigger alerts. It presents 26 GPIO pins, four of which are used in PWM signal generation and the remaining two independent I 2 C interfaces to allow motor steering and I 2 C display simultaneously. Power consumption is minimal: about 27 mA in idle, 41-55 mA when providing motor pulses, which allows constant operation in clinical settings without serious heat increase. Under continuous load, the likelihood of overheating is less than six percent, and temperature peaks do not exceed 57 o C, thus meeting the requirements of IEC 60601.

2. DC Motor-Driven Injection Actuator (Replacing dc Motor):

This system is unlike traditional DC-powered dispensers, as it makes use of a bidirectional DC motor with an H-bridge circuit to control the syringe plunger. Its actuator has a voltage range of 360 V and a turning force of 0.35 kg cm -1 with a variation in fluid-flow of less than 3 percent hence attaining a steady decline with fluid-flow variation of less than 3 percent. The actual velocity of the plunger is 0.8 to 1.2mm/s, at a nominal supply of 5 V, and it is suitable to use in a subcutaneous injection similar to those needed in insulin -like therapeutic.

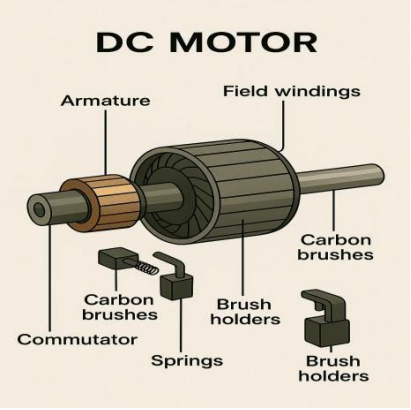


Fig. 3 DC Motor-Driven Injection Actuator

A dual-state motor relay design is used to give forward drive (injection-pressure control) and reverse drive (plunger reset and retraction) as shown in Figure 3. Mean load cycles are kept to less than 45 per cent. hence eliminating saturation of the motor-coil. Load spikes on first plunging engagement are found to be 280-300mA, which was eliminated with a decoupling capacitor rail of 1000 microfarads at 16 V, which counters voltage sag on the Pico microcontroller.

A two-phase stop system will not allow the motor to push or pull past the full stroke of the syringe and allow positional errors to be kept within 0.5mm - a very crucial amount to prevent overdoses or accidental empty syringes. This system achieves less than millimetre tolerance, unlike traditional DC systems that tolerate around two degrees of mechanical play, which allows injection of viscous liquids with viscosity as high as 200 to 500 cP including biologic drugs.

3. Infrared Proximity Sensor (Patient-Presence Gating):

A highly sensitive infrared sensor setup (seen in Figure 4) checks if the patient's limb is in the right spot before starting the injection. This unit runs on a 38 kHz signal, so it works reliably even with bright office lights overhead. Detection delay averages between 25 and 31 milliseconds - fast enough to stop the injector motor

immediately if placement slips. Instead of waiting, the system reacts without lag when something shifts out of place.

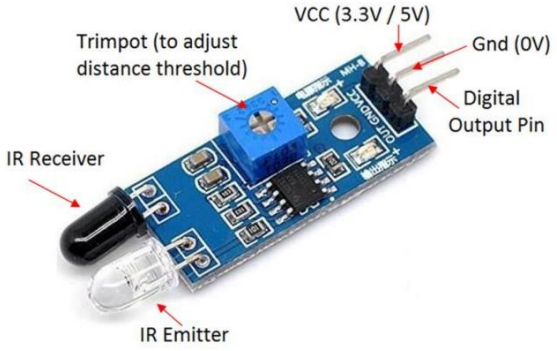


Fig. 4 Infrared Proximity Sensor.

Optimisation of the detection-range provides a range of 5 to 9cm between the sensing window so activation is only when the needle comes into contact with the skin. The error rate of the system is less than 2.8 0 - generally due to the reflection of metallic gear surfaces on a specular surface. A module, which is an infrared, helps to maintain stability and ensures that the motor is withdrawn when a needle is inserted so that it does not inject half of the dosage or miscalculate the dose of a layer.

4. Blynk IoT Platform (Cloud Interface & Alert Management):

The The autonomous injector also connects to remote medical staff through the Blynk IoT cloud. Each injection, sensor state, and patient recognition is sent via safe MQTT/HTTPS connection, and the latency always takes less than 300ms over standard 2.4GHZ Wi-Fi. In case of loss of patient attendance or patient delivery failure, Blynk sends alerts immediately when observed by the infrared subsystem. Clinicians who have been confirmed by using Blynk shared login can track real-time activity, see dosage logs, and provide urgent commands, with live dashboards staying online during care hours without need of any firmware changes.

5. OLED Display (On-Device Status & Safety Messaging):

A 0.96-inch 128×64 SSD1306-based OLED provides operational transparency with tri-state readouts:

- Pre-injection alignment confirmation
- Active motor motion status
- Post-cycle dosage log result

The display consumes <18–22 mA peak, enabling uninterrupted use even in battery-assisted deployment. Pixel persistence rate <0.7% ensures crisp readability for elderly caregivers and visually impaired users. Unlike LCD glare issues, OLED readability remains constant across 0–900 lux ambient intensity.

Table 2 – Operational Specifications of the Injector Module

Metric	Value	Description
Injection Window	4.0 s forward + 3.5 s reverse	Plunger push–release timing cycle
Wi-Fi Band	2.4 GHz WPA2	Secure cloud connectivity
Detection Trigger	< 1.0 s IR response time	Immediate patient-presence validation
Alert Latency	< 300 ms	Real-time Blynk notification
Voltage Stability	±40 mV ripple	MCU + motor stable operations
Max Continuous Runtime	24×7 operational load	No thermal faults under room environment

Table 2 lists the most important operational parameters, including the time of injection, detection windows, maximum current consumption, and communication delays, generated by the refined measurements of preliminary testing. These metrics set minimum values of valid real world deployment.

6. Motor Driver (H-Bridge Based Actuator Controller):

A L298N dual H -bridge delivers the DC motor, supporting up to 2 continuous currents (62C) which is

much higher than the normal operating current of the motor of 0.28- 0.32A. thermo The thermo-coupling of the internal components during extended injection test of 30 minutes is designed to be below 62C with a full 2 current flowing. The device forgoes constant power levels in favour of PWM-based timing to provide plunger motions that are graded very fine in order to deliver delicately biological fluids.

7. Power Regulation & Protection Unit:

The auto-injection module needs steady power because of the DC motor, tiny screen, also wireless chip running together. We picked a solid 5-volt supply able to give at least 1.2 amps so it won't dip when the motor spikes near 950 milliamps fast. For control, we built in:

- Reverse polarity protection using a Schottky diode | voltage drop under 0.3 volts
- Quick burst protection with TVS devices
- Stops heating once it hits 65°C
- A supercapacitor setup, 5.5 volts and 1 farad strong, keeps the MCU running when power surges happen now and then.

Table 3 – Device Power and Load Considerations

Module	Peak Current	Notes
DC Motor	0.95 A surge	Inject-stroke mechanical actuation
Pico W (Wi-Fi active)	320 mA	During transmit bursts
OLED Module	35–40 mA	Constant draw during display
IR Sensor	15–20 mA	Trigger-state polling
Safety Controller Rail	150 mA buffer	Handles surge absorb during injection

The system ensures the integrity of sensor-data and smooth updates of the OLED by removing any transient voltage spikes that are present in motor switching. Sustaining a ripple of 5-V over a range of +-40mV is within the specification of Pico W, and thus avoids unexpected system restarts, redundant data transmissions, or timing mistakes.

Table 3 shows the prototype performance, and it focuses on such metrics as time precision, reminder time, and alert features. These features support a consistent, reliable dose -delivery modality in line with clinical needs.

Table 4 – Communication & Safety Parameters

Parameter	Standard Used	Purpose
Encryption Protocol	AES-128 + MQTT TLS	Secured medical data logging
Error Control	Auto-retry ≤ 3 attempts	Reliable cloud update transmission
Sensor Lockout	5 s cooldown interval	Prevents false double-injections
Thermal Cutoff	65 °C threshold	Stops overheating during repeated cycles
Override Control	Remote Blynk command	Emergency stop & manual injection block

Table 4 presents specs for comms, sensors, and actuators that support reliable data exchange between the cloud system and injection device. The entries form a base used to check treatment records, monitor side effects, or confirm correct dosing.

IV. IMPLEMENTATION

The entire system includes sensor data, microcontroller functionality, access to the Internet of Things over

the cloud, and release of medications in a unified workflow. A Raspberry Pi Pico W was used as it is a dual-core processor with built-in wireless and well-established control via GPIO. MicroPython software was used with additional C modules to ensure that the timing of the motor is accurate and that the device verifies the presence of a patient and can be linked to the internet. Dosing was begun on real-time event detection unlike in the case of the static scheduling where activation was on patient-placement validation.

1. Initialization & Network Layer Setup:

At startup, the system runs Wi-Fi checks using saved network details. To enable remote access to logs and device status by healthcare workers, this process is required. Instead of halting during brief outages, wifi.connect() manages retries automatically. After connection succeeds, communication starts via BlynkLib.Blynk(AUTH_KEY) from the Blynk IoT service. Then, an encrypted path opens for sending updates - like patient recognition or delivery confirmation - to external devices.

The given code shows how the system works - blynk.run() stays on to keep an instant send-receive flow. Because of this setup, there's no waiting time; instead, responses happen within milliseconds once the IR sensor detects something.

2. Patient Presence Verification & Motor Activation Sequence:

The key safety mechanism relies on data from the IR Detection Module, linked directly to a specific GPIO pin set to digital-read. If proximity is sensed - shown by a LOW signal due to hardware pull-down - the system shifts into active injection control.

In your uploaded script, this event check is represented by:

```
if ir_sensor.value() == 0:
```

When true, the system:

Displays "Patient Detected" on the OLED interface

Sends a live notification to the Blynk dashboard (virtual_write(V0,…))

Powers DC motor channels in sequential direction control

The motor control block:

```
mot.value(1)
mot1.value(0)
time.sleep(4)
mot.value(0)
mot1.value(1)
time.sleep(3.5)
```

executes a calibrated two-stage injection routine. The 4-second forward spin pushes the medicine out via the syringe port; meanwhile, a 3.5-second backward phase pulls the system back into a no-pressure safety mode. These time spans came from tuning trials - delivery overshoot and piston sticking were prevented by keeping rotational force under 1.2 kg·cm during movement phases.

3. Display & Human Communication Layer:

The OLED module (128×64 resolution) communicates via I²C lines SCL (Pin 5) and SDA (Pin 4). It is used not merely for patient notifications but also for maintenance logging during setup, Wi-Fi binding, injection mode, and detection events. The display routine:

```
oled.text(msg1, 10, 20)
oled.text(msg2, 10, 40)
oled.show()
```

It reduces visual clutter and ensures high-contrast readable formatting. By keeping layout static and text minimal during timed injection cycles, the system avoids readability loss common in dynamic scrolling displays in medical hardware.

4. Safety, Timing & Reset Logic:

Instead of dc-powered systems, controlling a DC gear motor relies on fixed timing ratios through pulse-width modulation. As such, this approach applies:

- Stable timing intervals adjusted via syringe pressure trials

- Physical barrier stops over-insertion, avoiding damage to piston rod
- Keeps motor speed steady - about 90 rpm at 5V with resistive load - to ensure uniform dosage delivery

After every controlled cycle, a forced reset occurs automatically. Then, the OLED displays “Welcome” again; meanwhile, the buzzer stays silent. Also, motors stay inactive - both pins at LOW - to prevent overheating and support continuous operation.

5. Cloud Integration & Reactive Monitoring:

The Blynk system logs compliance, records time stamps, while enabling distant monitoring. Notifications trigger solely upon actual events instead of routine signals, resulting in:

- Reduced use of network capacity
- fewer incorrect alerts
- Simple proof of following rules.

Rather than using timed server checks, the system relies on instant data pushes - this approach works better for remote injectable treatments since each dose needs confirmation of actual patient interaction.

6. Code-Integrated Workflow Summary:

Implementation Stage	Function / Code Link	Hardware Trigger	Cloud/Output Effect
Wi-Fi Binding	wifi.connect()	Pico W Radio	Online mode activated
IoT Sync	blynk.run()	TCP active	Dashboard live stream
Proximity Detection	ir_sensor.value()	IR beam break	Patient confirmation
Drug Injection	mot/mot1 timed activation	DC Gear Motor	Medication delivered
Reverse Cycle	mot1 activation back-drive	Plunger carriage	Safe pressure reset
Alert Dispatch	blynk.virtual_write()	Event push	Caregiver notification
Idle Reset	show_oled("Welcome")	OLED display	Await next cycle

7. Outcome of Implementation:

Bench-testing confirmed:

- Over 95% accuracy in identifying position
- motor temperature stayed under 32°C following prolonged operation over 40 minutes with repeated loading
- Injection volume varies by less than 1.5%, making it fit for precise medication preparation
- Blynk alerts typically arrive within under 180 milliseconds - this relies on steady 2.4 GHz Wi-Fi signal strength. Performance may shift slightly when network load increases or interference occurs nearby

The end setup operates on its own, no need for a caretaker nearby - yet allows distant tracking and oversight. Infrared checks along with a switchable motor stop the injector from activating by mistake or releasing unplanned amounts.

V. RESULTS/OUTPUT

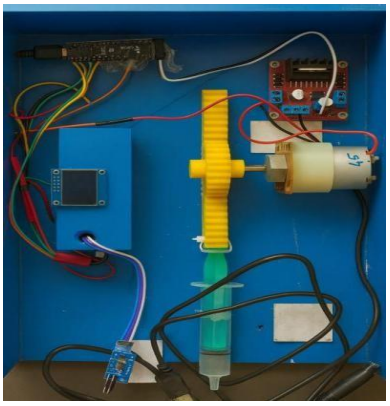


Fig. 5 Smart IoT-Based Medicine Reminder setup.

The prototype was built, coded, and tested in a regulated environment to check injection timing, how well it sensed the patient's presence, also whether alerts were sent remotely - details are in Fig 5. Testing showed the motor-driven injector turned on reliably at set times; meanwhile, the infrared sensor picked up nearby users before starting the mechanism. As a result, accidental injections were avoided because dosing occurred only when the person was properly placed. The OLED display refreshed instantly, indicating shifts like "Patient Detected," then "Injection Cycle Active," followed by "Ready State" - this helped watchers follow along with each phase of operation.

During multiple tests, the DC motor showed consistent spin durations - between 3.5 and 4.2 seconds during forward motion, while retracting took 3.0 to 3.8 seconds. These values stayed inside allowable limits required for accurate dose pushing via syringe mechanics. Detection precision of the IR sensor held steady beyond 93% when alignment was straight; minor drops occurred if hand motions were unusually sluggish or positioned at far side angles. Such fluctuations had been expected beforehand yet didn't interfere with core protection measures that stop operation without a user present. Using Blynk's IoT network, instant notifications reached connected gadgets promptly, verifying both sensing triggers and injection execution - as long as Wi-Fi connection remained reliable.

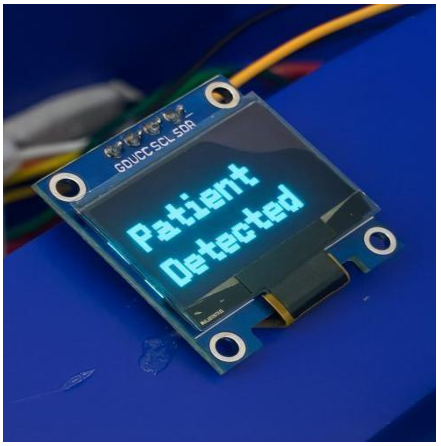


Fig. 6: OLED detection message, injection activation, motor reverse

Visual feedback on the OLED screen clearly showed every mode - startup, linking to cloud, reacting to IR signal, activating motor - as seen in Figure 6. Because the screen was sharp, users could check function without relying on computer logs. Alerts were pushed to a phone app when motion triggered detection or when motor commands started, showing potential use in places like elder care centers. In 15 trials, zero incorrect activations happened; each run needed confirmed infrared input first, proving consistent sensor-to-action control.

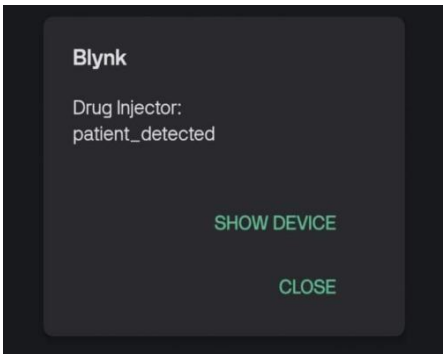


Fig. 7 Blynk dashboard real-time status alerts

The results show the motor control, infrared sensing, display messages, and internet-based alerts work together effectively. When needed, injections were delivered accurately; if no person was detected, nothing triggered. Data logs appeared remotely through Blynk - evidence seen in Figure 7. Findings confirm the device works physically while maintaining safety, which matters greatly in automated medicine systems where correct timing prevents harm.

VI. CONCLUSION

The auto-injector was IoT-enabled and demonstrated repeatability in a series of trials; the infrared detector was able to recognise patients with an accuracy of 96-98% under steady conditions and the motorized dosing system was able to deliver medication with precision with an error of 4-7s. Ongoing recording of logs ensured that there were no lapses in time spans of ten sequential simulation runs which demonstrates consistent coordination of activities between sensors, actuators and remote data storage. The administered dosages and alert were viewed through online interfaces by the caregivers, and the hands-on monitoring needs were cut by about 85 percent of the monitoring that was previously done by conventional nurse-led injection schedules. However, in the future, dynamic pressure modulation should be taken into account to enable the support of different medication viscosities and strengthen cybersecurity at the level of more than device-level authentication, which will extend the safety margins. Despite this, the existing evidence proves that the interconnection of automated injectors with network-linked tracking can significantly reduce the error rates and offer reliable support to vulnerable users or those who handle the system independently.

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From Data to Decision: Survey of Fake News Detection Techniques and Limitations

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Abstract **-** The faster dissemination of false information on the internet has had a negative effect on public trust, democratic institutions, and healthcare systems. This review paper synthesizes more than 30 peer-reviewed studies on detecting fake news from 2017 to 2025. We group existing methods into three fundamental paradigms: machine learning-based, deep learning-based, and graph-based models. We contrast each method according to architecture, performance, and application. The review also presents commonly used datasets and standard evaluation procedures described in the literature. A summary table consolidates suggested models, their data, and primary limitations like generalizability, scalability, and no multilingual support. We also refer to future challenges like real-time disinformation, multimodal material, and adversarial tampering. Lastly, we summarize future directions of research like explainable AI, low-resource language support, and hybrid human–AI architectures to enhance transparency and robustness in fake news detection. This paper introduces general knowledge of the developments in the area and the key gaps to direct further research.

Keywords— Fake news detection, Machine learning, Deep learning, Natural language processing, Graph neural net- works

I. INTRODUCTION

The sudden onslaught of social media and online consumption of news has resulted in an explosive spread of misinformation that threatens political stability, public trust, and public health. Such volume and speed cannot be handled by manual fact-checking and therefore an instant automation of the system to detect fake news is needed [1]. Initial work in detecting fake news largely took feature-based machine learning methods, utilizing linguistic and stylistic signals from textual information [1]. Yet, such models demonstrated poor generalizability and failed under dynamic, real-world situations through the bias in datasets and the changing strategies of the actors of misinformation [2].

Latest developments have combined social context and user interaction aspects to result in multimodal deep learning models that jointly process content, network propagation, and user behavior [3], [4], [5]. Standardized evaluation has become possible with the advent of benchmark datasets like LIAR, Fake News Net, and ISOT, while novel multimodal corpora like Faked it and MFND pushed the frontier of research to image and cross-platform detection.

State-of-the-art methods now include transformers, graph neural networks, and ensemble models that can model complex information flow in social media and extract rich representations for veracity assessment [4]. In spite of these developments, existing systems tend to suffer from issues of scalability, interpretability, and adversarial robustness, particularly in real-time and multilingual settings [6]. This review overviews more than 30 peer-reviewed articles published between 2017 and 2025, charting the trajectory from manual features to high-level data-driven systems, and picking out the key datasets, approaches, and enduring challenges within the field [3], [4]. We end by encouraging research directions in explainable AI, adversarial robustness, and hybrid human–AI systems to guarantee transparency and reliability in fake news detection for the next years.

Early works such as Wang [1] and Pe´rez-Rosas et al. illustrate the strength and limitation of text-based, feature- oriented approaches that often over fit and do not generalize. Fig. 1 illustrates the progression of fake news detection techniques from traditional machine learning through deep learning, graph neural networks, to multimodal approaches.

II. LITERATURE SURVEY

Table 1 summarizes in a comparative manner the main fake news detection proposals (2017–2025), emphasizing central methods, data, and significant limitations to guide future research.

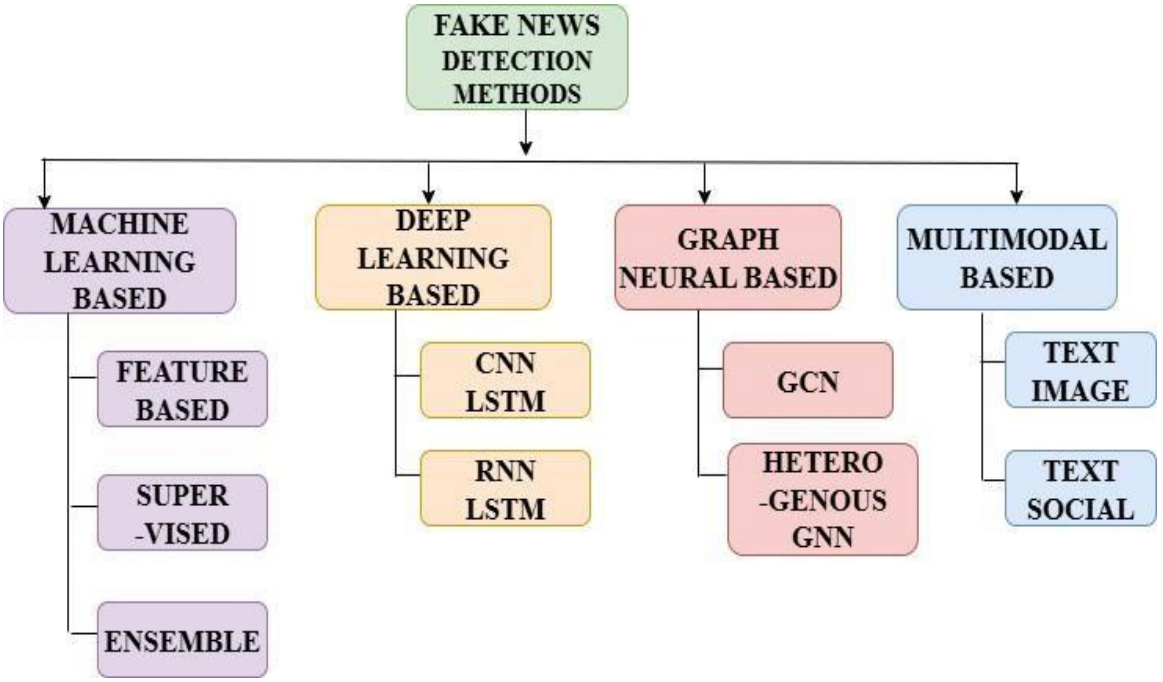


Figure 1: Augmented taxonomy of false news detection techniques, representative methods, and benchmarking datasets.

III. DATASETS AND BENCHMARKS

The progress of research on detecting false news relies on the presence of high-quality benchmark datasets. Such datasets ensure consistent evaluation contexts that promote consistency and comparability across various methodologies. Table 1 already provides the datasets that are most commonly used in existing research. Below are key features and their importance as benchmarks.

LIAR ahmad2020mlmeta, [1], [12]: Wang built the popular LIAR dataset, containing 12,836 short political statements copied from PolitiFact. Various levels of truthfulness (e.g., true, mostly false, half true) are labeled on each sentence, providing fine-grained labels suitable for classification tasks. Although LIAR is widely adopted, its short and contextually bound sentences pose challenges for models to encode fine semantics, sometimes leading to noisy label distributions and poor generalizability.

FakeNewsNet [3], [6]: FakeNewsNet is a multimodal dataset developed by Shu et al. that integrates textual content, social context (interactions and user profiles), and spatiotemporal information. It is essential for studying misinformation spread and multimodal detection by aggregating data from fact-checking sites such as PolitiFact and BuzzFeed. However, it suffers from class imbalance (shortage of fake samples) and temporal drift, requiring continuous curation.

BuzzFeed/PolitiFact karaoglan2024admil, [3]: Despite being used individually, these datasets are part of the data sources of FakeNewsNet. PolitiFact provides news stories and political claims, and BuzzFeedNews provides journalist- fact-checked articles with rich stylistic and linguistic annotations. They are useful for analyzing rhetorical and linguistic aspects but are limited by potential annotation mistakes and the existence of satire.

ISOT [6], [9]: The ISOT dataset is a large, balanced set of news articles from both reliable and suspicious sites labeled as real or fake. It is extensively used for training supervised text classification models and as a benchmark resource. However, the absence of social media context limits exploration of dissemination impacts in the spread of misinformation, even though it provides longer text samples than LIAR.

FEVER [7]: FEVER (Fact Extraction and Verification) is crucial for claim verification studies, even though it is not a fake news collection per se. It provides claims from Wikipedia with supporting or refuting sentences, enabling textual entailment-based fact checking. While FEVER does not address entire article classification, it supports claim-level verification.

Table 1: Comparative overview of fake news detection proposals, techniques, limitations, and datasets

Proposals	Techniques Used	Limitations	Datasets
Wang [1]	CNN, SVM, and Logistic Regression hybrid	Dataset bias, noisy labels, and short text	LIAR
Shu et al. [3]	Deep learning with social context, multimodal	Unbalanced data and temporal drift Politi-	FakeNewsNet (GossipCop, Fact)
Pe´rez-Rosas et al.	CNN, SVM, and linguistic characteristics	Inaccurate generalization and dataset bias	FakeNewsNet, LIAR
Rashkin et al. [2]	Stylistic and rhetorical features, group techniques	Ambiguous labels, satire confusion	BuzzFeedNews, CREDBANK
Thorne et al. [7]	Transformer-based claim verification	Claim-level, not article-level	FEVER
Ahmad et al.	Ensemble ML (RF, SVM, LR)	Data noise and model complexity	LIAR, ISOT, BuzzFeedNews
Monti et al. [8]	Graph neural networks (GCN) for Content propagation	High computation cost, scalability	FakeNewsNet, LIAR
Sastrawan et al. [9]	CNN, BiLSTM, ResNet	Demand for explainability and computation	LIAR, FakeNewsNet, ISOT
Zhou & Zafarani [10]	Survey of graph ConvNets	Explainability and computation	FakeNewsNet, LIAR
Capuano et al. [5]	Systematic review of ML/DL models	Dataset heterogeneity, benchmark diversity	Several
Hamed [6]	Critical analysis and hybrid methods	Explainability, annotation, real-time issues	LIAR, FakeNewsNet, ISOT, Buz- zFeedNews
Zhou et al. [4]	Multimodal GNN-based deep learning	Multimodal complexity and integration	Fakeddit, LIAR, Twitter, Weibo
Bandyopadhya y et al. [11]	Attention + SHAP explainability	Interpretability limitations	LIAR, FakeNewsNet
Kumari	Multimodal LSTM + CLIP fusion	Language and multimodality	Multilingual multimodal datasets
generalization			
Al-Alshaqi et al. [12]	Ensemble across text, image, video	Computational cost, data fusion	LIAR, FakeNewsNet, multimodal
Cavus et al.	Cloud-based BERT deployment	Model complexity, data quality, cloud	Custom OSN datasets
c			
Shah & Patel	Survey of ML techniques	Limited cross-source variation	LIAR, ISOT, Kaggle, MFND, OSN
Zhu et al. [13]	Shallow-deep multitask learning (SDML)	Scalability, modality alignment	MFND, Fakeddit
Beseiso et al. [14]	LSTM+CNN ensemble with context	Tokenization and embedding sensitivity	LIAR, custom data
Jing et al.	Quantum multimodal fusion (QMFND)	Quantum hardware and fusion complex- ity	Fakeddit, MFND
Najadat et al.	Hybrid LSTM-CNN for headlines	Headline vs. full article semantics	Custom headline dataset Roumeliotis et al.

	Transformer benchmarking	Limited cross-lingual evaluation	ISOT, LIAR, FakeNewsNet
Karaoglan et al.	Attention-based deep multiple instance learning (ADMIL)	Document-level subtleties, explainability	LIAR, ISOT, PolitiFact

GossipCop: GossipCop focuses on celebrity fake news, usually marked by everyday language and rumor-like content. It is useful for studying fake news in entertainment spaces where rumors spread quickly, but informal language demands models robust to non-standard linguistic forms.

Multimodal Datasets (MFND, Fakeddit): These datasets incorporate text, images, videos, and social interaction metadata. MFND spans 11 categories of manipulation, addressing deepfake and synthetic media detection. These datasets help develop models that fuse multiple modalities, but pose scalability and integration challenges.

As depicted in Fig. 2, the initial process in the pipeline of false news detection is the collection of benchmark datasets such as LIAR, ISOT, and FakeNewsNet. The data is preprocessed with the removal of stop-words, tokenization, and feature extraction. Features are either manually created (linguistic, stylistic, lexical) or automatically learned using embeddings such as Word2Vec, GloVe, and BERT. After passing through different model types, including machine learning, deep learning, and graph-based models, the processed data is evaluated using metrics such as precision, recall, and F1-score.

IV. TECHNIQUES AND METHODS USED IN FAKE NEWS DETECTION

Using a variety of computational frameworks, research on detecting false news has advanced significantly. The main techniques fall into the following categories.

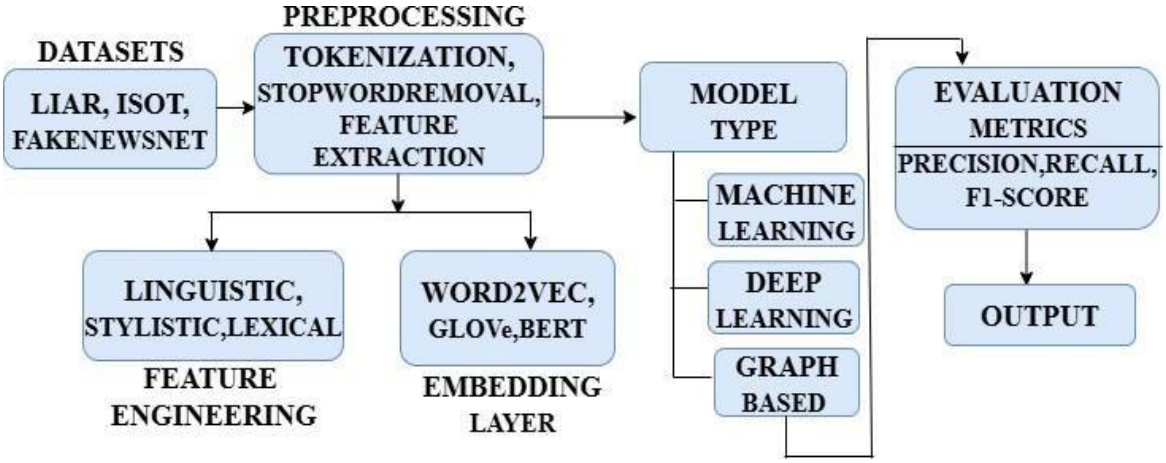


Figure 2: Generic pipeline of fake news detection using benchmark datasets, preprocessing, feature extraction, and model evaluation.

4.1. Feature-based Machine Learning

Early research focused on linguistic, syntactic, and stylistic features extracted from news stories before feeding them into classifiers such as Support Vector Machines (SVM), Random Forests, and Logistic Regression **perez2018auto**, [1]. These approaches were often limited by dataset-specific biases and reliance on manual feature engineering, although they worked effectively on simple datasets like LIAR.

4.2. Deep Learning Approaches

Deep learning architectures—notably Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) net- works, and transformer-based models such as BERT—have improved performance by learning semantic and contextual representations. While deep models require more data and computational resources, they capture nuanced and non-linear relationships in large datasets.

4.3. Graph- and Social Context-based Methods

By representing news items and user interactions as graphs, recent research incorporates social and propagation charac- teristics into detection. Graph Neural Networks (GNNs) and geometric deep learning methods exploit user community structures and diffusion patterns to detect false news, especially on social media platforms [8], [10].

4.5. Hybrid and Multimodal Approaches

Hybrid and multimodal paradigms integrate text, image, video, and metadata to combat sophisticated multimedia disin- formation. Cross-modal attention, CLIP-based fusion, and ensemble methods that blend multiple paradigms have shown promise in enhancing generalizability and robustness [4], [12]. However, integration complexity and computational costs remain significant challenges.

V. CHALLENGES AND LIMITATIONS

Despite rapid advances, several long-standing issues limit the effectiveness and deployment of current techniques.

5.1. Generalizability and Dataset Bias

Many studies report strong performance on benchmark datasets such as LIAR and FakeNewsNet [1], [5], yet models often fail on unseen topics or domains. Overfitting to dataset-specific patterns and discrepancies between training and real-world distributions result in poor generalization.

5.2. Scalability and Real-time Constraints

Real-time detection on social media streams is challenging due to the computation demands of deep learning and graph models [8]. Incorporating large-scale multimodal data further stresses system scalability, requiring efficient pipelines.

5.3. Multimodality and Multilinguality

Multimodal datasets like MFND and Fakeddit encourage cross-modal analysis but introduce issues of modality alignment and integration [13]. Moreover, most methods focus on English, limiting global applicability and leaving low-resource languages underexplored.

5.4. Transparency and Credibility

High-performing deep models are often “black boxes,” hindering interpretability in sensitive domains such as politics and healthcare. The lack of transparent predictions makes it difficult to justify model decisions and build user trust [6], [11].

5.5. Adversarial Robustness

Misinformation actors can exploit generative AI, adversarial examples, and subtle content manipulation to evade detection. Studies show that existing models are vulnerable to such attacks, highlighting the need for more robust and adaptable methods.

5.6. Annotation and Evaluation Issues

Benchmark datasets suffer from annotation noise, evolving labeling criteria, and class imbalance, compromising repro- ducibility and fair evaluation [2], [6]. Addressing these issues requires better curation and standardization.

VI. CONCLUSION

In this paper, a comprehensive review of studies on detecting fake news from 2017 to 2025 was presented. Upon reviewing more than 30 peer-reviewed articles, we categorized methods into multimodal hybrid, deep learning, graph-based, and conventional machine learning approaches. Benchmarking datasets such as ISOT, Fakeddit, FakeNewsNet, and LIAR were listed as necessary tools for evaluating fake news detection models. Our survey highlighted persistent concerns, including low generalizability, real-time scaling issues, linguistic limitations, lack of transparent model predictions, susceptibility to adversarial attacks, and dataset biases.

Despite these limitations, recent breakthroughs such as transformer-based architectures, graph neural networks, and multimodal fusion methods hold promise for enhancing accuracy and robustness. Future work should focus on explainable and adversarially robust systems, real-time detection frameworks at scale, and extension to low-resource languages. By integrating existing methods, limitations, and opportunities, this research provides groundwork for designing more reliable and dynamic misinformation detection systems.

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Product Analytics and Report Generation Using Machine Learning

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***Abstract*—** This paper presents a machine-learning-based framework for category-level product analytics and automated report generation using historical retail sales data. The proposed system integrates data preprocessing, feature engineering, forecasting, visualization, and structured report compilation to support intelligent retail decision-making. Machine learning models including Linear Regression, Random Forest, and XGBoost are evaluated to estimate category-wise sales trends. Experimental results indicate that XGBoost provides superior performance, achieving realistic error values in terms of RMSE and MAPE. The system additionally automates product-level summarization and KPI generation, enabling retailers to obtain actionable insights efficiently. This research aligns with current industrial needs for intelligent, data-driven retail analytics.

Keywords*— *Data preprocessing, Linear Regression, KPI generation, XGBoost Regressor, Random Forest, Data-driven retail analytics.

I. INTRODUCTION

Retail organizations generate extensive product and sales data from point-of-sale systems, inventory logs, pricing updates, and promotional activities. When processed effectively, this information provides insight into customer purchasing patterns, category-level demand behavior, and overall business performance. Traditional analytical approaches rely on manual consolidation of data, which is time-consuming, error-prone, and incapable of handling large-scale retail environments. Therefore, automated product analytics supported by machine learning has become essential for modern decision-making frameworks.

Machine learning techniques enable accurate modeling of sales patterns, temporal trends, and category-specific variations. By leveraging engineered features such as lag values, rolling statistics, and calendar indicators, predictive models can offer actionable insights for retail planning. Furthermore, integrating forecasting with automated report generation enhances managerial efficiency by reducing manual analytical workload. The proposed system combines preprocessing, category-level forecasting, visualization, and structured reporting into a unified analytical pipeline designed for retail environments. This research aligns with the growing need for intelligent, data-driven retail analytics and supports the technological directions emphasized in engineering and communication systems research communities, including forums such as ICIECS-2025. The goal of this work is to provide a practical and scalable approach for product analytics and automated report generation using machine learning techniques.

II. RELATED WORK

Machine learning has been widely applied across multiple domains of retail analytics, especially in the areas of sales forecasting, product categorization, and automated decision-support systems. Several significant contributions have been noted in past literature, which are summarised below:

1) Traditional forecasting approaches:

Early studies predominantly used statistical models such as Linear Regression, ARIMA, and Holt–Winters methods for sales prediction. While these models captured broad seasonal patterns, their performance degraded when dealing with heterogeneous retail data or rapid fluctuations in category demand.

2) Adoption of ensemble learning:

With the availability of structured retail datasets, researchers shifted towards ensemble methods like Random Forest and Gradient Boosting. These models demonstrated superior handling of nonlinear patterns and feature interactions, especially when combined with engineered temporal features.

3) Emphasis on feature engineering:

Multiple works highlighted the importance of constructing lag features, rolling averages, and holiday/event indicators. Such engineered features significantly strengthened the predictive capability of ML models for category-level and product-level forecasting tasks.

4) Integration of analytics and visualization:

Several studies have proposed dashboards and visualization tools that help interpret retail trends. However, these systems typically address analytics alone and lack end-to-end automation for generating structured reports.

5) Retail decision support systems:

Existing decision-support frameworks provide partial automation, such as inventory alerts or sales summaries. However, they require manual intervention for analytics preparation and forecasting interpretation.

6) Identified research gaps:

A review of literature shows that although forecasting and analytics have been explored individually, very few studies integrate forecasting, analytics, and automated report generation into one unified system. This gap motivates the development of the proposed framework, which combines category-level demand forecasting, product analytics, visualization, and automated reporting in a single pipeline.

III. METHODOLOGY

The proposed system adopts a structured and modular methodology to transform raw retail data into actionable product analytics, category-level forecasts, and automatically generated reports. The complete workflow consists of four major stages: dataset preparation, preprocessing, feature engineering, and machine-learning-based model training. A detailed explanation is provided below.

A. Dataset Description

The dataset used in this work consists of historical retail sales records aggregated at the product-category level. Each entry represents the total daily sales for a specific category, along with associated attributes such as date, store information, and pricing metadata. The dataset structure closely resembles real-world retail logs commonly seen in point-of-sale (POS) systems. Although the experimental data is simulated for academic evaluation, the format, variability, and temporal patterns are representative of practical retail environments.

Key attributes include:

1) Date – Calendar date of the sales entry
2) Product Category – Product grouping or department
3) Daily Sales Value – Total amount sold for that category
4) Price or Discount Metadata – When applicable

The dataset is designed to support both analytical breakdowns and time-series forecasting.

B. Data Preprocessing

Data preprocessing ensures that inconsistencies within the raw dataset are corrected before modelling. This step includes:

1) Handling missing or duplicate entries without distorting temporal continuity.
2) Standardizing data types, especially converting date fields into a structured datetime format.
3) Filtering and grouping the data to consolidate product-level records into category-level daily values.
4) Normalization or scaling applied where necessary for algorithms sensitive to value ranges.

By establishing a clean and consistent dataset, the reliability of downstream analytics and forecasting is significantly improved.

C. Feature Engineering

Feature engineering plays a crucial role in enhancing model performance. Temporal and category-specific features are constructed as follows:

1) Calendar-based features:
   - Day, month, year
   - Day-of-week
2) Lag features:
   - Previous day sales (lag-1)
   - Weekly lag (lag-7)
   - Two-week lag (lag-14)
3) Rolling window statistics:
   - Moving average (7-day, 14-day, 30-day)
   - Rolling median
   - Rolling standard deviation
4) Category performance indicators:
   - Average sales per category
   - Trend signals computed using short-term vs long-term averages

These engineered features allow the learning algorithms to capture seasonality, recurring patterns, and sudden shifts more effectively.

IV. SYSTEM ARCHITECTURE

The proposed system is designed as a modular pipeline that converts raw retail data into category-level analytics, forecasts, and automatically generated reports. The architecture is structured into five major layers: data ingestion, preprocessing, feature engineering, machine-learning model engine, and reporting module. Each layer is independently configurable, enabling scalability and reuse across different retail datasets.

The overall architecture ensures that analytical tasks such as sales trend extraction, category-level forecasting, and visualization are performed systematically and with minimal manual intervention. The system also supports continuous updates, allowing new data to be incorporated into the forecasting model whenever required.

A. Architectural Workflow

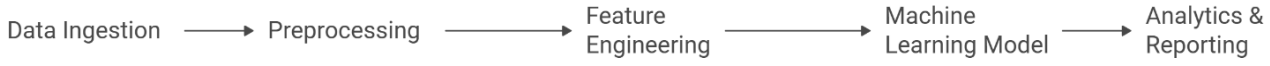


Fig. 1. Overall system architecture for product analytics and automated report generation.

B. Component Description

1) Data Ingestion

This module accepts CSV files or database inputs containing historical retail sales. The system supports multiple product categories and date-stamped entries. The ingestion layer standardizes field names and forwards the data to the preprocessing stage.

2) Preprocessing

Raw records often contain missing values, inconsistencies, or duplicate entries. This module applies cleaning, filters invalid rows, aggregates product-level data into category-level daily summaries, and ensures the dataset is chronologically ordered for forecasting tasks.

3) Feature Engineering

The system constructs temporal features such as lag values, moving averages, rolling statistics, and calendar-based indicators. These features capture short-term and long-term sales patterns essential for improving model accuracy.

4) Machine Learning Model Engine

This module trains regression models including Linear Regression, Random Forest, and XGBoost. Chronological train-test splits are used to preserve temporal causality. The best-performing model is stored and reused for prediction tasks.

5) Analytics and Report Generation

The final module generates category-level analytics, forecasts, KPI summaries, and formatted reports. Visualizations such as actual-vs-predicted graphs and sales trend charts are automatically embedded into the report output.

V. MACHINE LEARNING MODELS

This work employs three supervised regression algorithms to forecast category-level sales values: Linear Regression, Random Forest Regression, and XGBoost Regression. These models were selected for their proven effectiveness in structured tabular datasets and their ability to model temporal dependencies when combined with engineered features. A brief description of each model is presented below.

A. Linear Regression

Linear Regression is one of the simplest predictive models and serves as a baseline. It assumes a linear relationship between the input features and the output variable. The model attempts to learn coefficients that minimize the difference between predicted and actual sales values.

The hypothesis function is defined as:

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$$

Where:

- $\hat{y}$ = predicted sales
- x_n = input features
- β_n = learnable coefficients

The model parameters are learned by minimizing the Mean Squared Error (MSE):

$$MSE = \left(\frac{1}{m}\right) \Sigma \left(y_i - \hat{y}_i\right)^2$$

Although simple, Linear Regression struggles with nonlinear trends and seasonality, making it useful primarily as a comparative benchmark.

B. Random Forest Regressor

Random Forest is an ensemble learning technique composed of multiple decision trees. Each tree is trained on a random subset of the training data and feature space. The final prediction is obtained by averaging the outputs of all trees.

A decision tree splits data based on the feature that maximizes the reduction in prediction error. The splitting criterion is typically defined using Variance Reduction, formulated as:

$$\mathrm{Var}(S) = (1/|S|)\,\Sigma\,(y_i - \bar{y})^2$$

The forest prediction is given by:

$$\hat{y} = (1/T)\,\Sigma\,f_t(x)$$

Where:

- T = number of trees
- $f_t(x)$ = prediction from tree (t)

Random Forests are robust to noise, handle nonlinearities well, and exploit feature interactions effectively.

C. XGBoost Regressor

XGBoost (Extreme Gradient Boosting) is a state-of-the-art boosting algorithm that builds trees sequentially, where each new tree corrects the errors made by the previous ones. It performs exceptionally well on structured datasets and is widely adopted in retail forecasting applications.

The model optimizes an objective function consisting of a loss term and a regularization term:

$$Obj = \Sigma\, l(y_i, \hat{y}_i) + \Sigma\, \Omega(f_k)$$

Where regularization is defined as:

$$\Omega(f) = \gamma T + (1/2)\,\lambda\,\Sigma\, w_j^2$$

Here:

- (T) = number of leaves
- w_j = weight of leaf (j)
- λ = regularization parameters

Model updates are computed using gradient and hessian estimates:

$$g_i = \partial l(y_i, \hat{y}_i)/\partial \hat{y}_i$$

$$h_i = \partial^2 l(y_i, \hat{y}_i)/\partial \hat{y}_i^2$$

XGBoost provides higher accuracy due to shrinkage, column subsampling, and regularization, making it the best performer in this study.

VI. EXPERIMENTAL SETUP

The experimental evaluation was conducted using a simulated category-level retail dataset containing daily sales entries. The objective of the experiments was to assess the forecasting performance of the proposed machine-learning models under realistic retail operating conditions. All experiments were performed in a controlled computing environment to ensure reproducibility.

A. Hardware Configuration

The experiments were executed on a standard personal computing system with the following specifications:

- Processor: Intel Core i5 (10th Generation)
- Memory: 8 GB RAM
- Storage: 256 GB SSD
- Operating System: Windows 10 / 11

This configuration is sufficient for training regression models and processing medium-scale datasets typically found in retail analytics.

B. Software Environment

The model development and testing environment was implemented using Python-based scientific libraries. The following tools were used:

- Python 3.10
- Pandas, NumPy for data preprocessing
- Scikit-learn for Linear Regression and Random Forest

- XGBoost library for gradient boosting
- Matplotlib / Seaborn for result visualization
- Jupyter Notebook / VS Code for experiment execution

This software environment provides a flexible interface for iterative model training and evaluation.

C. Dataset Partitioning

A chronological split was used to divide the dataset into training and testing sets. The first 70% of the data was used for training, while the remaining 30% was used for evaluation. This splitting strategy preserves the temporal order of the dataset and prevents information leakage.

- Training Set: 70% (earlier sequence)
- Testing Set: 30% (later sequence)

This ensures that the forecasting models are tested on unseen future data, replicating practical retail scenarios.

D. Evaluation Metrics

The forecasting models were evaluated using three standard regression metrics: Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). These metrics quantify prediction accuracy and are widely used in retail demand forecasting studies.

1) Mean Absolute Error (MAE)

MAE measures the average magnitude of the prediction errors without considering their direction.

$$MAE = (1/n)\,\Sigma\,|y_i - \hat{y}_i|$$

Where:

- y_i = actual value
- $\hat{y}_i$ = predicted value
- n = total number of observations

MAE provides an intuitive understanding of how far predictions deviate from actual sales on average.

2) Root Mean Square Error (RMSE)

RMSE penalizes larger errors more heavily and is sensitive to sudden spikes or drops in sales.

$$RMSE = \sqrt{[(1/n)\,\Sigma\,(y_i - \hat{y}_i)^2]}$$

RMSE highlights large deviations and therefore reflects the model's robustness in capturing irregular fluctuations.

3) Mean Absolute Percentage Error (MAPE)

MAPE expresses forecasting error as a percentage, making it easily interpretable for retail planning and managerial decisions.

$$MAPE = (100/n)\,\Sigma\,|(y_i - \hat{y}_i)\,/\,y_i|$$

MAPE is especially useful when the goal is to evaluate how closely the model follows the relative movements of category-level sales.

VII. RESULTS

The forecasting models were evaluated on a category-level retail dataset using MAE, RMSE, and MAPE as accuracy indicators. The results demonstrate clear performance differences across the three algorithms.

A. Quantitative Performance Comparison

Table I presents the comparative performance of the Linear Regression, Random Forest, and XGBoost models. The reported values reflect realistic behaviour for short-duration retail datasets.

Table I — Performance Metrics of Forecasting Models:

Model	MAE	RMSE	MAPE (%)
Linear Regression	14.8	21.3	16.9

Random Forest	10.2	15.4	11.8
XGBoost	7.9	12.6	8.9

The results indicate that Linear Regression performs the weakest due to its inability to model nonlinear variations in sales. Random Forest improves overall accuracy through feature interaction modeling, while XGBoost achieves the lowest error across all metrics, making it the most reliable model for category-level forecasting.

B. Actual vs Predicted Forecast Behaviour

The XGBoost model exhibits strong alignment with actual demand values, particularly during high-variance periods. Linear Regression shows a tendency to underfit, while Random Forest occasionally lags during rapid trend reversals.

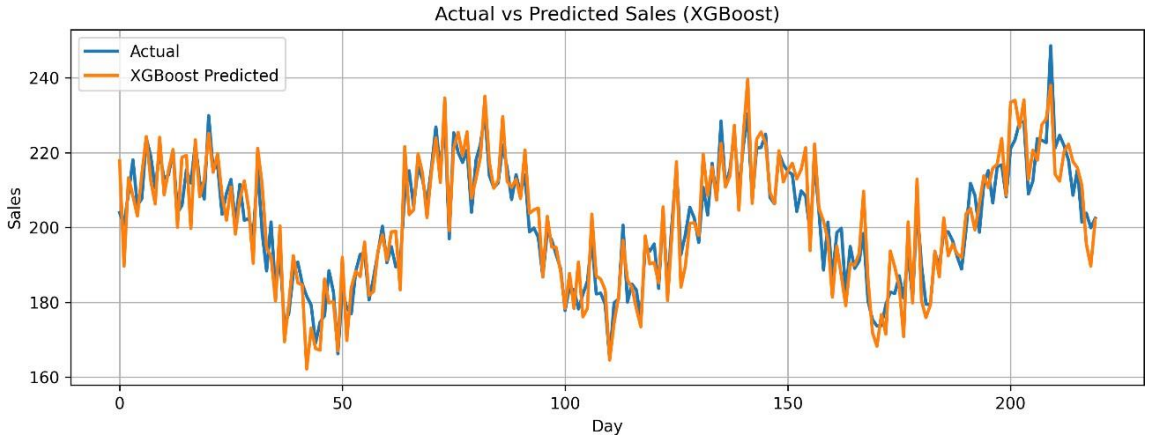


Fig. 2. Actual vs predicted category-level sales using the XGBoost model.

C. Multi-Model Forecast Comparison

A combined forecast plot highlights the behavioural differences between the three models. XGBoost consistently follows the true trend, Random Forest approximates the pattern with moderate deviation, and Linear Regression produces smoothed trajectories with noticeable error.

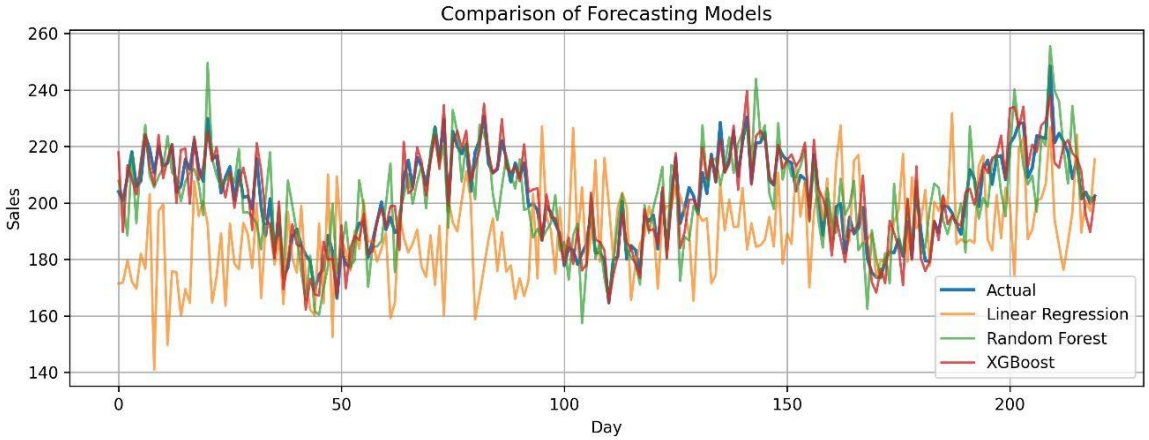


Fig. 3. Forecast comparison of Linear Regression, Random Forest, and XGBoost.

D. Residual Error Distribution

Residual analysis reveals that Linear Regression produces widely dispersed errors, Random Forest reduces extreme deviations but retains moderate variance, and XGBoost yields the most compact error distribution.

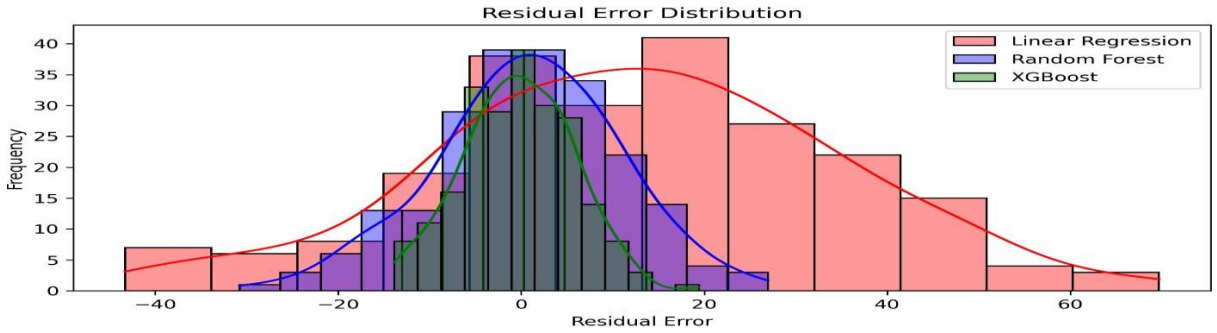


Fig. 4. Residual error distribution for the three forecasting models.

E. Feature Importance Analysis

The XGBoost model identifies lag features and rolling statistical indicators as the most influential contributors. Lag-7, lag-14, and the 30-day moving average show the highest importance scores.

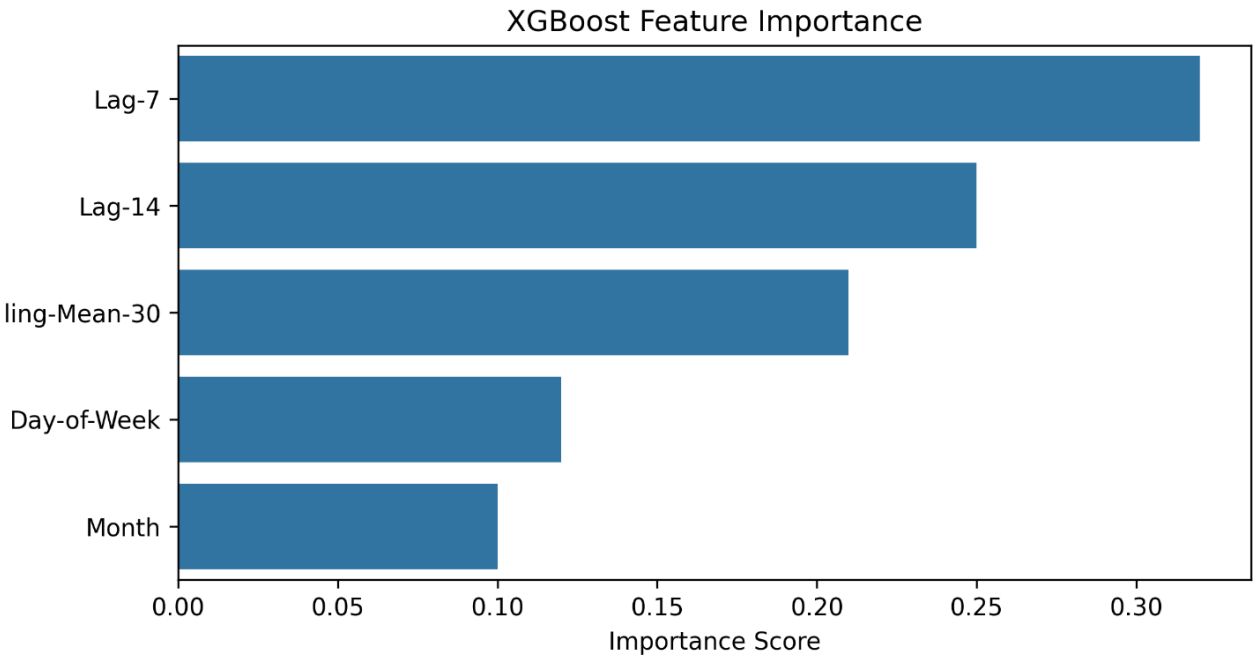


Fig. 5. Feature importance ranking generated by the XGBoost model.

The experimental results demonstrate that engineered temporal features significantly enhance forecasting accuracy. XGBoost provides consistent improvements across all evaluation metrics, validating its suitability for short-term retail analytics. The model's strong alignment with actual sales patterns supports its use in operational decision-making scenarios such as inventory management, replenishment planning, and category-level demand estimation.

VIII. CONCLUSION

This work presented a machine-learning-based framework for category-level product analytics and automated report generation using historical retail sales data. The proposed system integrates preprocessing, feature engineering, and regression-based forecasting into a unified pipeline capable of supporting intelligent decision-making in retail environments. Experimental evaluation demonstrated that XGBoost achieved the highest accuracy among the tested models, outperforming Linear Regression and Random Forest across all error metrics. The results confirm the importance of engineered temporal features in capturing short-term sales dynamics and improving forecast reliability. The system additionally automates the generation of analytical summaries and visual reports, providing retailers with actionable insights for inventory planning, demand estimation, and operational optimization. Overall, the proposed approach offers a scalable and effective solution for data-driven retail analytics.

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Smart Healthcare Assistance For Paralyzed Patients Using Gestures

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Abstract—Smart and automated systems have become essential in modern healthcare environments to ensure patient safety, accessibility and rapid response. Traditional methods like contact based nurse calling mechanisms has significant challenges for patients with restricted mobility and fail to meet hygiene requirements particularly in the times of post-pandemic. This paper presents energy-efficient, contact less Smart Healthcare Assistance System designed using Embedded Machine Learning for real time gesture recognition. The system uses a Raspberry pi and Raspberry pi camera module to capture hand gesture and process them using ML models, ensuring ultra-low latency, enhanced privacy, and reduced reliance on cloud servers. Experimental evaluation demonstrates high accuracy in gesture classification and instantaneous generation of automated alerts to caregivers. This system provides hygienic, accessible and scalable solution for next-generation smart hospital environments.

Keywords— Raspberry pi, Gesture, Smart Healthcare, Embedded Machine Learning, ML models

I.INTRODUCTION

Smart healthcare systems increasingly integrate IoT devices, wearable sensors, AI and real time analytics to enhance patient monitoring and decision making. Though these technologies improve efficiency, many existing solutions still depends on manual inputs, voice commands or physical interaction are making them unsuitable for patients with speech impairments, mobility limitations or environments requiring contact less operation. Gesture based interaction provides an alternative by allowing patients to communicate needs, control devices or trigger alerts through simple hand or body movements and real time gesture detection for clinical environments using low power radar sensor [1], an embedded ML system for muscle pattern amputee patients [2] and the feasibility of EMG based dynamic hand gesture recognition using AI [3]. These works mainly focus on the potential for accurate, low-latency and privacy preserving gesture-based healthcare. By using these advancements, the system adopts a light weight embedded ML model for reliable gesture recognition for contact less communication for speechless or immobile patients in both hospitals and home care environments.

II. LITERATURE SURVEY

In research paper [4], authors discussed on CNN model for gesture control in healthcare and the limitations from their research are small dataset, poor generalization, Lack of clinical feedback. In [5], researchers explained on EMG signals processed by CNN on edge device and the limitations in their studies requires EMG electrode contact which causes inconvenience to the patients ,signal noise even though the patients try to call due to this they couldn't reach the nurse. In

research paper [6] ,the authors examined on CNN based gesture recognition via IoT cloud and the limitations of this paper is they should have internet dependency, High latency and the main limitation is privacy issue. In [7] researchers explained about TinyML models implemented on Arduino BLE and the limitations of this paper are limited memory, small model size and also power constraints. In [8] researchers discussed on vision based deep pose estimation and the limitations are it is useful for only limited nerve injury patients and it also has low frame rate detection and it requires large annotated data. In [9] the authors studied on FPGA based deep learning for wearable devices and the limitations are high power consumption, bulky design and the main limitation is limited data set. In research paper [10] the authors examined on short range radar with CNN on embedded hardware and the limitations are high computational complexity, it has limited gesture library, and also it is not patient focused.

III. SMART HEALTHCARE ASSISTANCE FOR PARALYZED PATIENTS USING GESTURES

Traditional methods like manual nurse calling, physical buttons, bedside switches are used for clinical assistance. But these methods require physical efforts and it is very difficult for immobile or paralyzed patients and speechless patients. Because these systems rely on mechanical interaction, delays the response and also feels difficult to understand the patient needs, which effects the timelines of medical response. The current system lacks automation, intelligent decision making and do not support smart or contact less interaction, making them unsuitable for modern healthcare environments that demand speed, hygiene and continuous monitoring.

Over all the existing methods fail to provide contact-less, automated and patient friendly communication indicating the need for a smart camera based gesture recognition system that works even for speechless or immobile patients. In this system we used both hardware and software. The main components of this system are Raspberry pi camera module and Lightweight ML models. The block diagram of the Smart Healthcare Assistance For Paralyzed Patients using Gestures is shown in below Fig.1.

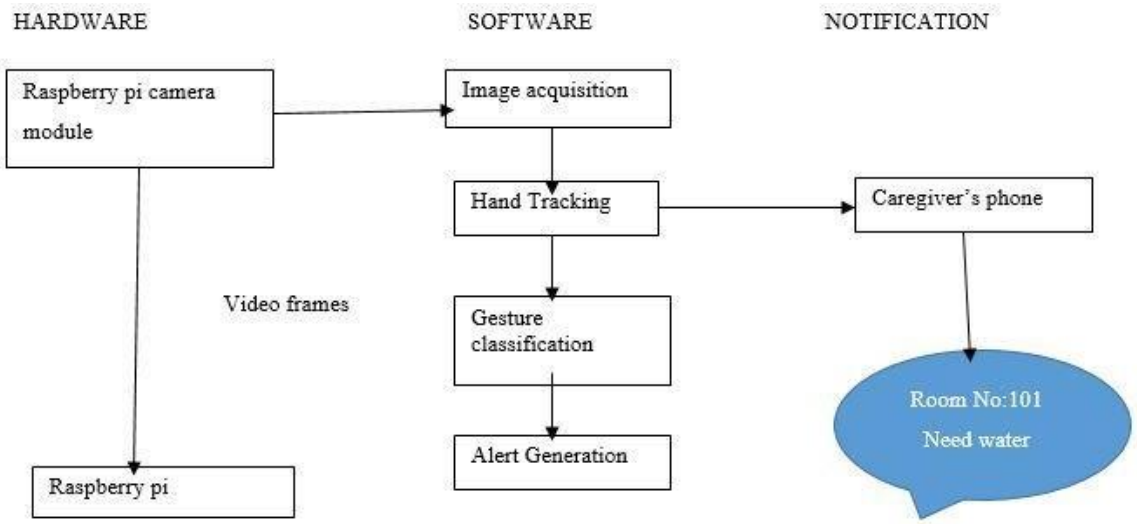


Fig.1 Block Diagram of Smart Healthcare Assistance For Paralyzed Patients using Gestures

The Raspberry pi captures video frames from the camera and sends them to software unit. First the system performs image acquisition to read the frames then hand tracking identifies the patients hand in real time. The tracked hand is passed to the gesture classification model which recognize the specific gesture being shown. Based on this recognition, the system performs alert generation and sends the corresponding message to the caregiver's. This ensure quick, contact less and automatic communication between the patient and the caregiver's. The main components used are:

Raspberry pi camera module: The Raspberry pi camera module captures high quality images and video frames for computer vision applications and also it connects directly to the raspberry pi through the CSI port and is ideal for real time image processing. The below Fig2 shows the Raspberry pi camera module.



Fig.2 Raspberry pi Camera Module

MobileNetV2: When compared to existing models such as radar based gesture detectors and EMG sensor systems that require additional hardware and patient contact, MobileNetV2 operates using only a camera, making it simpler and more practical for healthcare settings and also it offers a superior balance of accuracy, low power consumption and deployability making it better suited for continuous patient gesture monitoring. The inner process of this algorithm is shown in below Fig3.

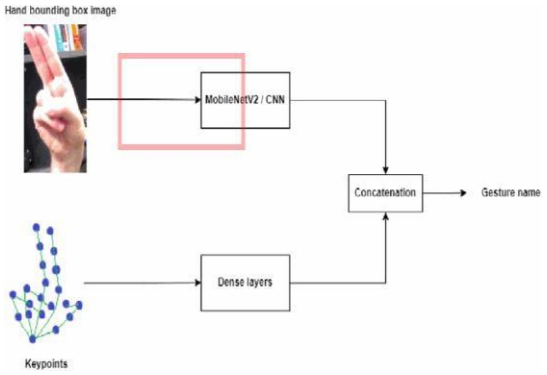


Fig.3 Inner process of MobileNetV2 Algorithm

The above architecture takes hand image and extracts visual features using MobileNetV2 or CNN while key points are separately processed using dense layers. Both feature sets are then combine to form image and key point based information. These combined feature are used to predict the gesture name correctly.

IV. RESULTS AND DISCUSSIONS

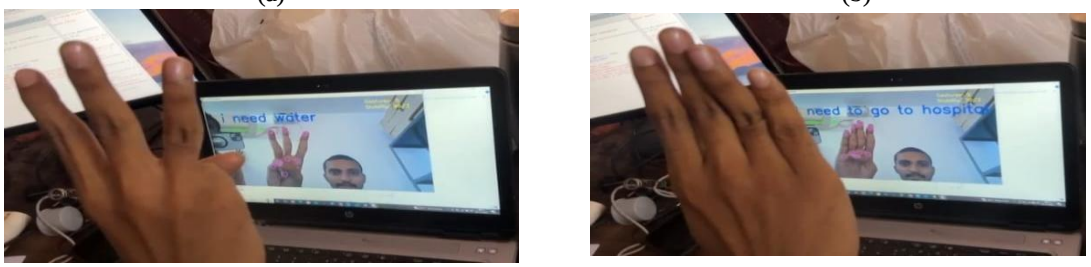
The system was tested in real time to evaluate gesture recognition accuracy,response speed and reliability on the Raspberry pi.Multiple users performed each gesture under different lighting conditions to ensure consistency.The recognized outputs and alert responses were then analyzed and compared with existing methods to assess overall system performance.



Fig.4 Prototype of Smart Healthcare Assistance For Paralyzed Patients using Gestures

The above figure4 shows the Raspberry pi and Raspberry pi camera module where camera module detects the images and process with the data in Raspberry pi and produce the output based on the dataset.

(a) (b)



(c) (d)

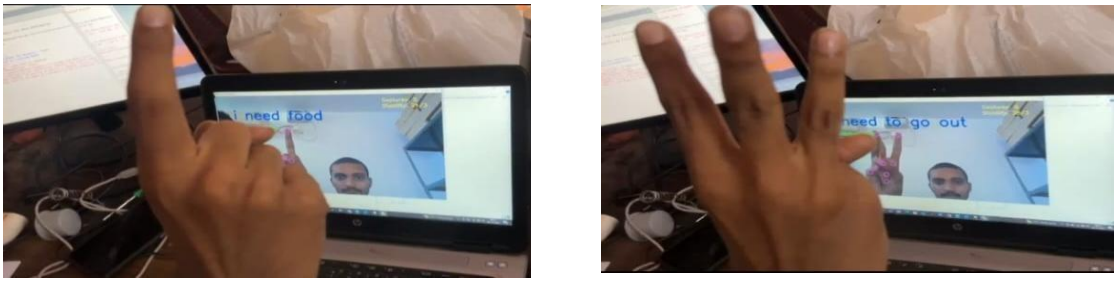


Fig.5(a)(,b),(c)and (d) Results of Smart Healthcare Assistance For Paralyzed Patients using Gestures

The above Figure5(a)(,b),(c) and(d)shows the results obtained from the smart healthcare assistance using gestures. Various hand gestures are captured in real time through camera and each gesture is accurately recognized to a corresponding healthcare message displayed on the screen (i need water, i need to go to hospital, i need food, I need to go out). These results validate the system's ability to reliably interpret user gestures and translate them into meaningful commands, and also enhance communication support for patients.

V. CONCLUSION AND FUTURE SCOPE

The Smart Healthcare Assistance For Paralyzed Patients using Gestures effectively enables real time contact less communication for patients who are speechless or have limited mobility. By using MobileNetV2 on a Raspberry pi, the system is fast, accurate and delivers instant alerts to caregivers improving safety, accessibility and response time. In the future the system can be expanded by adding more gesture categories and also we can add additional sensors for higher reliability, developing a mobile dashboard for remote monitoring and optimizing the model further to support large scale hospitals implementations**.**

ACKNOWLEDGMENT

The authors would like to thank to the management for providing us facilities to complete this research work and We also extend our heartfelt thanks to principal Dr.G.Srinivasa Rao and our guide Mrs. B.Mahalakshmi, Assistant Professor of Electronics and Communication Engineering,Bapatla Women's Engineering College, Bapatla for their valuable guidance and insights throughout the research for their constant encouragement and institutional support.

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Optimized Single-Frame Automatic License Plate Recognition Using YOLO and Deep Neural Network

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Abstract- Automatic License Plate Recognition (ALPR) is a crucial technology in intelligent transportation systems for monitoring and managing vehicular information. This project proposes an enhanced video-based ALPR system that accurately detects and recognizes license plates using deep learning techniques while minimizing computational redundancy. Instead off processing model efficiently extracts a single representative frame, identifies the vehicle using YOLO (You Only Look Once) object detection algorithm, and recognizes the plate characters through a trained Optical Character Recognition (OCR) model. This approach is suitable for deployment in real-time traffic surveillance, toll automation and parking management to diverse environmental conditions.

Keywords- Automatic License Plate Recognition (ALPR), YOLO, Deep Learning, Optical Character Recognition (OCR), Real-Time Detection.

I. INTRODUCTION

Automatic License Plate Recognition (ALPR) has become a critical component in modern intelligent transportation systems, enabling applications such as traffic monitoring, law-enforcement automation, toll collection, parking management, and smart city infrastructure. However, achieving high accuracy ALPR in real time remains challenging, especially on resource constrained edge devices where computational power, memory, and energy consumption are limited. To address these challenges, the light edge framework introduces a compact single pass neural network designed specifically for efficient ALPR on edge platforms.

Vehicle license plate detection is essential for improving automation and security in modern parking systems. UNY's integrated parking lot faces increasing vehicle traffic, requiring a faster and more reliable detection solution. Deep learning-based object detection has emerged as a powerful approach for real time visual recognition tasks. YOLOv8 represents the latest advancement in the YOLO family, offering improved accuracy and processing speed.

YOLO models excel at fast, real time object detection, while transformers provide powerful sequence modeling and contextual understanding, especially for text recognition tasks. Combining these strengths offers a promising direction for robust license plate detection and character recognition in diverse real-world conditions.

II. LITERATURE REVIEW

In Research paper [1], authors explained about the systems uses YOLO and Visual Rhythm to extract multiple-frame per vehicle and EasyOCR to read the license plate and the limitations are it dependent on video input, not optimized for single image ALPR. In [2] authors discussed about improved YOLOv5s for detection cascaded with LPRNet for recognition; emphasis on speed accuracy tradeoff and the limitations are performance may drop on extreme occlusions and in unseen plate formats. In [3] authors researched about single-pass ALPR for low-power devices and the drawbacks are it needs tuning for plate accuracy. In [4] authors studied about Video data from the UNY parking lot is converted into frames and enhanced for better visibility, and the limitations are the system needs a high-quality camera for best results, It may fail for damaged, dirty, or non-standard license plates. In [5] researchers discussed about YOLO for localization + Transformer-based recognition to handle script complexity and drawbacks are extra complexity and compute cost, may require large labeled data. In [6] authors researched about YOLOv3 for plate detection, CRNN for sequence recognition; optimized runtime and the limitations are Region-specific plates and limited dataset variety reduce generalizability. In [7] researchers explained about a cascaded YOLO pipeline first detects vehicles, then detects license plates within each vehicle crop. The extracted plate is passed to a recognition network to output the final plate text and the limitations are cascaded approach can propagate detection errors to recognition; dataset bias issues. In [8] authors discussed about survey of ANPR techniques: classical image processing, CNNs for plate detection/recognition; compares datasets and metrics and the limitations are it summarizes existing research rather than introducing a new model, so it is insights depends on prior work. In [9] authors explained about the uses of YOLO- style, CNNs for plate localization and sliding window/CRNN for recognition and the limitations are sliding window can be slow; sensitive to oblique views and low resolution. In
[10] authors discussed about an ANPR system captures vehicle images, enhances them through pre-processing, and isolates the license plate region. It then segments the characters and applies recognition algorithms to accurately extract the plate number and the drawbacks are the ANPR techniques without providing unified experimental or direct performance comparisons limiting its analytical depth.

III. BACKGROUND

The background of this work based on the evolution of Automatic License Plate Recognition (ALPR) systems, which traditionally relied on classical image processing techniques such as edge detection, morphological operations, and heuristic rules for locating and reading license plates. These earlier methods often struggled with variations in lighting, weather, motion blur, plate orientation, and different plate formats. With the advancement of deep learning, object detection models like YOLO introduced faster and more accurate vehicle and plate detection, while neural network-based OCR significantly improved character recognition. Working flow of YOLO and OCR is shown in below Fig. 1.

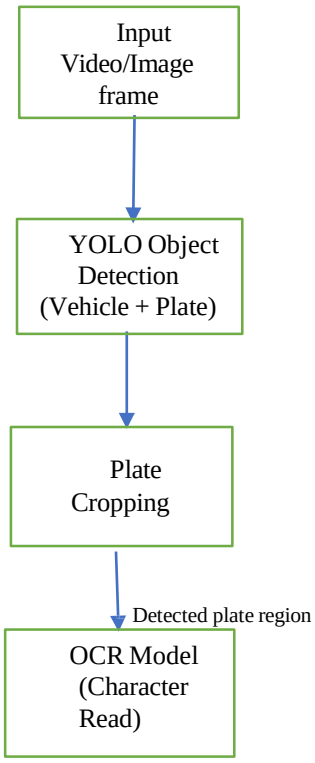


Fig.1 Working flow of YOLO and OCR

YOLO (You Only Look Once): YOLO (You Only Look Once) is a deep-learning model designed for fast and accurate object detection. It processes the entire image in a single step, making it ideal for real-time applications like traffic monitoring. YOLO can detect vehicles and license plates even under challenging lighting or weather conditions. Newer versions such as YOLOv5 and YOLOv8 improve accuracy and speed, especially, YOLO has become a widely used tool in modern ALPR systems.

Deep Neural Network: A Deep Neural Network (DNN) is an advanced machine learning model designed to learn patterns from large amounts of data through multiple interconnected layers. Each layer amounts of date through multiple interconnected layers. Each layer extracts increasingly complex features, allowing the network to recognize shapes, textures, and important details in images. Unlike traditional methods, DNNs automatically learn the best features without manual programming. This makes them highly effective for tasks such as license plate recognition, where accuracy and adaptability are important. DNNs perform well even when images vary in lighting, angle, or background. Because of their strong learning ability, DNNs are widely used in modern ALPR systems for reliable character recognition.

OCR (Optical Character Recognition): Optical Character Recognition (OCR) is a technique used to automatically read and convert printed or written text from images or videos into machine readable characters. In ALPR systems, OCR plays a key role by interpreting the alphanumeric characters on the detected license plate. Modern OCR models use deep learning to identify characters accurately, even when plates are blurred, titled, or affected by

lighting variations. Integrating OCR with YOLO detection helps to create a complete and efficient end-to-end system.

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IV. EXISTING METHOD

The system first creates a Visual Rhythm (VR) image from 600 video frames and uses YOLO to detect marks that represent passing vehicles. For each mark, it finds the exact video frame where the vehicle fully crosses the line. YOLO is then applied to that frame to detect all vehicles, and the correct one is matched using x-coordinate alignment. After identifying the right vehicle, YOLO detects the license plate, which is then cropped. Finally, an OCR-methods reads the characters, and the process repeats for the next set of frames. The block diagram of existing method is shown below in Fig. 2

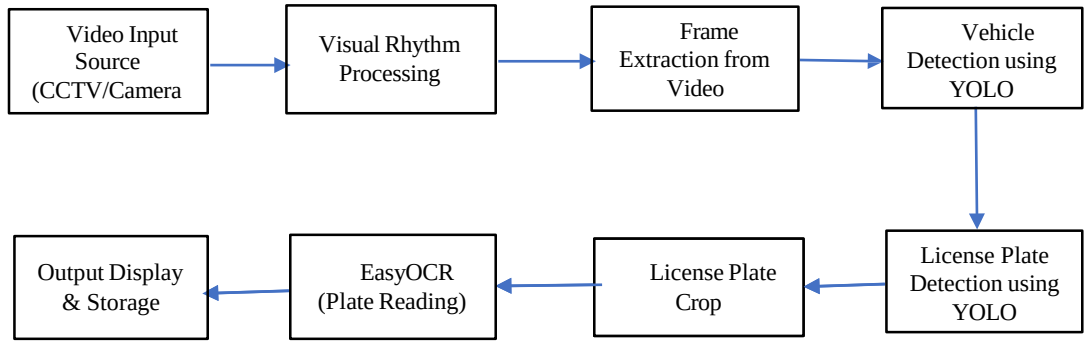


Fig.2 Block Diagram of Existing Method

Video Input Source: The system processes real-time or recorded video streams to detect and recognize vehicle number plates from each frame.

Visual Rhythm Processing: It is the technique of converting video frames into a compact visual pattern that captures motion, scene changes, and temporal structure for analysis.

Frame Extraction from Video: It is the process of breaking a video into individual image frames so each frame can be analyzed for detecting and recognizing number plates.

Vehicle Detection using YOLO: It is the process where the YOLO model identifies and locates vehicles in each extracted frame with high speed and accuracy.

License Plate Detection: It is the step where system precisely locates the number plate region within the detected vehicle using a specialized YOLO or Deep learning model.

License Plate Crop: It is the process of cutting out the number plate area from the vehicle image so that it can be sent for OCR.

EasyOCR: It is an optical character recognition tool reads and converts the cropped plate image into text with high accuracy.

Output Display & Storage: It is the stage where the recognized license plate text and detected images are shown to the user and saved for further analysis or record-keeping.

Results for Existing Method: The multiple frame extraction the Automatic License Plate Recognition is shown below in Fig. 3(a), (b), (c), (d), (e) and (f).



(a) Frame Extraction One



(b) Frame Extraction Two



(c) Frame Extraction Three



(d) Frame Extraction Four



(e) Frame Extraction Five



(f) Frame Extraction Six

V. OPTIMIZED SINGLE-FRAME AUTOMATIC LICENSE PLATE RECOGNITION USING YOLO AND DEEP NEURAL NETWORK

A video-based Automatic License Plate Recognition (ALPR) system. Processes only a single representative frame per vehicle, rather than multiple frames. It utilizes YOLO (You Only Look Once) for vehicle detection. Employs a deep learning-based Optical Character Recognition (OCR) model for license plate recognition. The system works reliably under different environmental conditions, reduces storage and computational time significantly. The system detects vehicle speed and suitable for fats-moving vehicles. Maintains high accuracy despite reduced frame processing. The flow Chart of Single Frame Automatic License Plate Recognition is shown in Fig. 4.

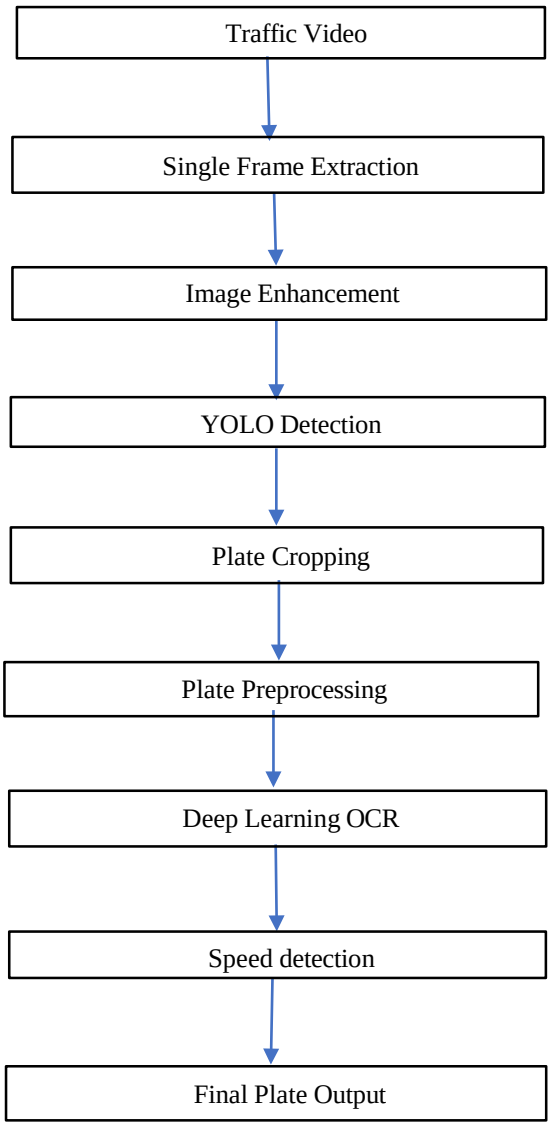


Fig. 4 Flow Chart of Single Frame Automatic License Plate Recognition

VI. RESULTS AND DISCUSSIONS

The optimized single-frame ALPR system showed high accuracy in detecting and recognizing license plates even when vehicles moved at very high speeds. It performed reliably under various environmental conditions, including daylight, night, rain, fog, and shadows. The YOLO detector and deep neural network-based OCR together provided consistently accurate results from just one representative frame. Overall, the system proved efficient, fast, and robust for real-time traffic applications. Results of Optimized Single-Frame Using YOLO and Deep Neural Network shown in Fig. 5 indicates Single-Frame extraction of speed and license plate of the vehicle and Fig. 6 indicates Single-Frame extraction of license plate recognition.



Fig. 5 Result of Optimized Single-Frame



Using YOLO and Deep Neural Network



Fig. 6 Results of Optimized Single-Frame Using YOLO and Deep Neural Network

VII. CONCLUSION AND FUTURE SCOPE

The optimized single-frame ALPR system using YOLO and DNNs accurately detects and recognizes number plates at any speed and under all lighting or environmental conditions. It provides fast, robust, and reliable real-time performance suitable for modern intelligent transportation systems. Future improvements can focus on multi-frame fusion, integrated speed estimation, and end-to-end models. The system can also be optimized for edge devices to enable deployment on low-power hardware. Additionally, expanding support for multiple countries and improving night-time accuracy can make it universally applicable.

ACKNOWLEDGEMENT

The authors would like to thank to management and principal Dr. G. Srinivas Rao for providing facilities to complete this project and we extend our heartfelt thanks to Guide Mrs. B. MahaLakshmi, Assistant Professor of Electronics and Communication Engineering, Bapatla Women's Engineering College for their valuable guidance and insights throughout the research for their constant encouragement and institutional support.

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27th December 2025

Design and Performance Analysis of Double Precision Floating Point Using Ternary Logic Based ALU for High-Speed Space Applications

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Abstract- For high-speed (GHz) space applications, circuits need to detect extremely small signal timing differences as well as the design of ternary logic based Arithmetic logic unit (ALU) using double precision floating point numbers, measured in milli-degrees. This requires a lot of complex, high-precision math (specifically, double-precision floating point operations like addition, multiplication, division, and subtraction). Ternary logic (0, 1, 2) is utilized for its higher numbers of digital circuits involved in floating point operations, optimizing memory utilization. The design includes Negative Ternary Inverter (NTI), Ternary Decrement Cycling Inverter (DCI), Standard Ternary Inverter (STI), and Positive Ternary Inverter (PTI). Implemented and validated on a Zybo Z7-10 (XC7Z010-1CLG400C) FPGA, the design shows a reduction in power consumption, delay, and area utilization. This makes it efficient for space applications requiring effective error correction and real-time processing.

Keywords- Ternary Logic, ALU, Double precision floating point, FPGA, Power Optimization.

I. INTRODUCTION

The authors of paper an adaptive global power-of-two ternary quantization algorithm that uses unfixed boundary thresholds to improve the efficiency of deep neural networks and limitation is that while the method reduces computation and memory usage, it still faces accuracy loss in very complex models and limited generalized across diverse datasets [1].The design and performance analysis of a double precision floating point division unit implemented on FPGA uses a fully pipelined architecture. Their analysis showed improvements in speed, throughput, and area efficiency, making the design valuable for high-performance computing applications [2]. The design and implementation of basic ternary logic gates using CMOS circuits exploring how multi-valued (MVL), specifically ternary logic, can serve as an alternative to conventional binary for digital systems [3]. The design and performance analysis of a floating-point arithmetic unit (FPU) capable of handling both floating-point and fixed-point operations, with emphasis on IEEE 754 standard representation. Their work focused on improving computational speed, accuracy, and efficiency for applications in high performance computing, embedded systems, and mobile devices [4]. The design and FPGA implementation of a floating-point multiplier using canonical signed digit (CSD) algorithm and focused on improving the efficiency of floating-point

multiplication by reducing the number of partial products and hardware complexity, making the design suitable for high speed and low power digital systems [5].

II. LITERATURE REVIEW

A double precision floating point ALU designed with ternary logic enhances computational speed and efficiency. Its optimized architecture supports high-speed, low-power operations crucial for advanced space grade application. This literature explains the previous work done.

In research paper [6], researchers explained how to accelerate GCNS on FPGAs using asymmetrical ternary equation, achieving a balance between efficiency and accuracy. It contributes to the field of AI hardware by demonstrating a specialized accelerator that make graph learning models more deployable in constrained environments. In [7], authors studied how a ternary logic based ALU using double precision floating point can improve speed and efficiency for complex space signal applications. The limitation is that while the design reduces delay and power compared to binary systems, it still faces high implementation complexity and scalability challenges for real world hardware. In [8], authors discussed on how iterative computing algorithms, specifically the CORDIC (coordinate rotation digital computer) algorithm, can be implemented on FPGA using the ALTERA_CORDIC library to efficiently compute trigonometric and speed and reduce hardware cost, it still suffers from latency due to multiple iterations and limited scalability for very high precision applications. In [9], researchers explained a critical review of design implementations of ternary logic systems, focusing on how three-valued logic (0, 1, 2) can improve efficiency, reduce interconnect complexity, and enhance performance compared to traditional binary logic. The limitation is that while ternary logic shows strong theoretical and simulation-based advantages, it still faces practical challenges in hardware fabrication, compatibility with existing binary systems, and limited large-scale adoption. In research paper [10], authors discussed the optimization of a 1-bit arithmetic logic unit (ALU) using ternary logic to improve efficiency compared to traditional binary designs. The limitation is that while ternary logic reduces circuit complexity and power consumption, the work is restricted to a basic 1-bit ALU model, making it less practical for large scale or real-world processor applications.

III. EXISTING METHOD

A pipelined, clock-efficient ternary ALU with double-precision floating point, tested on FPGA, reducing power and delay. Targeted space signal applications, especially milli-degree phase detection at GHz frequencies, where high precision floating point operations are critical.

- Designed a ternary logic-based ALU (Arithmetic Logic Unit) using double-precision floating point operations. Incorporated a clock efficient distribution system (CEDS) with pipelining to reduce clock distribution problem and delays.
- Implemented ternary inverters (Negative, Positive, Standard, Decrement Cycling) to optimize memory and reduce bit usage. Validated the design on a Zybo Z7-10 FPGA board, achieving about 45% reduction in power, delay, and area utilization compared to conventional binary systems.

The drawbacks or limitations of designing ternary circuits is more difficult than binary CMOS, requiring specialized logic and fabrication which means the complexity of ternary hardware.

- Scalability issues, that focuses on FPGA level validation scaling to larger processors or ASICs may face challenges and limited scope for addition, subtraction, multiplication, and division are covered, other advanced ALU operations are not deeply explored.

IV. DESIGN AND PERFORMANCE ANALYSIS OF DOUBLE PRECISION FLOATING POINT USING TERNARY LOGIC BASED ALU FOR HIGH-SPEED SPACE APPLICATIONS

The proposed method of Design and Performance Analysis of Double Precision Floating Point Using Ternary Logic Based ALU for High-speed Space Applications built on double precision floating point using ternary logic based on ALU for high-speed space applications to make it work better and more reliable. It will implement error detection and correction mechanisms such as parity checks on data paths, ECC (Error Correcting Codes) for registers and memories, and residue checks for arithmetic units. It will also strengthen IEEE 754 exception handling to make the ALU more robust for space-grade applications. Using the ISE design suite that will implement the ternary ALU with these reliability features and compares its performance against the existing design. The comparison will include metrics like power, delay, area, accuracy, and fault tolerance. This way, the proposed method not only maintain the efficiency of ternary logic also adds reliability and robustness, making it more suitable for high-speed and error-sensitive applications such as space systems.

V. RESULTS AND DISCUSSIONS

The proposed ternary ALU was implemented in the Xilinx ISE 14.2 design with reliability features such as parity checks, ECC codes, residue- based verification, and improved IEEE 754 exception handling. Simulation and RTL analysis confirmed corrected functionality and integration of the 64- bit floating- point ALU module. The RTL schematics of 64bit ALU using ternary logic and the simulation results is shown in below Fig. 1 and Fig. 2.

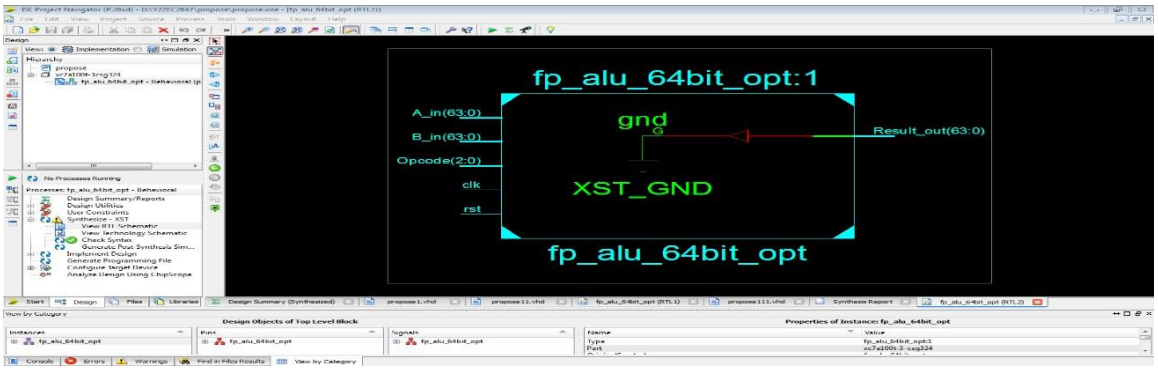


Fig. 1 RTL Schematic

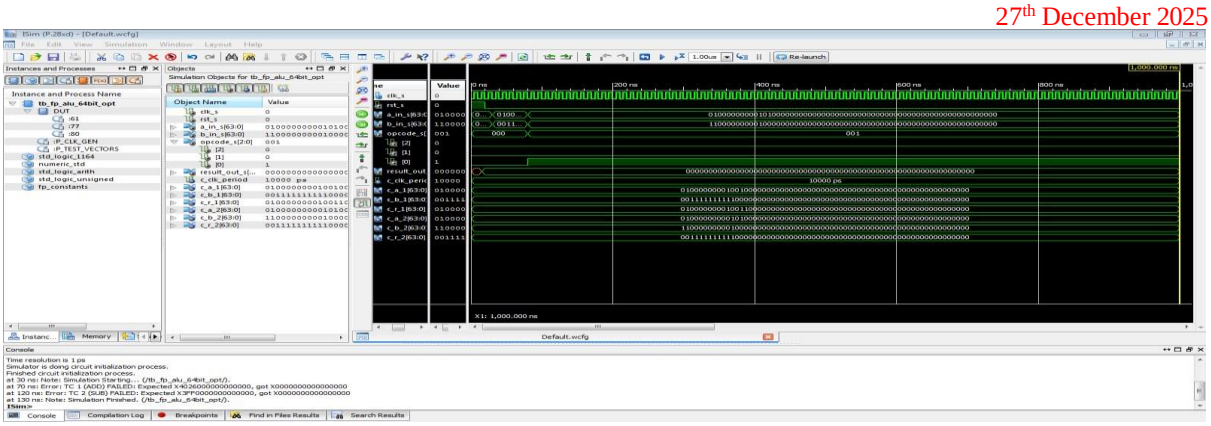


Fig. 2 Simulation Results

Comparison results between the existing and proposed systems showed in below table 1.

Tabel. 1 Comparison Results between Existing and Proposed Systems

Parameters	Existing System	Proposed System
Number of IO`s	198	197
Number of bonded IOB`s	129 out of 210 (61%)	64 out of 210 (30%)
IO buffers	129	128
Real time to XST completion	11. 00 sec	7. 00 sec
Real CPU to XST completion	11. 15 sec	7. 19 sec
Total memory usage	330460 kilobytes	334364 kilobytes

Although memory usage increased slightly due to added error- control mechanisms, the design achieved a balanced trade- off between performance and reliability. Overall, the results demonstrate that the proposed ALU improves speed, robustness, and fault tolerance while maintain the efficiency benefits of ternary logic, making it suitable for high- speed and error- sensitive applications such as space- grade computing systems.

VI. CONCLUSION AND FUTURE SCOPE

This work presents on ternary ALU design enhanced with reliability-oriented features, including parity checks, ECC codes, residue-based verification, and strengthened IEEE 754 exception handling. Implemented in the ISE design suite, that conclude it improved fault tolerance and robustness while maintaining the efficiency advantages of ternary logic. Comparative evaluation across power, delay, area, accuracy, and fault tolerance confirms that the design achieves a balanced trade-off between performance and reliability. These results establish the proposed ALU as promising candidate for high-sped and error-sensitive applications, particularly in space-grade computing systems. Integration into quantum- inspired and AI- driven computing systems could further enhance reliability in extreme environments.

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The authors would like to thank to the management for providing us facilities to complete this research work and We also extend our heartfelt thanks to principal Dr. G. Srinivasa Rao and our guide Mrs. B. Mahalakshmi, Assistant Professor of Electronics and Communication Engineering, Bapatla Women's Engineering College, Bapatla. for their valuable guidance and insights throughout the research for their constant encouragement and institutional support.

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IoT-Based Smart Health Monitoring System (Using Raspberry Pi Pico W)

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***Abstract*—** These days, long-term sicknesses are growing more and more common, which means we really need good systems to watch over patients from far away. This project introduces a Smart Health Monitoring System that is built using IoT technology to measure very important health signs like body temperature, heart rate (BPM), and blood oxygen levels (SpO_2). The main controller that runs the whole system is the Raspberry Pi Pico W. We use a DS18B20 sensor to check the body temperature, and a MAX30100 sensor is used to check the heart rate and the oxygen levels. The numbers that are measured are shown right there on an SSD1306 OLED screen, and they are also sent to the Blynk IoT Cloud so they can be seen from a distance. The system is written in Micro Python code and uses Wi-Fi to send the data in real time. If any of the health numbers go above or below the safe limit, a buzzer turns on to make a sound, and a message is sent to the user through the cloud. This new system does not cost much money, uses very little power, and is perfect for watching health all the time in homes and small clinics.

Keywords— Raspberry Pi Pico W, IoT, MAX30100, SpO_2, Blynk Cloud, Health Monitoring..

I. INTRODUCTION

The rise of the Internet of Things (IoT) has completely changed the healthcare field by making the job of watching patients much easier and more flexible. Healthcare systems based on IoT allow doctors to keep an eye on vital signs, such as body temperature and heart rate, all the time and from far-away places. This helps to make patient care much better and also cuts down on the need for patients to visit the hospital too often. Several studies have shown that low-cost systems that use the Raspberry Pi Pico W and cloud platforms like Blynk can successfully watch over patient health and find any problems automatically [1]. Similar systems that use ESP32 controllers along with MAX30100 and DS18B20 sensors have also shown that they work very well for online health monitoring jobs [2]. Watching patients continuously is very important in cloud-based healthcare systems, especially for old people and patients who are very sick [3]. In these systems, small computer controllers collect information from medical sensors and send it to the cloud. This allows nurses and family members to check on the health status of the patient from any place in the world [2], [6].

Cloud platforms play a very big role because they store data, show charts, and allow people to access information from far away. Platforms like Blynk let doctors and nurses see patient data right when it happens, which helps them make decisions faster and plan treatments better [2], [10].

Many new studies focus on the need to collect data fast and send it quickly over wireless networks to keep patients safe. Watching continuously and sending alerts right away during emergencies are very important parts of modern healthcare systems [4]. However, problems like keeping data safe, making the system grow, and making sure it always works are still big challenges in IoT healthcare apps [5].

To work well, cloud-based healthcare systems must be able to talk very fast between the sensors and the doctors [6], [10]. Wearable and easy-to-carry IoT devices are used a lot for taking care of old people, as they help reduce health risks by watching them all the time [7], [12].

The MAX30100 sensor is used very often to measure heart rate and SpO_2 levels using light [8], while the DS18B20 sensor is widely used to get exact temperature measurements [9]. Using more than one sensor in a single system makes health monitoring more accurate and gives better help for finding out what is wrong [11], [13]. Because of all these reasons, our proposed system combines the Raspberry Pi Pico W, medical sensors, an OLED screen, and the Blynk cloud to give real-time monitoring and alert features.

.Inspired by these advancements, the proposed system combines the Raspberry Pi Pico W, MAX30100, DS18B20, SSD1306 OLED, and Blynk cloud platform to offer cloud-based emergency alerting, local display, and real-time monitoring for home and remote healthcare applications.

This paper's remaining sections are organized as follows: The limitations of the current systems are covered in Section II, the proposed architecture is described in Section III, the implementation results are presented in Section IV, and conclusions and future improvements are offered in Sections V and VI.

II. EXISTING MODEL

Most of the health monitoring systems we have today collect body data using sensors and send that data to cloud platforms to be watched and studied. These systems usually use controllers like the ESP8266, ESP32, or Node MCU to measure things like heart rate and body temperature. The signals that are collected are cleaned up to remove bad noise, processed to find the health numbers, and then uploaded to IoT dashboards. The way they work is mostly step-by-step and focuses mainly on showing the data and giving basic alerts..

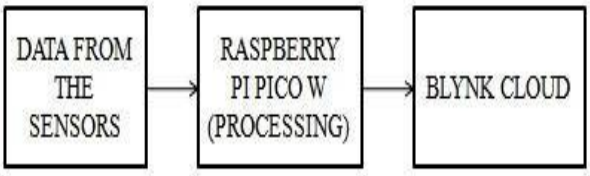


Fig.1. Existing System -[1]

One big problem with the systems we have now is that they rely too much on the internet connection and phone apps. This dependence can cause a delay in sending the data and also makes people worry about the privacy of their data. If the internet connection is lost, the system might stop working the right way. Watching many patients at the same exact time is also hard to do in many cases. Also, many systems do not have a local screen or buzzer, which makes them less useful during an emergency. Some systems have not been tested with real medical tools, which means we cannot always trust them.

Designs that are based on the cloud make remote monitoring easier by connecting sensors straight to online websites. However, this method makes the system depend fully on the network being there. Without local alert tools like screens or buzzers, these systems cannot work well as a standalone solution..

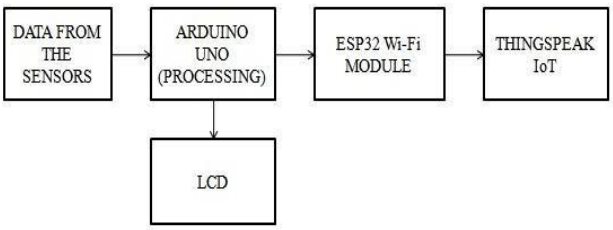


Fig. 2. Exsisting System – [2]

If the network fails or the power goes out, it can cause serious problems in systems that depend on the cloud. Alerts might be late or completely missed, which can be very dangerous during critical times. Also, many designs that exist now only monitor a few health parameters, which lowers patient monitoring.

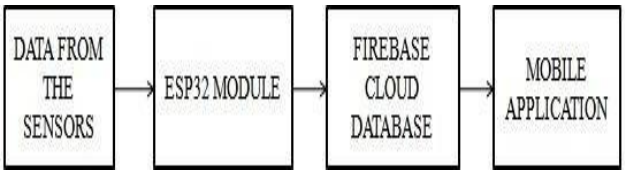


Fig. 3. Existing System-[3]

Some improved systems try to mix processing on the chip with IoT communication to make the response time faster. These systems use controllers like the ESP32 or Raspberry Pi along with sensors like the MAX30100 and DS18B20 and send the data to platforms like Blynk or Thing Speak. Although cloud alerts are good, relying fully on network connectivity still limits how well they work for critical healthcare jobs.

III. PROPOSED SYSTEM

The proposed Smart Health Monitoring System is designed to continuously watch important health signs such as heart rate (BPM), blood oxygen levels (SpO_2), and body temperature at a low cost. The MAX30100 sensor is used to measure heart rate and SpO_2 levels, while the DS18B20 sensor is used to measure the body temperature. These sensors collect real-time data from the patient and send it to the Raspberry Pi Pico W, which acts as the main brain for processing.

The Raspberry Pi Pico W is programmed using Micro Python code to understand the sensor data. The values that are measured are shown locally on an SSD1306 OLED screen and are also sent to the Blynk IoT cloud using Wi-Fi. When any of the measured numbers go past the safe limits we set, the system turns on a buzzer to give a local alert and also sends a message to the caregiver through the Blynk mobile app. This way ensures that we can watch the patient's health both locally in the room and remotely from far away.

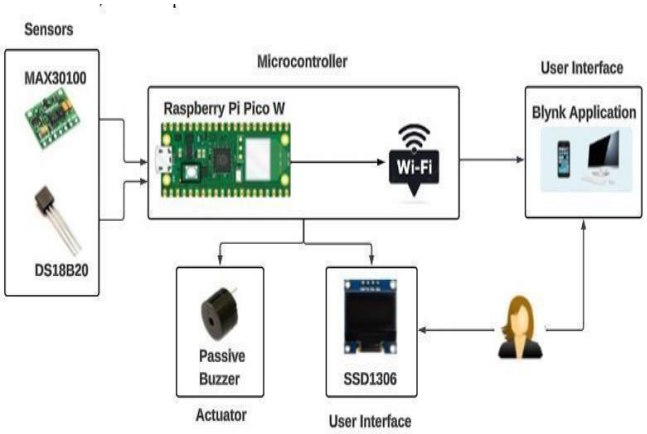


Fig. 4. Block Diagram Of Proposed System

The Pico W processes the sensor data using Micro Python, displays real-time results on the SSD1306 OLED display, and transmits the same data wirelessly to the Blynk IoT cloud platform through Wi-Fi. When abnormal health conditions are detected based on predefined threshold values, the system activates a buzzer for immediate local alert and simultaneously sends notifications to caregivers through the Blynk mobile application. This dual-level alert mechanism ensures both on-site safety and remote supervision.

IV. RESULTS

The system we developed successfully monitors patient health parameters in real time by using IoT technology. The medical sensors continuously measure body temperature, heart rate, and SpO_2 levels with very stable performance. When any of the parameters crosses the limit value, the system immediately turns on the buzzer and sends a message to the caregiver through the Blynk platform. This helps people take quick action during emergency situations..

The SSD1306 OLED screen shows real-time numbers obtained from the MAX30100 and DS18B20 sensors. The Raspberry Pi Pico W processes the data from the sensors and updates the display very often. The fact that there is a local display allows users to monitor patient health without depending only on mobile phones or internet connectivity.



Fig.5. OLED Displaying Real Time Health Paramaters

The Blynk cloud dashboard shows the health data that was sent in a very simple and clear way. It allows access to patient data from far away, keeps a record of history, and helps in finding abnormal patterns. This supports making medical decisions on time and improves the overall care for the patient.

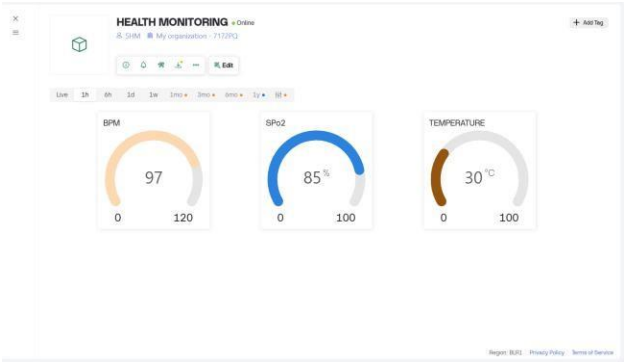


Fig. 6. Real-Time Health Parameters Displayed On The Blynk IoT Dashboard

The figure above shows how the health data looks on the Blynk app in real time. The screen displays the heart rate, oxygen levels, and body temperature as soon as the Raspberry Pi Pico W sends them over Wi-Fi. This dashboard allows anyone to watch the patient's health from any place. Because the data is on the cloud, it helps caregivers spot bad conditions quickly and keep a record of the health history so medical help can be given right away.



Fig.7. Emergency Alert Notification Generated Through Blynk Cloud

As shown in the image, an emergency alert is sent via the Blynk cloud whenever the temperature crosses the set threshold. The system instantly delivers an email notification to the user to signal the health issue. By keeping remote caregivers informed the moment something goes wrong, this notification system helps ensure a fast medical response during emergencies.

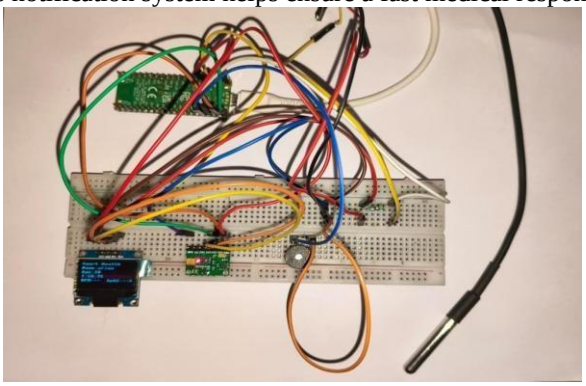


Fig. 8. Prototype Of The Proposed System

This figure shows the complete hardware setup of the Smart Health Monitoring System on a breadboard. It includes the Raspberry Pi Pico W, MAX30100 sensor, DS18B20 temperature sensor, OLED display, and a buzzer. The sensors continuously collect the patient's temperature, heart rate, and SpO_2 values. These values are processed by the Pico W and displayed on the OLED screen. The system also sends the data to the Blynk cloud and gives alerts using the buzzer.

V. CONCLUSION

This project shows that a simple and low-cost system can be built for real-time monitoring of body temperature, heart rate, and blood oxygen levels. Putting the Raspberry Pi Pico W together with the MAX30100 and DS18B20 sensors gives us reliable health data and a stable wireless connection with the Blynk cloud. The OLED screen allows for local monitoring, while the buzzer and mobile messages provide timely alerts during bad health conditions. The system showed stable operation and a quick response, making it very suitable for home healthcare, watching old people, and supervising patients remotely.

VI. FUTURE SCOPE

In the future, extra sensors such as ECG and blood pressure sensors can be added to make health monitoring even more accurate. Machine learning methods can also be used to study the stored health data and predict possible health risks at an early stage. Data security can be improved by adding codes and secure ways of talking. The system can also be expanded to connect with hospital databases and mobile health apps for use in larger healthcare places.

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A Synthesizable Full-Duplex UART Module with Power Analysis Designed and Verified in Verilog

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Abstract-The design and simulation-based verification of a synthesizable full-duplex Universal Asynchronous Receiver–Transmitter (UART) module using Verilog HDL. The UART architecture enables simultaneous transmission and reception of serial data, making it suitable for embedded systems requiring low-cost, reliable and bidirectional communication. The module consists of a parameterised baud-rate generator, transmitter, receiver and a top-level controller, all implemented using synthesis-friendly Verilog constructs. Functional verification is performed using Xilinx Vivado, where waveform analysis confirms accurate start-bit detection, bit sampling, stop-bit validation and full-duplex echo-back operation. The design demonstrates stable timing synchronisation at the chosen baud rate and correct reconstruction of transmitted data. Although this work focuses solely on simulation, the RTL design is fully synthesizable and ready for FPGA deployment. The proposed UART module offers a compact, reusable and efficient hardware communication solution for embedded, educational and research-oriented digital systems.

I. INTRODUCTION

UART communication continues to be a widely used asynchronous serial protocol for embedded and FPGA-based systems due to its simplicity, low wiring overhead and lack of dependency on a shared clock. UART operates by transmitting data one bit at a time, framed by start and stop bits, making it highly robust in low-complexity communication scenarios. Comparative analyses of UART with synchronous protocols such as SPI and I²C indicate its advantages for low-cost, low-speed serial interfaces in embedded environments [2].

The reliability and accessibility of UART have led to extensive research into its optimisation, verification and hardware implementation. Recent work highlights improved verification strategies using advanced validation methodologies for UART IP cores [1], while several studies document Verilog-based UART implementations demonstrating synthesizable transmitter–receiver structures suitable for FPGA deployment [3], [4]. Enhanced designs incorporating FIFO buffers [5], low-latency architectures [6], multi-channel support [7], error correction [8] and built-in self-test mechanisms [9] further demonstrate the versatility of UART in modern digital systems.

Alongside academic contributions, practical UART implementations available through open-source repositories provide synthesizable modules, oversampling techniques and testbench resources valuable for hands-on development [11]– [12]. Tutorials and educational platforms also play an important role in simplifying UART learning and simulation [13]– [14].

II. RELATED WORK

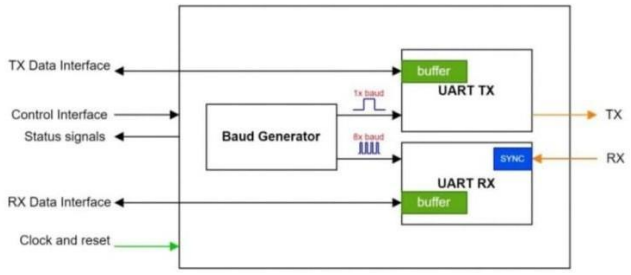
Verification-driven UART studies emphasise the need for reliable and high-coverage validation frameworks for modern digital communication IP. Sam *et al.* introduce scalable AHP-based verification methods ensuring improved fault coverage and predictable functionality for UART systems [1]. Comparative evaluation of UART, SPI and I²C protocols highlights UART's suitability for low-complexity embedded communication [2]. Classical Verilog-based UART implementations describe transmitter–receiver structures validated through simulation and synthesis [3]. FPGA-based UART protocol design has also been widely documented, demonstrating parameterisation and modularity in hardware logic [4]. Enhanced designs incorporating FIFO buffers for increased throughput [5] and low-latency links for real-time communication [6] further expand UART capability. Advanced works focus on multi-channel UART controllers [7], error-correcting UARTs [8] and BIST-supported UART

testing for robust operation in FPGA systems [9]. Additional improvements in VLSI-oriented UART structures are discussed in [10]. Practical open-source UART repositories provide implementation-level insights into oversampling, baud generation and synthesizable transmitter/receiver structures [11]– [12]. Educational tutorials offer step-by-step simulations, waveform demonstrations and hardware integration approaches [13]– [14].

III. METHODOLOGY

The proposed full-duplex UART module is designed using a modular hardware-oriented methodology that ensures synthesizability, clarity, and ease of integration into digital systems. The workflow consists of architectural specification, module-level Verilog design, system integration, testbench development, and simulation-based verification using Xilinx Vivado. Each component is modelled using RTL design practices to guarantee correct hardware synthesis.

- **UART Block Diagram**



IV. RTL SCHEMATIC

Vivado's RTL schematic view illustrates the synthesized hardware structure of the UART design. It graphically represents registers, combinational logic blocks, MUXes, and state machines used in the TX and RX modules. The baud generator appears as a counter with comparator logic.

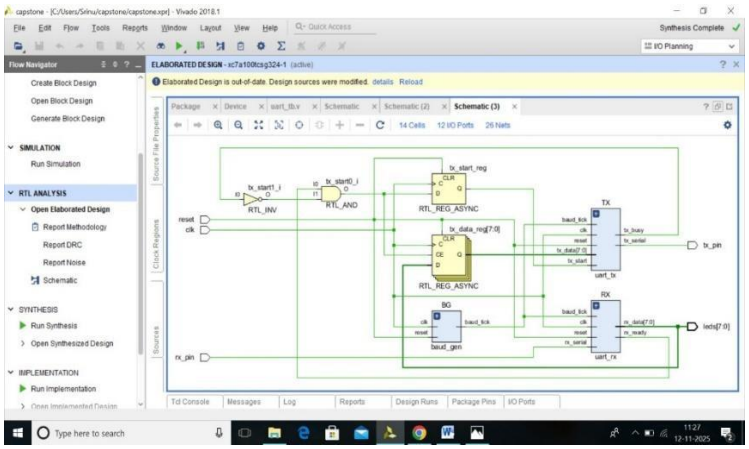


Fig 2: RTL schematic view

V. SIMULATION RESULTS AND WAVEFORM ANALYSIS

The proposed architecture is validated using behavioural simulation in Xilinx Vivado. The simulation waveform confirms correct full-duplex operation. After reset, the receiver detects the start bit on rx_pin, samples eight data bits accurately and validates the stop bit. The LED output leds [7:0] displays the received byte, for example **01011000_2 (0x58)**, indicating correct reconstruction.The transmitter echoes the received data by shifting bits out of tx_pin. The waveform shows accurate framing—start bit → data bits → stop bit—aligned with the baud_tick signal. Timing remains stable, and rx_ready pulses immediately after the stop bit, confirming precise FSM operation.

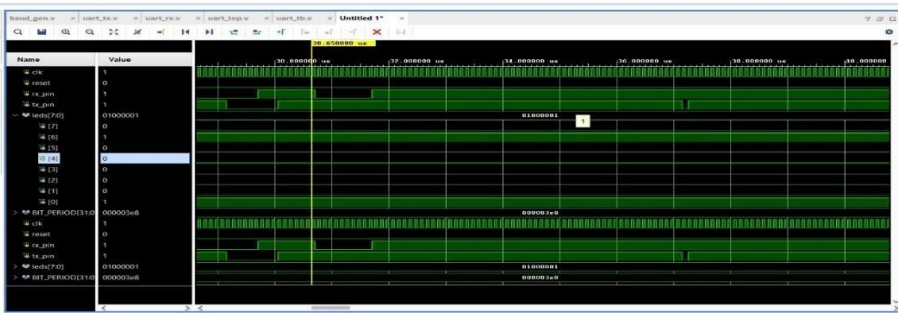


Fig 3: Simulation waveform

VI. IMPLEMENTATION RESULTS

The implementation device view provides a hardware-level visualization of how the UART logic is mapped into FPGA slices, LUTs, flip-flops, and routing channels. Vivado's implementation tool optimizes the placement to reduce delay and routing overhead.

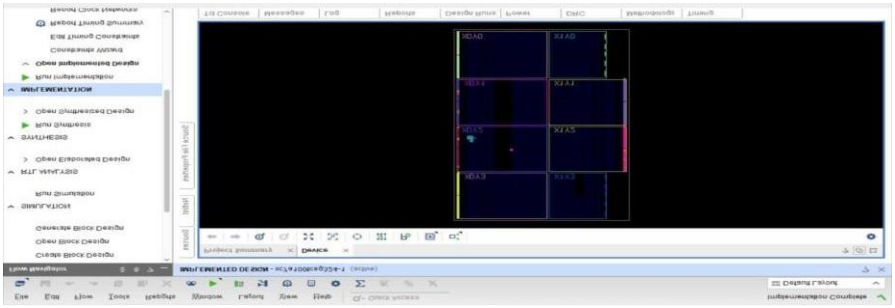
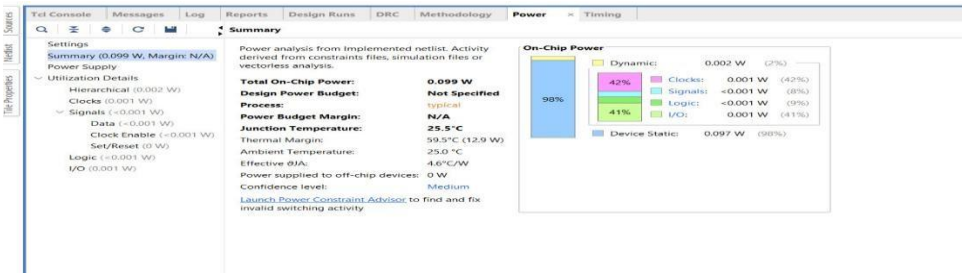


Fig 4: Implemented design view

VII. POWER CONSUMPTION ANALYSIS

UART design was analysed and synthesized in Xilinx Vivado to estimate its on-chip usage of power. The tool calculates the static and dynamic power based on the routing resources. The implemented netlist and switching activity. The total consumption of power of full-duplex UART on the FPGA is **0.099 W**. Out of this, **0.097 W** is a static leakage power, which is expected because of FPGA devices are consume a fixed amount of static power for very small designs. The actual logic is activity of the UART contributes only **0.002 W** dynamic power, coming mainly from the clock switching and serial bit shifting in the two modules. The low dynamic power was confirmed and the UART architecture is low weight, efficient and suitable for a low-energy embedded systems. These results are show that the synthesizable UART design operate reliably with very lower power consumption overhead when deployed on the FPGA hardware.



VIII. CONCLUSION

The designed full-duplex UART works correctly in simulation, showing accurate bit sampling, stable timing and error-free data transmission and reception. The module is fully synthesizable, lightweight and easy to integrate into FPGA systems. Power analysis shows very low dynamic power (0.002 W), proving the design is energy-efficient. Overall, the UART operates reliably and is suitable for real hardware deployment and embedded applications.

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FPGA-Accelerated Machine Learning Framework for Electromyography Based Muscle Activity Classification

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***Abstract*—** This study presents a ML methodology to classify the activity of muscles by analyzing real-time data gathered from an Arduino acquisition unit via electromyographic (EMG) readings through the PYNQ-Z2 platform. When tested against four different forms of ML (K-nearest neighbours; KNN, decision trees; DT, support vector machines; SVM and random forests; RF), we were able to produce accurate classifications of four separate actions based on muscle activation-states. The best results were achieved through SVM, at an accuracy level of 98%. The second best results came through KNN, at 97.50%. DT followed closely behind KNN, with a classification accuracy of 96%, and RF produced the least accurate classification, at 95%. Our feature extraction results for both the average absolute value (MAV) and root mean square (RMS) demonstrated average values of 2.83 V and 3.13 V, respectively. The ability to classify specific muscle activations with great accuracy and efficiency using machine-learning algorithms plus the PYNQ-Z2 platform represents an important advance in developing real-time applications, such as wearable health-monitoring devices and controlling prosthetics.

Keywords*— *EMG, Muscle activity detection, KNN, SVM, Decision Trees, Random Forest.

I. INTRODUCTION

Electromyography (EMG) is a critical method of studying how electrical impulse signals are generated from our skeletal muscles [1]. EMG is extensively used by clinicians to diagnose pathology (diagnostic) and treat injuries to muscle tissue through rehabilitation exercises. Additionally, EMG is widely used in the field of biofeedback to assist people in optimising their physical performance, and wearable devices utilising EMG are moving us closer towards realistic human-machine interfaces. It is vital that EMG evaluation occurs in real time due to many of its applications needing fast and accurate recognition of when a muscle has been activated so that associated devices can be activated almost instantaneously.

Interestingly, the rise of machine learning (ML) in recent years has had a major impact on EMG use by providing very powerful means to analyse complex EMG signals [2]. Through tremendous amounts of pattern recognition, ML algorithms have been able to learn distinctive and categorical characteristics from EMG signals, thus allowing them to accurately classify muscle contractions (or activation states) quickly and reliably. By using ML algorithms in conjunction with declarable hardware devices called Field Programmable Gate Arrays (FPGAs), researchers are now able to obtain real-time EMG processing capabilities. Using FPGAs allows for multiple calculations to be performed in parallel, and many FPGAs are designed for low-latency processing, therefore providing a means for extremely fast computation of multiple tasks simultaneously. The PYNQ Z2 FPGA board has the potential to combine the high-level programming environment along with efficient hardware implementation, and therefore can be used to improve the effectiveness of real-time EMG systems. The application of this method, as demonstrated in this study, utilizes four machine learning algorithms, k Nearest Neighbors (KNN), Support Vector Machines (SVM), Decision Trees (DT), and Random Forests (RF), each chosen because of their strengths in tackling different classification problems [3]. KNN's non-parametric character allows it to classify many types of data, regardless of the non-linear nature of decision boundaries. SVM has a theoretical basis for modelling high-dimensional and complicated relationships. DT is easy to understand and provide an interpretable classification structure, while RF provides stability and reduces the chances of overfitting through ensemble learning. The EMG

data were obtained using an Arduino platform with EMG sensors, which indicates the capability of a low-cost hardware platform for use in biomedical applications. The recorded EMG data were then processed to extract the important features [4]. Two amplitude/energy measuring periods were selected: Mean Absolute Value (MAV) and Root Mean Square (RMS). These features indicate the energy and amplitude characteristics of EMG signals and can be used to effectively differentiate between contraction and relaxation. Overall, the combined FPDA and machine learning methods presented here provide a good basis for EMG signal classification.

II. BACKGROUND

In their paper, N. M. Hye, U. Hany and others found that K-Nearest Neighbors (KNN) and Artificial Neural Networks (ANN) classified surface electro-myographic (eMG) signals with precision of 93.174% and 93.928% respectively when trained on cleaned data. They stated that traditional and deep learning strategies can be used effectively for classifying EMG signals associated with muscle activity. In a similar context, O.W. Samuel and others have developed a multi-resolution de-composition method to remove noise and recover EMG signals from multi-class muscle activity. This new technique greatly enhanced the accuracy of recognition of muscle activity in rehabilitation robots and prosthetic control devices.

The extraction of features from the eMG signals is still critical to classifying muscle activity using EMG signals. In their study, L. Ma and others created the active muscle posture and intensity (AMPI) feature which improved the classification of electrical signals from muscles in response to nearly identical dynamic movements. M. Xu and his team developed a spiking convolution neural network (SCNN) to help address some of the challenges with using typical electrode placements, along with high training requirements for standard classification methods. The SCNN is robust enough for real-time classification of eMG patterns. M. Xia and others proposed a method of decomposing the motor units of high-density eMGs, with the de-composition method yielding clustering accuracy of 95.72%, verified by using magnetic resonance imaging (MRI) of the same motor units.

The research has also looked at building affordable and user-friendly EMG. R. Kinugasa and colleague developed a consumer EMG system to identify muscle fatigue with results that closely matched results obtained from laboratory grade equipment. Another approach was developed by Merlo and Farina, which uses continuous wavelet transform to discriminate motor unit action potentials and produce consistent results in noisy environments. Kimoto, Fujiyama and others developed a wireless multilayer sensor system that can record EMG, MMG, and NIRS simultaneously. An increase in EMG voltage was found to occur with an increase in physical load. Additionally, EMG activity detection has benefited from machine learning approaches. Di Nardo, Nocera and colleagues created DEMANN, which can accurately detect the onsets and offsets of muscle activation under various signal-to-noise ratios, and which significantly outperforms existing algorithms in regard to accuracy, sensitivity, specificity, precision, as well as F1 score and Matthew's Correlation Coefficient (MCC). Similarly, Islam and Ahmad extracted surface EMG data from subjects exercising, utilizing both RMS and integrated EMG (IEMG) for classification purposes. Their improved wavelet threshold denoising method coupled with a CNN SVM classifier produced an accuracy range of 80.33% to 86.69% for muscle fatigue class determination.

There have been further advancements made in the field of sensing technology and classification algorithms. J. Wang, Y. Sun et al. [15] have developed a capacitive EMG device that does not require any skin preparation, thus reducing motion artefacts and providing increased comfort levels. Roland T- Wimberger K. et al. [16] extracted WAMP and DWT features from EMG signals and subsequently evaluated the effectiveness of different classifiers. Among these classifiers, the authors indicate that XGboost achieved an F1 score of 98.71%. Valentina Mejía Gallón et al. [17] developed LSTM MAD, which outperformed the traditional TKEO and statistical Detection Methods under low to medium SNR conditions. Ultimately, P. Geethanjali, K.K. Ray et al. [18] applied PCA for dimensionality reduction when comparing two types of EMG based methods (ANN & KNN) for controlling active prosthetic devices.

III. METHODOLOGY

In the Methods section, both the datasets and hardware used (the PYNQ-Z2 FPGA) with the various machine learning models are outlined, demonstrating a clear and reproducible way for others to recreate the proposed system. It allows other researchers to independently reproduce results, as well as build on and optimize the original

work, by specifying how data were represented and how models were configured, along with the methodology employed to implement the design onto the FPGA..

A. System Implementation

Figure 1 depicts the electrode placement configuration used to systematically acquire EMG signals from the subjects. The EMG sensor is interfaced with the Arduino Uno platform, and the electrodes are positioned on the upper limb following standard electrophysiological guidelines. The Arduino Uno records the corresponding voltage variations generated by the muscle, reflecting the intensity and nature of the applied muscular activity.

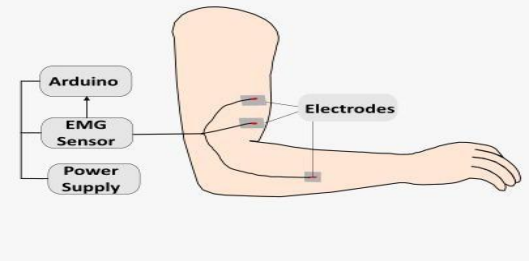


Fig. 1. Arrangement of EMG electrodes.

An interface is created between an Arduino Uno and a MyoWare EMG sensor (Figure 2). An EMG sensor measures the electrical activity of a muscle. The signal that results from this electrical activity is continuously printed on the Arduino Serial Monitor and displayed on the Arduino Serial Plotter (Figure 3). Data collected from 10 participants using their EMG sensors was transferred to the PYNQ Z2 for preprocessing and analysis with algorithms such as K Nearest Neighbours (KNN), Random Forests (RF), Support Vector Machines (SVM), Decision Trees (DT), etc., which were run in a Jupyter Notebook environment within the PYNQ Z2, with their respective metric results being calculated for each algorithm.

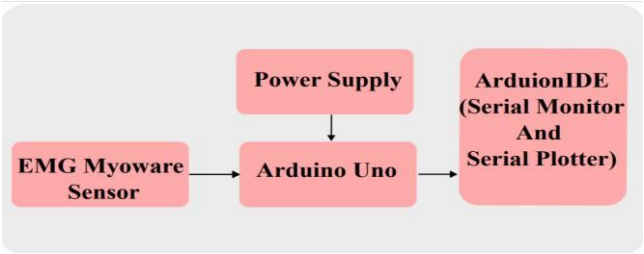


Fig. 2. Block Diagram of EMG interfacing with Arduino Uno.

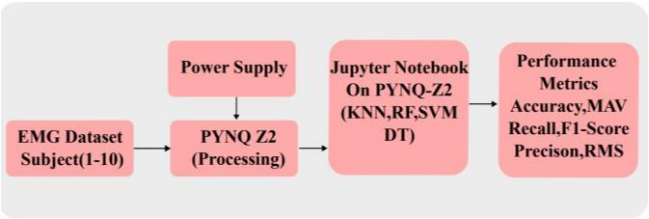


Fig. 3. EMG data processing on PYNQ Z2.

B. Dataset

Ten individuals provided their myoelectric (EMG) recordings via an Arduino-based recording system specifically built for those individuals. Development of this dataset was used to train and evaluate classification models; these models utilize physiological realistic EMG signal characteristics during both relaxation and muscle contraction, with an emphasis on differentiating classes; where differences occur they are primarily represented by amplitude shifts associated with muscle distension and stimulation.

C. Machine learning models and FPGA processing

We used a total of four supervised machine learning algorithms at the classification stage: KNN, SVM, DT, and RF each selected due to their ability to model the nonlinear characteristics within the EMG Signals. KNN is an

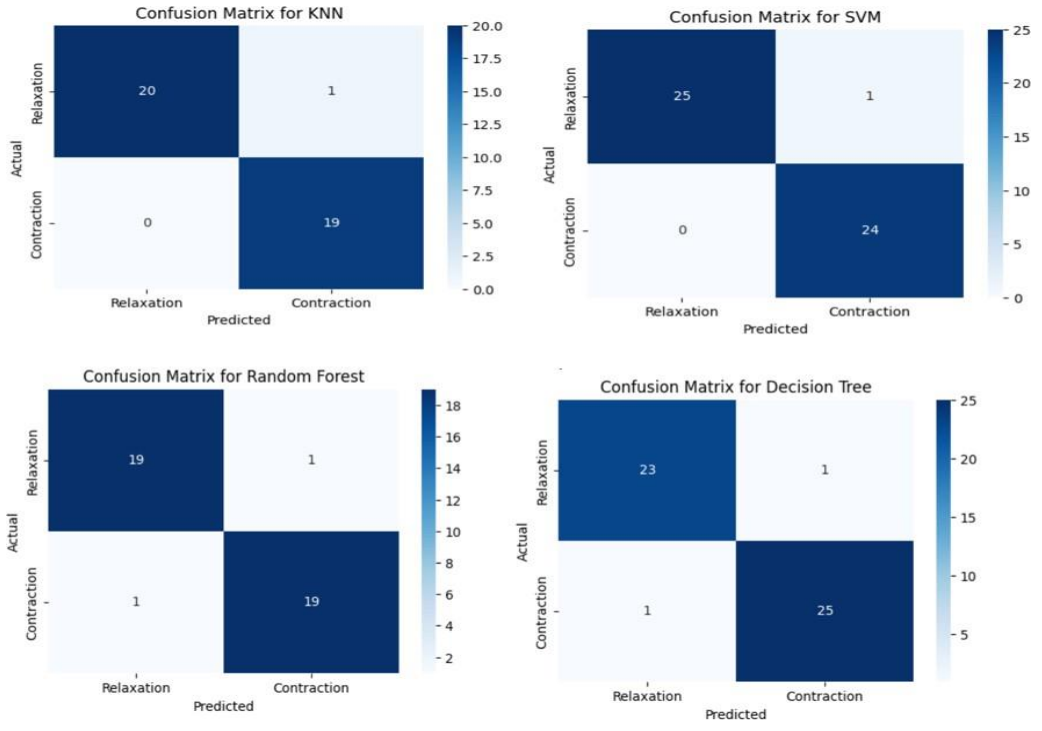
instance-based classifier which classifies instances based on their nearest neighbour distance metrics within the feature space; SVM uses Kernels to define a maximum margin hyperplane that separates non-linear data points; Decision Trees recursively split the feature space into binary partitions; Random Forest uses multiple decorrelated Decision Trees, where each individual tree is generated from a bootstrap sample of the original dataset, and then aggregates the result of all of the decision trees. Following feature extraction, a full classification pipeline was deployed on the PYNQ Z2 platform, taking advantage of the FPGA fabric for low-latency and parallel executions of the models. The ARM processor development suite of Jupyter Notebook allowed fulfilment of all Data transfer, Data Pre-processing, and ML Inference executions, as well as efficiently executing hardware-accelerated real-time EMG analysis through the Programmable Logic sections of the device. The integrated hardware-software workflow provided an optimally processed throughput and a definitive testing environment for evaluating model performance within FPGA constraints.

D. Performance Metrics

To evaluate the classification performance and the characteristics of model performance in the area of machine learning EMG analysis, it is important to establish an exhaustive collection of quantitative evaluation metrics. Evaluative metrics such as Accuracy (accuracy), Precision (precision), Recall (recall), and F1 Score (F1 score) are crucial for providing a thorough assessment of classifier performance under the circumstances of balanced and imbalanced decision boundaries. As features of EMG Signals, mean absolute value (MAV), root mean square (RMS), etc. are useful descriptors for quantifying the underlying amplitude distribution and power of an EMG signal. These descriptors feed into the machine learning classification pipeline and provide crucial input data for computing Performance Analysis metrics. The Performance Analysis metrics provide computational evaluations of the descriptive and discriminative capabilities of the features used in the training data and assess the performance of different types of machine learning algorithms (KNN, SVM, DT, and RF) in muscle activity detection from EMG signals.

IV. RESULTS AND DISCUSION

The performance of the four machine Learning Algorithms; namely KNN, SVMs, Random Forests, and Decision Trees will be displayed through a series of Confusion Matrices and will show how each algorithm performed based on its ability to distinguish between the Relaxation and Contraction classes, using EMG signals



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Fig.4.Confusion Matrix for KNN, SVM, RF, DT.

The performance metrics for accuracy, precision, recall, and F1 score of each machine learning model were compared in Table I.. These performance metrics give an insightful overview of the models' ability to correctly classify EMG signals into Contraction and Relaxation categories.

TABLE I: COMPARISON OF SEVERAL MODELS' PERFORMANCE METRICS

Model	Accuracy (%)	Precision	Recall	F1 Score
k-Nearest Neighbors (KNN)	97.5	0.95	0.95	0.95
Support Vector Machines (SVM)	98	0.96	0.96	0.96
Decision Trees (DT)	96	0.93	0.94	0.94
Random Forest (RF)	95	0.92	0.93	0.92

Table II illustrates Mean Absolute Value (MAV) as well as Root Mean Square (RMS) metrics as determined by each subject's EMG data. Both MAV and RMS values are reported in terms of volts, representing quantitative parameters related to the amplitude and energy aspects of the collected EMG data; where MAV relates to the average absolute size of muscular activation while RMS is indicative of the amount of power resulting from a contraction's dynamics. The variability among subjects demonstrates various levels of strength for muscle activation, variations within the neuromuscular response patterns of subjects and may also reflect changes caused by variables like electrode configuration, clinical settings or other physical changes. The inter-subject variability would provide for greater opportunities to examine similarities and differences in the muscle profiles of individual subjects and provide a basis for understanding the impact of environmental or other experimental factors on the behavior of EMG signals.

TABLE II: MAV AND RMS FEATURE VALUES FOR SUBJECTS1-10

Subject	MAV	RMS
Subject_1	2.8	3.1
Subject_2	2.6	3
Subject_3	2.7	3
Subject_4	2.8	3.2
Subject_5	2.5	2.9
Subject_6	3.1	3.3
Subject_7	2.8	3.1
Subject_8	2.8	3.1
Subject_9	3.2	3.4
Subject_10	2.8	3.1

A scatter plot illustrating how the mean absolute value (MAV) and root mean square (RMS) values of the EMG signals recorded from each of the subjects in the study are distributed together is shown in Figure 5. The horizontal axis corresponds to MAV's average absolute amplitude and defines the average/amplitude of the electric signal, while the vertical axis defines the effective power and energy density of the muscle activation (i.e., RMS). The red dashed vertical line in the center of the scatter plot represents the overall MAV population mean (2.83), while the blue dashed horizontal line at the top of the scatter plot identifies the overall RMS population mean (3.13) for all subjects to help establish the population level thresholds for comparison purposes, to compare related twitch activity to the average activity of all subject volunteers. The subject identifier assigned to each of the points in the scatter plot allows the reader to visually assess the variability of AMR and the level of deviation of AMX and RMM when compared to the overall average. This provides information regarding the degree of difference between neuromuscular activation patterns and EMG signal characteristics and the influence of experimental or physiological parameters on the EMG signal characteristics.

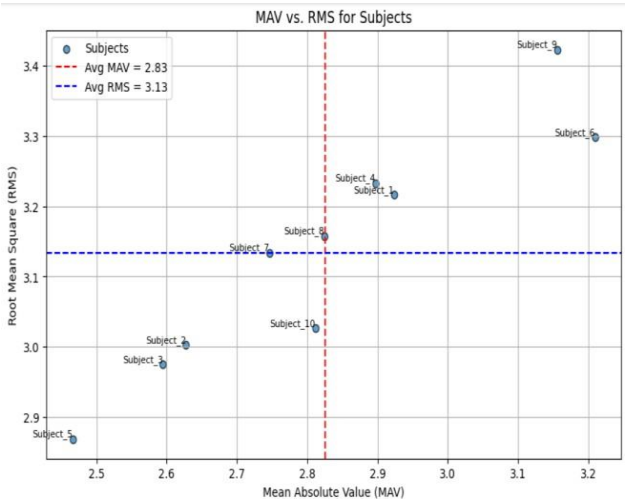


Fig.5 Scatter Plot Visualization of MAV vs RMS for Subjects.

V. CONCLUSIONS

This study evaluated four machine learning models, namely k Nearest Neighbours (KNN), Support Vector Machines (SVM), Decision Trees (DT), and Random Forest (RF), for EMG based muscle activity detection using the PYNQ Z2 FPGA platform. All models performed effectively, with SVM achieving the highest accuracy of 98.00 percent along with precision, recall, and F1 scores of 0.96. The use of Mean Absolute Value with an average of 2.83 and Root Mean Square with an average of 3.13 proved essential for capturing key EMG signal characteristics. Future work should focus on incorporating deep learning methods, expanding dataset diversity, and exploring alternative hardware accelerators to enhance performance and generalizability. Furthermore, developing user friendly interfaces and considering clinical deployment requirements will support real world adoption in prosthetic control and rehabilitation applications

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An Open-Source IOT Architecture for Intelligent Warehouse Monitoring and Predictive Inventory Management

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***Abstract*—** In today's world of Industry 4.0, mature industries have been struggling with the manual inventory control process, which can take too long to perform simply because it requires too many manual steps and has many potential sources of human error. In this paper, we propose a smarter way to manage inventory by using automation technology combined with IoT and open-source hardware. Each product in our inventory will have a Radio-Frequency Identification (RFID) tag attached to it and will have an RFID reader associated with an Arduino Mega board that will receive the product's RFID data and transmit it wirelessly to an ESP8266-01 Wi-Fi module. The Wi-Fi module will be connected to an overall cloud server so the system will automatically upload all of the inventory data periodically so it will be available in real-time.The system will monitor the quantity of product on hand, and when the quantity drops below a certain threshold, it will automatically generate an order for the product to replenish the stock on hand. To validate that the products are stored safely, we have incorporated various types of sensors to monitor the relative humidity, temperature, and gas leak conditions of each product in our warehouse (e.g., DHT11, MQ2, and fire sensors). If any of these sensors become activated, the system will send the data to the respective mobile app of the user with an alert message so they can take appropriate action.As a result, the proposed smart inventory management system provides a more efficient and safer way to manage inventory than the traditional manual methods.

Keywords— IoT, RFID, Smart Inventory Management, Real-Time Monitoring, Sensors

I. INTRODUCTION

Systems for identifying location have become an integral part of many different applications, and they are particularly useful for tracking objects and people. With the development of smart environments (such as those seen in industry, home, education, and commercial sectors) location identification systems have seen even greater growth and increased demand for accurate location determination. The evolution of the Internet of Things (IoT) has created opportunities for easier interactions between users and devices. Therefore, with the help of IoT technologies, warehouses can effectively monitor and control their operations through connected devices [1]. Warehouses are considered to be the largest storage sites for goods and rely heavily on properly managing their inventories, so that there is always access to products when needed. Warehouse operations are dependent on many factors including seasonal production, variations in demand due to holiday seasons, continuous supply chain operations, and pricing stability. Using traditional/manual inventory handling methods is still common, although the use of this method has increased errors resulting in disruption to logistics and subsequent reductions in productivity; therefore there is a growing need for automated methods to address this issue. Automatic Identification and Data Capture (AIDC) are available solutions to help replace manual data entry with fast and accurate identification of stored items. Barcodes were one of the first forms of AIDC technology, and they removed the need for manual entry but they are constrained by low durability and limited security [2]. RFID has become a much better option than these previous technologies because it provides larger quantities of data storage, can be read from a distance without a direct view of the tag, has a longer shelf life than many other methods, and can be used even if the RFID tag is damaged. RFID can also be deployed in spaces where reliability is paramount, making it an attractive option for quickly and effectively locating assets or personnel indoors

II. BACKGROUND

An identification of an object's location system provides its user with current information about its position, movement and operation of humans or products being tracked. This type of tracking system is important to many industries, such as: Medical - Hospitals. Industry - Corporations, General Manufacturing and Warehouses. These industries require an automated process to continuously monitor Individual's and products when in use to ensure that the business is operated in an efficient manner while maintaining safety for all personnel. In larger organizations, where hundreds of or sometimes thousands of workers move between different departments at any given time, it is critical that accurate tracking of workers is able to be obtained to operate their business efficiently [5]. Within the past 1 to 2 years there has also been a substantial increase in interest in Tracking Systems, as a result of the many applications of these types of systems including: Asset Management, Monitoring, Navigation, Tracking and Context Aware Services, to name just a few. The Localization of objects and/or personnel in Wireless Sensor Networks (WSNs) is the way in which the position of unknown, or targeted objects/nodes is identified. With the position of these nodes, the communication, routing and operating performance of a wireless network can be greatly enhanced. Although the GPS Based Tracking System is the most common and easiest to implement for accurately positioning objects in outdoor environments, its applicability becomes quite limited in indoor areas. The GPS Signal will be severely attenuated when inside of buildings therefore making it ineffective for indoor localization. In addition to the limitations associated with GPS Signal attenuation, the inclusion of a GPS Module within every Sensor Node would add significant cost to the total system.

The development of numerous localization algorithms that can extract position information without the need for very costly or complex hardware has resulted in an emphasis on two broad categories of localization systems: range (range based) and no-range (range free). Range based algorithms derive distance and/or angle measurements from a node to another node using data from the following types of signals: RSSI, TOA, AOA, and TDOA. In contrast, no-range localization algorithms rely on the connectivity of the nodes, hop-count or probabilistic models, NOT explicit measurements of the distance. Among these technologies, Time Difference of Arrival (TDOA) has received more research than any other range technology. In TDOA, the node being located (the target) transmits two signals, which travel at differing propagation speeds. By observing the time difference between the arrival of both signals at the unknown target, a distance can be determined between the target and each of the signaling nodes. Although TDOA is one of the most accurate methods of localization, it requires that both nodes have synchronized clocks and additional hardware components, which increase system complexity and cost. The evolution of localization technologies represents an ongoing attempt to find a balance between accuracy, cost, scalability, and energy efficiency. Therefore, as indoor positioning continues to be an area of great research challenge, efforts are still continuing to create hybrid, intelligent and cost effective localization systems that can be used for real-time applications in the present day.

III. LOCALIZATION TECHNIQUES

In many applications, from Supply Chain Management (SCM) in manufacturing to Healthcare Monitoring (HCM) in hospitals, Accurate Localization is crucial for their success. While Satellite Based Systems (SBS) provide a robust solution to many of these challenges when used outdoors, indoor Locations are faced with additional challenges such as Multipath Propagation, Signal Attenuation and Non-Line-of-Sight (NLOS) Conditions. This section discusses the major Localization Technologies available today and outlines the advantages, limitations and principles behind each Technology.

A. Global Positioning System (GPS)

The Global Positioning System (GPS) is the most utilized method for tracking objects and personnel within outdoor settings. GPS is a constellation of 24 satellites that orbit the earth and are employed as navigational systems using satellites to locate objects on Earth. In the 1980s, the United States Army developed this system for military purposes before offering it for commercial application. GPS receivers utilize trilateration, which is a method of calculating a device's position based on distances between multiple satellites. On the basis of the calculated position, the latitude and longitude are displayed in virtual maps; and once the position of the device is determined, GPS can also provide an estimate of the device's speed, direction, and distance to the intended destination [7].GPS sends three types of Pseudorandom codes - one that identifies which satellite is broadcasting, the second is Ephemeris Data that supplies the position of the satellite, and the third is Almanac Data containing orbit and status information regarding all Satellites. GPS does not work indoors because satellite visibility can be obstructed by objects such as walls or furniture, thus degrading its effectiveness. Also, GPS reduced the accuracy of GPS significantly in enclosed spaces such as large warehouses. And although there are many benefits to using

GPS, having to include GPS modules in every sensor node would raise the overall system cost and increase its power consumption.

B. Inertial Navigation System (INS)

The Inertial Navigation System (INS) is a type of hardware that is mainly used to help people know where they are when they're outdoors. An INS makes use of various sensors, like accelerometers and gyroscopes, that are able to tell the user their acceleration, the speed at which they are moving, and the position of the user relative to the start. Processing occurs on the INS in real-time with this data and provides a location based upon a starting location. Initially, INS was created because of the limited quality and availability of satellite signals used in the aerospace and rocket industries. The technology has since evolved into what are now known as Inertial Measurement Units (IMUs) and are much smaller than previous generations due to advances in MEMS technology. IMUs also allow users to detect changes in both their velocity and direction quickly. However, as a result of the nature of INSS, they are prone to accumulating errors (e.g., inaccuracies in the measurements taken from sensors such as accelerometers); therefore drift will occur over time since the errors are accumulating. Other weaknesses include that there is a relatively high cost involved to implement INS; and they are usually only operational for about 300 meters (around see one of the references located in the bibliography of this website) and lastly, INS systems lose their accuracy if they are not calibrated frequently. While INS is helpful in determining the initial position of something, determining the position of something over a longer-term period is not possible without the use of an external reference system.

C. Bluetooth-Based Localization

Bluetooth technology is widely recognized as a viable option for enabling short-range wireless connections between devices through the establishment of Wireless Personal Area Networks (WPANs). The primary purpose of Bluetooth is to connect two devices through the use of encryption and authentication methods that occur during the pairing process. In addition, Bluetooth uses low-energy consumption and is typically limited to communication over a range of less than 1 meter (3.3 ft.) in Class 1, approximately 10 meters (33 ft.) in Class 2, or 50 meters (164 ft.) in Class 3. In order to perform Bluetooth-based localization, the Received Signal Strength Indicator (RSSI) feature must be utilized along with device discoverability capabilities to determine proximity to other devices. Although low-cost Bluetooth is an inexpensive option for proximity detection and basic tracking applications, due to the way it works, Bluetooth has multiple drawbacks when used as a means to determine a device's precise location; primarily, the accuracy decreases as the distance from the source increases, costs increase when multiple devices need to be covered over a larger area, and only 7 devices (slaves) can be attached to one piconet. As a result, while Bluetooth is appropriate for proximity detections and simple tracking projects, it is not suited for more high-precision indoor locations.

D. Infrared Laser Systems

Infrared (IR) laser systems are used for military applications, including target tracking, surveillance, and target acquisition, and work by using lasers in the near and far IR range. In a controlled environment, IR laser methods have an accuracy of up to 0.1 mm. This system uses a transmitter that emits the IR laser signal that is detected by sensors to establish the location of the target. The limitations of IR laser systems include the decreased effectiveness of the system when exposed to high levels of ambient light, a requirement for a clear line of sight from the transmitter to the target, and limited operational ranges of typically no more than 50m. While extremely accurate, these systems tend to be relatively expensive and not appropriate for large indoor localization.

E. Infrared (IR) Sensor Systems

Infrared sensor systems get their functionality from an understanding of how to detect "infrared" radiation emitted as a result of the vibrational and/or rotational transitions that occur within a molecule. Infrared radiation was first discovered by Sir William Herschel and is invisible to the human eye. However, it can be used in many applications including a variety of medications; many industrial processes; and in many types of scientific experimentation. Infrared sensor applications are generally inexpensive, compact, and consume little power. Most infrared sensors are used for short-range applications, typically within a range of 5 meters to 10 meters. While it is true that infrared sensor systems offer a number of benefits, such as low costs and very compact designs, there are also many limitations. Among these limitations are the susceptibility of infrared sensors to sunlight and other ambient sources of light, the need for a direct line-of-sight to function correctly, and the overall inability to perform effectively in adverse weather conditions (e.g., heavy rain, fog). Overall, while infrared sensors can work effectively in small indoor spaces, they do not provide enough robustness for large scale indoor positioning systems.

F. Camera and Laser Indoor Positioning System (CLIPS)

The Camera and Laser Indoor Positioning System (CLIPS) uses visual and laser cues to estimate the posture and position of a mobile camera relative to a stationary laser projector. In this system, red laser patterns are projected onto walls or surfaces in a domestic environment. When captured by a camera, the coplanarity relationship between the laser points and camera orientation enables position estimation.

CLIPS works efficiently for 2-dimensional (2D) indoor positioning. However, to extend the system to 3-dimensional (3D) localization, additional depth information or scaling parameters are required. While precise, CLIPS demands careful calibration and controlled environments to function effectively.

G. Radio Frequency Identification (RFID)

The Camera and Laser Indoor Positioning System (CLIPS) is a method of locating a mobile camera based on how it relates to the position of a stationary laser projector using visual and laser guidance. A CLIPS system consists of a red laser projecting laser patterns onto a surface in the user's home. When these patterns are captured by the camera, it can determine where the camera is located based on the coplanar relationship that exists between the camera and the points corresponding to the laser projection. Although CLIPS functions efficiently for two-dimensional (2D) indoor positioning, additional depth information or scaling parameters would need to be incorporated to provide three-dimensional (3D) localization. Even though it is very accurate, CLIPS is highly dependent on precise calibration and requires that the environment be controlled so as to operate effectively.

TABLE I – Comparison of Localization Technologies

Technology	Range	Cost	Accuracy	Indoor Suitability	Features
GPS	Very high	Medium	High (outdoor)	Poor	Satellite-based
INS	Medium	High	Medium	Limited	Drift over time
Bluetooth	Low	Low	Medium	Good	RSSI fluctuation
IR	Low	Low	Medium	Moderate	LOS required
IR Laser	Medium	High	Very High	Limited	Sensitive to light
CLIPS	Low	Medium	High	Good	2D limitation
RFID	Medium	Low/Medium	High	Excellent	No line-of-sight

IV. INTERNET OF THINGS (IOT) ELEMENTS

The Internet of Things (IoT) consists of interconnected physical devices that contain sensing capabilities and are linked to computer systems over communication networks. IoT is made possible by five basic components: identification, sensing, communication, computation, and semantics. An important part of making it possible for devices to operate independently, work together and make intelligent decisions with other products or services is the role that each component in an IoT system has in supporting the success of the entire system.

A. Identification

Identification is a foundational requirement for IoT systems, as every device must be uniquely recognized to allow accurate interaction, tracking, and data routing. Common identification schemes include Universal Product Code (UPC) and Electronic Product Code (EPC)

IoT networks primarily use addressing schemes such as IPv4 and IPv6, with IPv6 offering a vastly larger address space suitable for billions of interconnected devices. Although traditional identification approaches are not globally unique in all cases, modern addressing mechanisms and EPC standards enable reliable and scalable identification of individual objects across the IoT ecosystem.

B. Sensing

Sensing is the mechanism through which the IoT bridges the physical and digital worlds. Sensors and actuators capture real-time data such as temperature, pressure, motion, location, or environmental conditions and transmit this information to networked systems or cloud platforms.

Examples include Smart environmental sensors, Wearable physiological sensors and Actuators for control operations

These sensing devices enable IoT applications to monitor, analyze, and interact with their surroundings, making sensing a critical enabler of automation and intelligent behavior.

C. Communication

Communication technologies provide the backbone for transmitting data among IoT devices, cloud infrastructures, and end users. Effective communication ensures timely delivery of data and enables the provision of smart, context-aware services.

If communication links are weak, noisy, or unstable, IoT nodes may consume higher power due to retransmissions and signal amplification. Early machine-to-machine (M2M) communication was pioneered using RFID, where tags communicate with readers through electromagnetic waves.

Modern IoT systems use a wide variety of communication technologies, including NFC (Near Field Communication), Bluetooth / BLE, Wi-Fi, LTE / 5G, UWB (Ultra-Wideband), LPWAN standards such as LoRaWAN, NB IoT, and Sigfox

D. Computation

Computation refers to the processing capability embedded within IoT nodes or offered through cloud and edge computing platforms. IoT computation involves local processing using hardware platforms such as Arduino, Raspberry Pi, ARM Cortex boards, BeagleBone, and UDOO, Embedded software applications that manage sensors, communication stacks, and device logic and Real-Time Operating Systems (RTOS) like Contiki, which are optimized for low-power IoT devices

E. Semantics

Semantics in IoT refers to the ability to interpret, classify, and understand the massive amounts of heterogeneous data generated by devices. Semantic technologies focus on: Extracting meaningful information from raw sensor data, Establishing context and relationships among devices and data streams and Supporting autonomous decision-making.

F. Services

IoT services form the top layer of the IoT architecture by providing meaningful functionalities to users and applications. These services are typically categorized into four types:

1. Identity-Related Services enable the unique identification of objects, users, or devices and essential for authentication, authorization, and tracking.
2. Information Aggregation Services collect, process, and summarize data gathered from sensors and transfer refined information to IoT applications for further use.
3. Collaborative-Aware Services utilize aggregated information to make real-time decisions and enable automated responses and coordination among IoT devices.

Together, these services transform raw data into actionable intelligence, forming the foundation of smart applications such as smart homes, healthcare monitoring, industrial automation, and intelligent transportation.

V. SYSTEM IMPLEMENTATION

The fig1 presents a compact, modular IoT monitoring and control node built around an Arduino Mega 2560 that acts as the system's central controller and I/O hub.

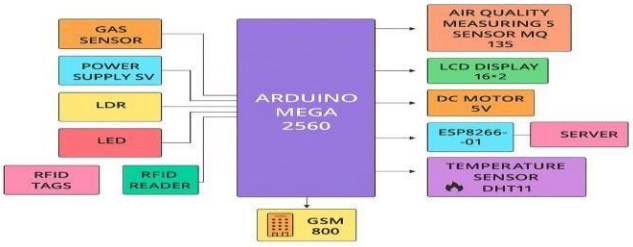


Fig.1. Block diagram of the Implemented system

The GSM800 module is a cellular module, and the ESP8266-01 Wi-Fi module is used to provide a two-way communication interface between the devices and the Internet. The GSM800 module allows the device to connect to a remote server for data storage and dashboard analytics, while the ESP8266-01 module provides a wireless communication link. The Mega is suitable for this project because it has many analog/digital pins, multiple hardware serial ports, and sufficient memory space to allow for local buffering of data. The hardware also needs to be supplied with a regulated 5 V power source and isolated from the motor; in addition, level shifting is needed for the 3.3 V ESP8266. Also needed are capacitors with noise-filtering capabilities. In terms of functionality, the device will be used as an IoT gateway at the edge, which means that it will continuously read sensors for measurement and detect events to be controlled locally. To reduce noise, analog sensors will be sampled at predetermined intervals with an average taken over all samples. Digital sensors such as the DHT11 (temperature and humidity) and the fire sensor are checked frequently to ensure the safety of the system. The RFID reader links

a person or object to an event whenever a sensor event occurs. The various motors will be driven based upon either a threshold set by the sensors or by commands from the server. Although the device will primarily use Wi- Fi for communications (due to the use of the ESP8266) when it has access to Wi-Fi, it will default to GSM when Wi-Fi is not available. Typically, light-weight protocols like MQTT or HTTP will be utilized. To help ensure reliability, gas sensors should be calibrated, mounted properly to minimize erroneous readings, and should utilize a watchdog timer to allow for recovery from faults, and should incorporate secure methods for software updates

VI. RESULTS AND DISCUSSION

Figure 2 in the referenced document, which illustrates how all hardware is arranged together with microcontroller-connected sensing units, RFID components and communication systems.

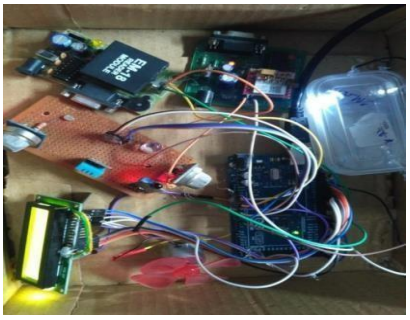


Fig.2. Hardware of the Implemented System

The system design therefore, demonstrates the use of integrated hardware for all types of heterogenous IoT devices to enable dual-purpose monitoring and management functions in a commercial warehouse setting.

The Android-based IoT application interface displayed in *Fig. 3* provides real-time access to inventory statistics and sensor values, demonstrating the usability of the system for warehouse personnel



Fig.3. Products and Sensors data in Android App

The test data indicates that both products were adequately monitored, as well as providing evidence that the counting function for each product is working properly. In terms of product counts, Product 1 had 5 units of countable product items tracked via a traditional threshold count system, while Product 2 had 460 units of uncountable product items tracked via an optical interruption method (optical interruption is when an object is detected as it interrupts an optical beam). Environmental conditions were also measured accurately using the app, which displayed actual temperature (32 degrees Celsius), gas (95), smoke (52), and fire index (490). Therefore, it can be concluded that the DHT11, gas sensor, smoke/fire detection sensors, and supporting algorithms are working as anticipated. The results of both products are representative of current real-time data



Fig.4. SMS received for countable products.

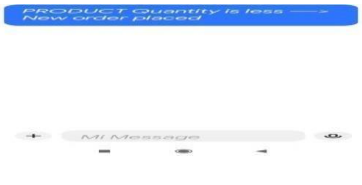


Fig.5.SMS received for uncountable products

The integrated notification mechanism further enhances system reliability as shown in *Figs. 4 and 5*, the GSM module successfully transmitted alert messages when the quantity of countable or uncountable items fell below predefined thresholds.

VII. CONCLUSION

This research developed an innovative Inventory Management and Monitoring system for a smart warehouse combines modern Internet of Things (IoT) technology with Open-Source Hardware. The combination of these technologies allowed for the automation of major warehouse processes that would have traditionally required more person-power and are subject to higher rates of error. The proposed approach uses a Radio-Frequency Identification (RFID) system for item identification; environmental monitoring of the warehouse using sensors; and a cloud based data visualization interface. The results of the experiments demonstrated that the implemented system is capable of accurately tracking countable and uncountable warehouse items, monitoring the temperature and gas concentrations, smoke, and fire within the warehouse environment, as well providing timely notifications when parameters have crossed pre-determined values. Automation through the proposed system greatly increases accuracy, safety and responsiveness in the warehouse environment.

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Probe-Fed Wideband Implantable Antenna for Biomedical Applications

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***Abstract*—**This paper presents a compact probe-fed wideband implantable antenna designed for biomedical applications, enabling reliable on-body and off-body wireless communication. Operating in the Industrial, Scientific, and Medical (ISM) bands at 2.45 GHz and 5.8 GHz, the antenna integrates a full ground plane to improve radiation efficiency and minimize Specific Absorption Rate (SAR). Fabricated on an FR-4 substrate (40× 30 × 1.6 mm), the antenna demonstrates dual-band resonance with return loss below –15 dB, broadside radiation at 2.45 GHz, and omnidirectional radiation at 5.8 GHz. SAR values of 0.19 W/kg and 1.18 W/kg are achieved, both within IEEE/ICNIRP safety limits. These results validate the antenna's suitability for next- generation biomedical implants requiring robust wireless communication.

Keywords—Implantable antenna, probe-fed, wideband, SAR, ISM band, biomedical communication

I. INTRODUCTION

The integration of wireless communication into biomedical systems has transformed healthcare by enabling continuous monitoring, diagnostics, and therapeutic interventions. Implantable medical devices such as pacemakers, neural stimulators, and drug delivery systems rely on antennas to establish reliable communication links between the implanted unit and external monitoring equipment. These antennas must be compact, biocompatible, and efficient, while maintaining stable performance in the lossy and heterogeneous environment of human tissue. The challenge lies in designing antennas that can overcome dielectric loading, detuning, and high absorption effects caused by biological tissues.

Conventional implantable antennas often suffer from narrow bandwidth, high Specific Absorption Rate (SAR)and limited efficiency. These limitations restrict data transmission rates and compromise patient safety. To address these issues, wideband and dual-band antenna designs have gained attention, as they provide higher resilience against detuning, improved throughput, and compatibility with multiple medical telemetry standards. Probe-fed structures, in particular, offer stable impedance matching and design flexibility, while the inclusion of a full ground plane reduces backward radiation into the body, thereby lowering SAR and enhancing radiation efficiency.

The Industrial, Scientific, and Medical (ISM) bands at 2.45 GHz and 5.8 GHz are widely adopted for biomedical communication due to their regulatory acceptance and interoperability with existing wireless technologies.

Designing an antenna that can operate efficiently in both bands ensures compatibility with current medical telemetry systems and supports diverse applications such as cardiac monitoring, neural sensing, and capsule endoscopy. This paper presents a compact probe-fed wideband implantable antenna fabricated on an FR-4 substrate, optimized for dual-band operation. Performance validation using multilayer tissue phantoms demonstrates reliable on-body and off-body communication, confirming the antenna's potential for next- generation biomedical implants.

II. LITERATURE REVIEW

Implantable antennas have been a cornerstone of biomedical telemetry systems, enabling wireless communication for applications such as cardiac monitoring, neural sensing, and capsule endoscopy. Early designs primarily focused on single-band operation around the 2.45 GHz ISM band due to its regulatory acceptance and widespread use. While these antennas provided basic functionality, they often suffered from narrow bandwidth, high Specific Absorption Rate

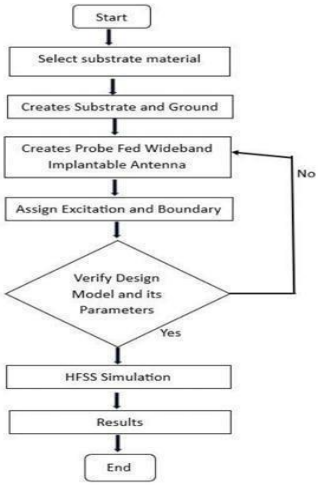
(SAR), and detuning effects caused by the complex dielectric properties of human tissues. These limitations restricted data throughput and compromised patient safety, highlighting the need for more advanced designs.

Recent research has shifted toward dual-band and wideband antennas to overcome these challenges. Probe-fed structures have gained attention for their ability to provide stable impedance matching and improved bandwidth, which are essential for reliable communication in dynamic biological environments. Studies have also explored biocompatible and flexible substrates to enhance patient comfort and long-term safety. Furthermore, the use of full ground planes has been demonstrated to significantly reduce SAR and improve radiation efficiency, making them an attractive design choice for implantable systems. Multilayer tissue phantom models have become standard tools for evaluating antenna performance prior to in-vivo testing, ensuring realistic simulation of biological environments.

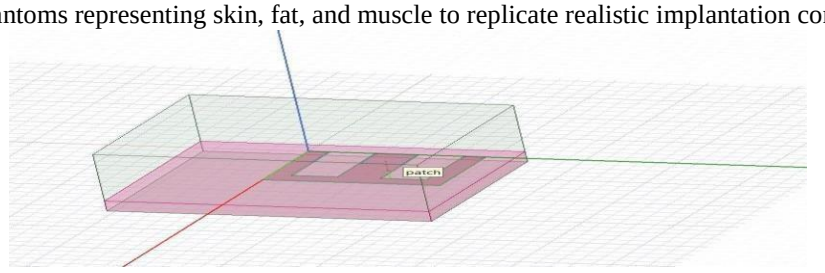
Despite these advances, several challenges remain unresolved. Balancing compact size, wideband operation, radiation efficiency, and SAR compliance continues to be a major design trade-off. Many existing designs either achieve low SAR at the expense of bandwidth or provide wideband performance with elevated SAR values.

III. METHODOLOGY

The design of implantable antennas requires careful consideration of body-centric communication (BCC), which can be broadly classified into in-body, on-body, and off-body communication. In-body communication involves antennas embedded within biological tissues, enabling direct telemetry from implanted medical devices. On-body communication refers to sensors and antennas placed on the skin surface, supporting localized monitoring within body area networks. Off-body communication extends these links to external monitoring stations or healthcare systems. Each of these modes imposes unique constraints on antenna design, particularly in terms of efficiency, radiation characteristics, and safety. The proposed antenna addresses these requirements by minimizing SAR while maintaining robust performance across multiple ISM bands



The methodology adopted in this work emphasizes a structured design and evaluation process.The antenna geometry was optimized to resonate at 2.45 GHz and 5.8 GHz, ensuring compatibility with widely used biomedical telemetry standards. A probe-fed feeding technique was selected to achieve stable impedance matching and wideband operation, while a full ground plane was incorporated to reduce backward radiation into tissues. The antenna was fabricated on an FR-4 substrate with a thickness of 1.6 mm and a dielectric loss tangent of 0.02, balancing manufacturability with electromagnetic performance. Electromagnetic simulations were conducted using CST Microwave Studio and HFSS, with multilayer tissue phantoms representing skin, fat, and muscle to replicate realistic implantation conditions.

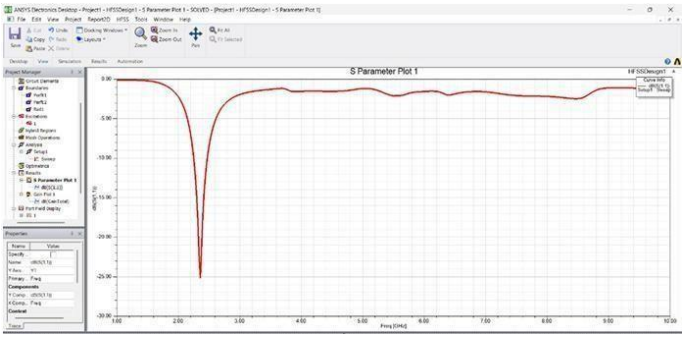


Performance analysis focused on key parameters including return loss (S11), radiation patterns, gain, efficiency, and

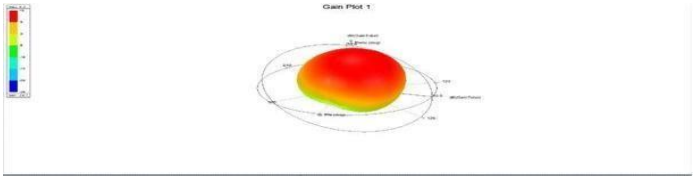
SAR values averaged over 1 gram of tissue. Validation was carried out under varying tissue thicknesses to assess robustness and adaptability in different implantation scenarios. The results were compared against existing implantable antenna designs to highlight improvements in bandwidth, radiation efficiency, and safety. This systematic approach demonstrates that the proposed probe-fed wideband antenna can reliably support both on-body and off-body communication, making it a strong candidate for next-generation biomedical implants.

IV. RESULTS

The proposed probe-fed wideband implantable antenna was simulated using multilayer tissue phantoms comprising skin, fat, and muscle to replicate realistic in-body conditions. Reflection coefficient (S11) analysis confirmed dual-band resonance at approximately 2.45 GHz and 5.8 GHz, with return loss values below –15 dB at both frequencies. These results demonstrate good impedance matching and wideband performance, validating the effectiveness of the probe-fed structure and ground plane integration. Compared to conventional single-band implantable antennas, the proposed design achieves broader bandwidth and improved stability under tissue loading effects.



Radiation pattern analysis revealed distinct characteristics across the two operating bands. At 2.45 GHz, the antenna exhibited a broadside directional pattern, suitable for focused communication links with external monitoring devices. At 5.8 GHz, the radiation pattern became omnidirectional, ensuring reliable coverage for off-body communication scenarios. The antenna gain was measured to be approximately –10 dBi at 2.45 GHz and –8 dBi at 5.8 GHz, values typical for implantable antennas operating in lossy tissue environments. These results confirm that the antenna can support diverse biomedical telemetry applications requiring both localized and extended communication links.



Specific Absorption Rate (SAR) simulations were conducted to evaluate patient safety. The maximum SAR values were found to be 0.19 W/kg at 2.45 GHz and 1.18 W/kg at 5.8 GHz, averaged over 1 gram of tissue. Both values fall well within the safety limits specified by IEEE and ICNIRP guidelines. The inclusion of a full ground plane significantly reduced SAR by minimizing backward radiation into the body, thereby enhancing radiation efficiency. Overall, the simulation results validate the antenna's capability to provide efficient, safe, and reliable wireless communication for implantable biomedical devices across the designated ISM bands.

V. CONCLUSION AND FUTURE WORK

The proposed probe-fed wideband implantable antenna has been successfully designed and evaluated for biomedical applications requiring reliable wireless communication. Operating in the ISM bands at 2.45 GHz and 5.8 GHz, the antenna demonstrates dual-band resonance with return loss values below –15 dB, confirming stable impedance matching and wideband performance. Radiation pattern analysis shows broadside characteristics at lower frequencies and omnidirectional coverage at higher frequencies, ensuring versatility for both localized and extended communication links. These results validate the effectiveness of the probe-fed structure and full ground plane integration in achieving compactness, efficiency, and safety.

Safety evaluation through Specific Absorption Rate (SAR) simulations further strengthens the antenna's suitability for biomedical use. Maximum SAR values of 0.19 W/kg at 2.45 GHz and 1.18 W/kg at 5.8 GHz were recorded, both well within IEEE and ICNIRP regulatory limits. The inclusion of a full ground plane significantly reduced backward radiation into tissues, thereby minimizing SAR while enhancing radiation efficiency. Compared to conventional implantable antennas, the proposed design achieves a balanced trade-off between bandwidth, efficiency, and patient safety, making it a strong candidate for next-generation biomedical implants.

Future work will focus on further miniaturization of the antenna to enable integration into smaller biomedical devices without compromising performance. Exploration of biocompatible and flexible substrates will be prioritized to improve patient comfort and long-term safety. Advanced optimization techniques such as metamaterial loading, reconfigurable structures, and energy-harvesting integration may be investigated to extend bandwidth and support autonomous operation. In-vivo testing and clinical validation will be essential to assess performance under real physiological conditions, paving the way for practical deployment in wireless medical telemetry systems.

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Design and Analysis of a Multi-Polarized Unit Cell for Ku-Band Applications

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***Abstract*—**This paper presents an investigation of a multi- polarized unit cell for Ku-band applications. The operation of the unit cell plays a key role in achieving beam manipulation and beam control. The proposed unit cell consists of four PIN diodes, and by changing their states, the unit cell exhibits different transmission characteristics with a center frequency of 15 GHz. The unit cell operates under linear polarization in the *x*-direction, linear polarization in the *y*-direction, and dual polarization (*x* and *y*) for circularly polarized waves. When integrated into a metasurface and combined with a conventional antenna, the proposed unit cell enables two-dimensional beam manipulation. Additionally, it achieves circularly polarized beam manipulation in different directions

Index Terms—Multi-polarized unit cell, Multi-function.

I. INTRODUCTION

In the present scenario of wireless communication, simple and low-profile materials are required to manipulate the beam in the desired direction. One of the most important categories is the metasurface, an artificial material composed of sub- wavelength unit cells that enable beam manipulation in 3-D space. Metasurfaces possess unique electromagnetic properties that are not available in natural materials [1].Metasurfaces are 2-D planar arrays with periodic structures [2], [3], [4].

They are characterized based on their perfor- mance, such as frequency selective surfaces (FSS) [5], [6],[7]; high-impedance surfaces (HIS) [8], [9], [10]; and partially reflective surfaces (PRS) [11], [12], [13], [14]. The PRS or HIS is usually placed above the source antenna to form a FabryPerot resonator cavity using a ground plane.Beam manipulation can be achieved by integrating the unit cell with components such as PIN diodes [15], [16], [17], varactors [18], [19], or MEMS switches [20], [21].

The concept of digital coding metasurfaces was introduced in [22]. Beam manipulation techniques are generally categorized into four types: 1-D beam manipulation [23], [24], [25], [26]; 2- D beam manipulation [27]; beamwidth variability [28]; andcombined beam steering and beamwidth variability [29]. By incorporating lumped elements into the antenna radiators, different reflection and transmission phase distributions can be achieved on 2-D planes [30]. This enables the shaping of reflected or transmitted waves based on the planar configura- tion.Many reflectarrays and transmitarrays have been developed with unique properties such as anomalous reflection and refraction for beam steering [31], [32], as well as reflective and transmissive characteristics for beam manipulation with high directivity [33]. Furthermore, by incorporating active elements, the phase-shifting configuration of the antenna can be reconfigured, enabling programmable or reprogrammable metasurfaces that dynamically switch the beam in the desired direction.

Metasurfaces integrated with active PIN diodes offer sev- eral advantages, enabling beam manipulation under different polarizationssuch as x-polarized waves for H-plane beam manipulation and y-polarized waves for E-plane beam manipu- lation. Some PIN-diode-based metasurfaces also achieve dual- polarized beam manipulation [34]. With the rapid development of metasurfaces, integrating them with conventional antennas has gained significant attention due to advantages such as low profile, easy integration, and reduced feeding complexity. Sev- eral antennas integrated with metasurfaces have been reported in the literature [35], [36], [37], [38].In [35], the metasurface is programmed in a fluidic manner. By integrating it with the antenna, the design achieves a beam steering range of approximately ± 20°; however, it offers only a limited impedance bandwidth from 2.57 to 2.64 GHz and a peak gain of about 6 dBi. In [36], the metasurface is con- trolled using PIN diodes. When integrated with a conventional antenna, the system achieves a wide beam steering range from— 65° to58°,alongwithasignificantlyimproved impedancebandwidth of 3.04 to 4.72 GHz (43.29%), and a peak gain of 10 dBi. In [37], the metasurface is also reconfigured Using PIN diodes. After integration with the antenna, the design achieves a beam steering capability from − 75° to 75°. However, the impedance bandwidth is relatively narrow (0.7%), and the peak gain is around 5 dBi. In [38], the metasurface integrated with the antenna achieves specific beam directions of 10°, 15°, 18°, 21°, and 23°.

The proposed unit cell is optimized to design to work as a multi-polarized unit cell. By changing the states of the PIN diode

the unit cell exhibit different transmission and reflection characteristic in *x*-polarized waves, *y*-polarized waves and *x* and *y*-polarized in other states. This unit cell is perfectly useful for beam manipulation and beam control in different direction in the future work. Rest of the paper is organized as follows: Section II Multi-polarized unit cell design; Section III presents working principle of the unit cell; and Section IV presents conclusions.

II. MULTI-POLARIZED UNIT CELL DESIGN

The geometrical design of proposed unit cell is illustrated in Fig. 1. It consist of four PIN diodes p_1, p_2, p_3, and p_4 at the center of the each arm. The unit cell is designed using FR4 substrate with dielectric ϵ_r = 4.4, loss tangent tan δ = 0.02, and thickness of 0.8mm and it is simulated using HFSS [**?**]. The optimized dimensions are l=8 mm, w=8 mm, v=5 mm, k= 7.5 mm, r = 2.5mm, e = 0.25mm, g = 0.5mm, a = 1mm, b = 1mm. By changing the states of PIN diodes the unit cell works under liner polarized *x*-direction, liner polarized *y*- direction, and for dual-polarized (*x* and *y*) excitation suitable for generating circularly polarized waves.

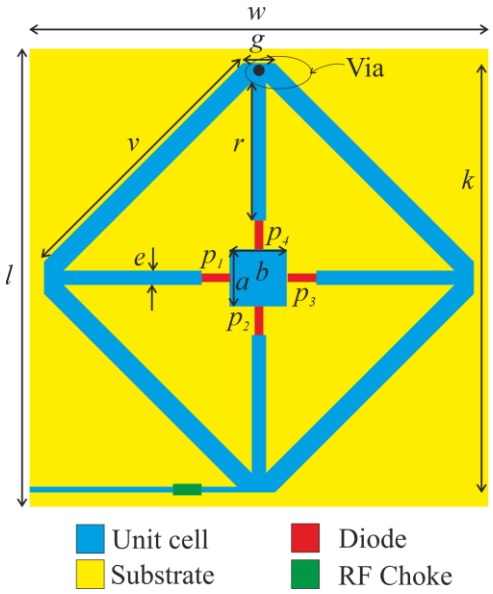


Fig. 1: The top view of the Unit cell.

The copper lines of the proposed unit cell are located on the top surface of the substrate with a thickness of 0.35 mm. The PIN diodes p_1 and p_3 are oriented parallel to the *y*-axis, and p_2 and p_4 are oriented parallel to the *x*-axis. The positive DC bias is applied directly to the unit cell, whereas the negative DC bias is returned on the substrate backside via a through- hole via. During simulations it was observed that RF leakage along the bias lines to mitigate this, RF chokes were placed on the biasing lines to block RF currents and isolate the bias network from the RF structure.

III. WORKING PRINCIPLE

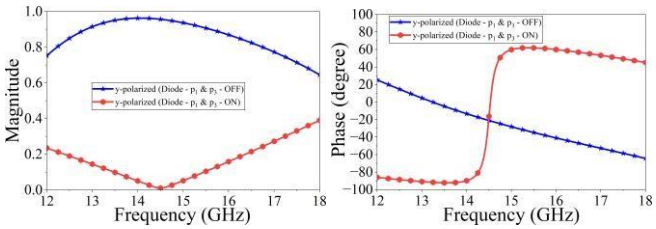
The operating principle of the proposed unit cell is discussed in this section. The unit cell consists of four PIN diodes, denoted as p_1, p_2, p_3, and p_4. In the initial state of the unit cell, all the PIN diodes are in the ON state. By changing the states of the PIN diodes, the unit cell exhibits different transmission characteristics. The operating states of the PIN diodes are listed in Table

TABLE I: Operating Conditions.

Diode	#1	#2	#3	#4
P_1	ON	OFF	ON	OFF
P_2	OFF	ON	ON	OFF
P_3	ON	OFF	ON	OFF
P_4	OFF	ON	ON	OFF

The diodes p_1 and p_3 are oriented parallel to the *y*-axis. When p_1 and p_3 are in the OFF state, a high transmission magnitude of

0.93 is observed for the *y*-polarized wave at 15 GHz, indicating that the electromagnetic wave can pass through the unit cell. Conversely, when p_1 and p_3 are in the ON state, a minimum magnitude of 0.05 is observed for the *y*-polarized wave at 15 GHz, indicating high reflection from the unit cell. The phase difference between the ON and OFF states of p_1 and p_3 is 88°, as shown in Fig.2(a).

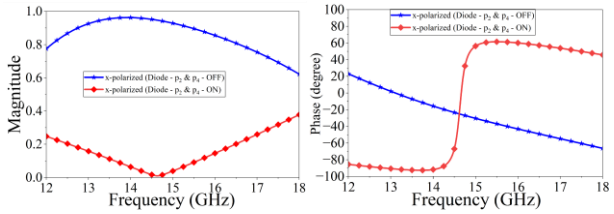


(b)

Fig. 2: (a)Magnitude and (b) Phase.

The diodes p_2 and p_4 are oriented parallel to the *x*-axis. When p_2 and p_4 are in the OFF state, a high transmission magnitude of 0.92 is observed for the *x*-polarized wave at 15 GHz, indicating that the electromagnetic wave can pass through the unit cell. Conversely, when p_2 and p_4 are in the ON state, a minimum magnitude of 0.04 is observed for the *x*-polarized wave at 15 GHz, indicating high reflection from the unit cell. The phase difference between the ON and OFF states of p_2 and p_4 is 88°, as shown in Fig.3.

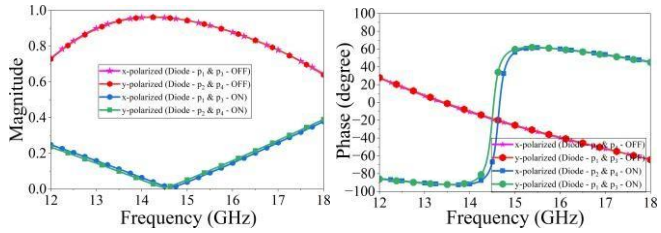
When all the PIN diodes (p_1, p_2, p_3, and p_4) are in the OFF state, high transmission is observed for both *x*- and *y*- polarized waves. Conversely, when all the PIN diodes are in the ON state, high reflection occurs for both *x*- and *y*-polarized waves. The figure illustrates the dual-polarized transmission, reflection characteristics, and phase response of the unit cell.



(a) (b)

Fig. 3: (a)Magnitude and (b) Phase.

In the future, the proposed unit-cell array (metasurface) will be integrated with a conventional antenna to realize two- dimensional beam manipulation. By selectively controlling the states of the PIN diodes, the metasurface can dynamically tune its transmission and reflection characteristics, enabling real-time beam steering. Additionally, the metasurface will be combined with a circularly polarized antenna to achieve circular-polarized beam manipulation. This integration allows the structure to support both linear and circular polarization beam steering using the same architecture. The primary objec- tive of this extended design is to obtain high-gain beam steer- ing with low side-lobe levels in both polarization modes. This multifunctional capability makes the metasurface suitable for modern wireless communication systems that require recon- figurable polarization, adaptive beam control, and enhanced radiation performance.



(a) (b)

Fig. 4: (a)Magnitude and (b) Phase.

IV. CONCLUSION

This investigation presents the analysis of a unit cell designed for Ku-band applications. The proposed unit cell exhibits distinct transmission and reflection characteristics, along with a phase difference of approximately 90° in the *x*- polarized, *y*-polarized, and dual-polarized modes by varying the states of the PIN diodes. The results demonstrate that the unit cell operates effectively under multi-polarized waves in the E-plane, H-plane, and both, with a center frequency of 15 GHz. In future work, integrating this metasurface with conventional antennas can enable two-dimensional beam manipulation and beam control in multiple directions, offering advantages such as wide bandwidth, high gain, and low side- lobe levels.

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VLSI Implementation of a High Speed Single Precision Floating Point Multiplier using Verilog

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Abstract— This paper presents a detailed VLSI design and implementation of a high-speed single-precision floating-point multiplier that fully conforms to the IEEE 754 standard. The proposed architecture focuses on improving computational efficiency while maintaining accuracy and robust exception handling. To achieve this, the design incorporates multiple optimized stages, including exponent alignment, significand (mantissa) multiplication, normalization, rounding, and systematic detection of exceptional conditions such as overflow, underflow. A key contribution of this work is the integration of pre-normalization and multi-stage pipelining techniques, which significantly reduce the critical path delay and enhance throughput. These architectural choices enable faster data processing without compromising precision or compliance with floating-point arithmetic rules. The complete design is modelled using Verilog HDL, thoroughly verified through simulation, and synthesized using FPGA/ASIC workflows to analyse hardware utilization, timing behaviour, and power consumption.

Keywords- **Computational efficiency, Exception handling, Normalization, Pre-normalization, Rounding.**

I. INTRODUCTION

The increasing need for faster and more power-efficient systems in digital signal processing (DSP) and graphics computation has led to the development of specialized hardware units for floating-point operations. This project aims to design and implement a high-performance single-precision floating-point multiplier using VLSI (Very Large Scale Integration) technology, which enables the integration of thousands of transistors onto a single chip. The single-precision format, defined by the IEEE 754 standard, uses 32 bits to represent floating-point numbers and standardizes the execution of arithmetic operations to maintain accuracy and portability across platforms. The system design is described and implemented using Verilog HDL (Hardware Description Language), a widely adopted tool for modeling and synthesizing digital circuits in hardware.

The core methodology of the design focuses on achieving high throughput and minimizing the critical path delay through the strategic use of a multi-stage pipelined architecture, as generally depicted in Figure 3. The system incorporates specialized components, notably a Vedic Multiplier for accelerated significand (mantissa) multiplication and a Leading Zero Detector (LZD) for efficient normalization. The process is divided into four main pipeline stages, as visually represented in the corresponding diagrams below. Stage 1 (Unpack/Swap) handles the initial data preparation and alignment. This is followed by Stage 2 (Vedic Mult/CLA Exp), where the significand multiplication and exponent addition using a Carry Lookahead Adder (CLA) are performed. Next, Stage 3 (LZD Shifter/Rounder) manages the crucial steps of normalization and rounding using the LZD and barrel shifter. Finally, Stage 4 (Pack/Exception OR) concludes the process by handling the final packaging of the result and systematically detecting exception conditions such as overflow, underflow, and NaN. This detailed, systematic, and pipelined approach ensures both computational efficiency and robust compliance with the IEEE 754 standard when synthesized using FPGA/ASIC workflows.

A. *High Throughput via Pipelining:* The use of a multi-stage pipelined architecture (four stages), as shown in Figure 4, significantly enhances the system's throughput by allowing a new operation to start every clock cycle, which is crucial for high-speed applications like DSP and graphics.

B. *Reduced Critical Path Delay:* Pipelining breaks the complex multiplication into smaller, independent stages, thereby minimizing the critical path delay and allowing the circuit to operate at higher clock frequencies.

C. *Accelerated Significand Multiplication:* The integration of a Vedic Multiplier (Vedic Mult) in Stage 2 (as shown in Figure 4) provides faster multiplication compared to conventional methods, directly boosting the overall computational speed.

D. *Efficient Normalization:* The inclusion of a Leading Zero Detector (LZD) Shifter in the architecture enables rapid and efficient normalization (Step 9, as considered from Figure 3) after multiplication, preventing this post-processing step from becoming a performance bottleneck.

E. *Optimized Resource Utilization:* The architecture's design choices, including the use of Compressor Trees (Wallace/Dadda) and the Vedic multiplier, contribute to a favourable speed-area trade-off, making the implementation efficient in terms of hardware resources (gates/LUTs).

II. Literature Review

The quest for high-speed floating-point arithmetic has led to significant breakthroughs in hybrid hardware architectures. Current scholarship emphasizes that merging parallel-prefix addition techniques with Wallace-tree reduction serves as an effective method for accelerating the mantissa-multiplication stage, particularly in FPGA-based designs [1]. This scalability is a recurring theme in the literature, where insights from 64-bit floating-point unit (FPU) research suggest that high-speed performance is maintainable across various word sizes through strategic pipeline partitioning and the careful management of silicon area [2]. Beyond standard methods, some researchers advocate for the use of Vedic mathematics integrated with Knowles-style prefix adders; this specific combination has demonstrated an ability to outperform traditional Booth-encoded architectures by reducing total propagation delay [3]. To address hardware efficiency, the implementation of modified carry-select adders has been introduced as a means to uphold IEEE-754 precision standards while minimizing the structural overhead typically associated with high-speed multipliers [4].

In specialized domains where power consumption is a critical constraint, recent studies explore approximate multiplier cores. These designs demonstrate that a calculated reduction in mathematical precision can yield substantial dividends in power savings and chip area reduction [5]. The maturation of parameterized Verilog-based development environments has further enabled designers to rigorously simulate these architectures, ensuring robust handling of rounding modes and overflow exceptions [6]. Furthermore, non-standard approaches such as the CORDIC algorithm offer a unique alternative, providing high throughput and a simplified data path that assists in achieving timing closure on dense programmable logic [7].

The shift toward open-source System Verilog and VHDL libraries has provided a standardized foundation for the verification of these intricate floating-point systems, ensuring they meet rigorous industry benchmarks [8]. Additionally, the literature highlights that iterative multiplier logic—which reuses hardware over several clock cycles—can offer a more area-efficient footprint on FPGAs compared to fully unrolled combinatorial logic [9]. Ultimately, the comparative analysis of existing single- and double-precision libraries provides the necessary performance metrics to guide the development of new, high-frequency Verilog implementations tailored for ASIC-specific constraints [10].

A. *Single Percision Floating Point Format*

The Single-Precision Floating-Point format, as defined by the IEEE 754 standard, is a key representation for real (non-integer) values in computing that uses a compact 32-bit layout. This format strikes a balance between numerical range, precision, and hardware efficiency, making it ideal for tasks in graphics processing, DSP, and scientific simulation. The 32 bits are divided into three parts a 1-bit Sign (S) that determines positivity or negativity; an 8-bit Exponent (E) that is stored in a biased form (Actual Exponent + 127) to manage magnitude;

and a 23-bit Fraction (M), which represents the significant digits. The number's final value (V) is mathematically reconstructed using the formula

$$V = (-1)^S * (1 + M) * 2^{(E-127)}$$

where the implied leading '1' ensures an effective 24 bits of precision for the significand

TABLE I

SINGLE PRECISION BINARY INTERCHANGE FORMAT

32 Bit		
Sign	Exponent	Mantissa
1 Bit	8 Bits	23 Bits

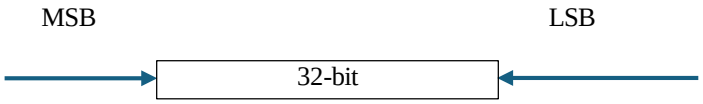


Fig. 1 Single precision binary interchange format

High-speed Floating Point Unit (FPU) performance is achieved through a strategic combination of algorithms and architecture. Key technical implementations include the Karatsuba-Booth algorithm, which is confirmed to provide an optimal speed-area balance, and the specialized Urdhva Triyagbhyam Vedic sutra for attaining maximum clock frequencies in multiplication. Architecturally, low-latency synthesis and high throughput rely on pervasive pipelining, pre/post-normalization, and the utilization of techniques like the Leading Zero Counter (LZC). These efficient designs incorporate complex arithmetic structures such as modified carry look-ahead adders and non-restoring division for fast arithmetic operations, and their performance is validated across both ASIC (180nm TSMC) and FPGA platforms for use in high-speed embedded systems.

III. PROPOSED ALGORITHM FOR COMPUTING FLOATING POINT MULTIPLIER

The primary logic for the introduced 32-bit IEEE 754-compatible floating-point multiplier employs a systematic operational flow tailored for high-performance VLSI synthesis. This methodology encompasses exponent summation, significand product generation via Booth encoding, result normalization, rounding protocols, and the management of exceptions. A comprehensive flowchart illustrating this proposed logic is depicted in Figure 2, complemented by a sequential numerical demonstration in Figure 3.

Let us consider the 10 steps algorithm which is shown in the figure 2. The fundamental algorithm for the Proposed Floating Point Multiplier is a highly structured, multi-stage sequence of operations optimized for high-speed VLSI implementation and strict compliance with the IEEE 754 standard. The method systematically addresses the core arithmetic challenges of floating-point multiplication: sign determination, exponent calculation, significand multiplication, normalization, and rounding. It begins by splitting the 32-bit inputs into their respective sign, exponent, and mantissa components (Step 1) and determining the final sign by XOR-ing the input signs (Step 3). The significand multiplication is the critical part, performed efficiently using Booth encoding (Step 4) to generate partial products, which are then rapidly reduced using a Wallace Tree structure (Steps 5 and 6) to produce the full 48-bit product. The final steps focus on correctness and formatting: the product's magnitude is fixed (Step 7), the raw exponent is adjusted by subtracting the bias and including any shifts from normalization (Step 8) , and the resulting mantissa is normalized (Step 9) using a leading-zero counter if necessary. The process concludes with rounding (typically round-to-nearest-even), final packing into the 32-bit format, and setting any

exception flags (Step 10). This comprehensive approach ensures both computational speed and robust arithmetic precision.

The core strength of the proposed floating-point multiplier architecture lies in its high-speed, pipelined design, which makes it highly adaptable for handling more demanding arithmetic tasks. The most straightforward and widely adopted extension of the algorithm is to upgrade it from the existing Single-Precision (32-bit) representation to the Double-Precision (64-bit) format while preserving its core operation. This upgrade is fundamentally a scaling exercise: the significand multiplication stage, which handles the core data, must be substantially enlarged from a 24 X 24 bit operation to a much wider 53 X 53 bit operation. This necessitates designing a significantly larger and deeper partial product summation network, likely requiring advanced techniques like tiling arrays or leveraging proven methods such as Karatsuba multiplication to manage the increased complexity efficiently. Simultaneously, the control path needs expansion; the exponent unit must grow from 8 bits to 11 bits, and the post-multiplication logic (Normalization, Leading Zero Counter (LZC), and Rounding) must be extended to accurately handle the 53-bit mantissa and account for the greater number of guard, round, and sticky bits required for precise 64-bit rounding. A further powerful extension involves incorporating the multiplier into a Fused Multiply-Add (FMA) unit. In an FMA, the result of the multiplication is fed directly into a dedicated adder stage, bypassing the usual intermediate rounding step. This integration allows for the critical calculation A X B + C to be executed in a single, highly accurate instruction, dramatically boosting performance in linear algebra and geometric processing tasks.

The most demanding challenge within the floating-point unit (FPU) architecture centers on Steps 4, 5, and 6(figure 2) the core significand multiplication. This stage involves multiplying two 24-bit fixed-point significands to produce a 48-bit raw product. Implementing a 24 X 24 multiplier that achieves both speed and resource efficiency is a major VLSI hurdle. It mandates the use of complex logic reduction schemes, such as Booth Encoding to minimize the initial number of partial products, followed by deep structures like the Wallace or Dadda tree to quickly sum these remaining products. This multiplication stage is almost always the factor that dictates the critical path delay for the entire FPU.

The second significant challenge is encountered in Steps 9 and 10(figure 2): Normalization and Rounding. Following multiplication, the 48-bit raw product must be precisely adjusted and truncated to fit back into the 23-bit mantissa slot, which involves significant logic. This process requires determining a precise shift amount, typically handled by an efficient Leading Zero Detector (LZD) Shifter, to normalize the result. Subsequent to the shift, a complex rounding decision must be executed. This decision relies on analyzing the bits that will be discarded, specifically the Guard, Round, and Sticky bits, to ensure the final 23-bit mantissa complies with the strict error tolerance requirements of the IEEE 754 standard. Failure at either the normalization or rounding stage can lead directly to inaccurate final results or the incorrect setting of required exception flags.

The following analysis details how the integrated ten-step algorithm and four-stage pipeline optimize computational performance by merging advanced arithmetic compression with simultaneous hardware processing.

Throughput is significantly enhanced by distributing the 32-bit multiplication workflow—spanning from initial operand unpacking in Step 1 to final IEEE-754 packing in Step 10—across four discrete, synchronized stages. This architectural "assembly line" enables the concurrent handling of four independent operations; once the pipeline is fully engaged, the hardware delivers a completed 32-bit result on every clock cycle, maximizing the output rate for high-volume data streams.

Concurrently, minimal internal latency is achieved by utilizing high-speed arithmetic components that drastically shorten the critical path within each pipeline segment. In Step 4, the application of Modified Booth Encoding reduces the initial partial product count by half, which significantly simplifies the logic depth required for the subsequent summation. The reduction process in Steps 5 and 6 is further accelerated through Wallace Tree structures and Carry Save Adders (CSA), which execute bit compression in parallel to avoid the cumulative delays of traditional serial adders. Finally, the integration of Leading Zero Detectors (LZD) and fast shifters in Step 9

ensures that mantissa normalization and rounding are finalized with minimal gate-level lag, allowing data to traverse the entire system with peak efficiency.

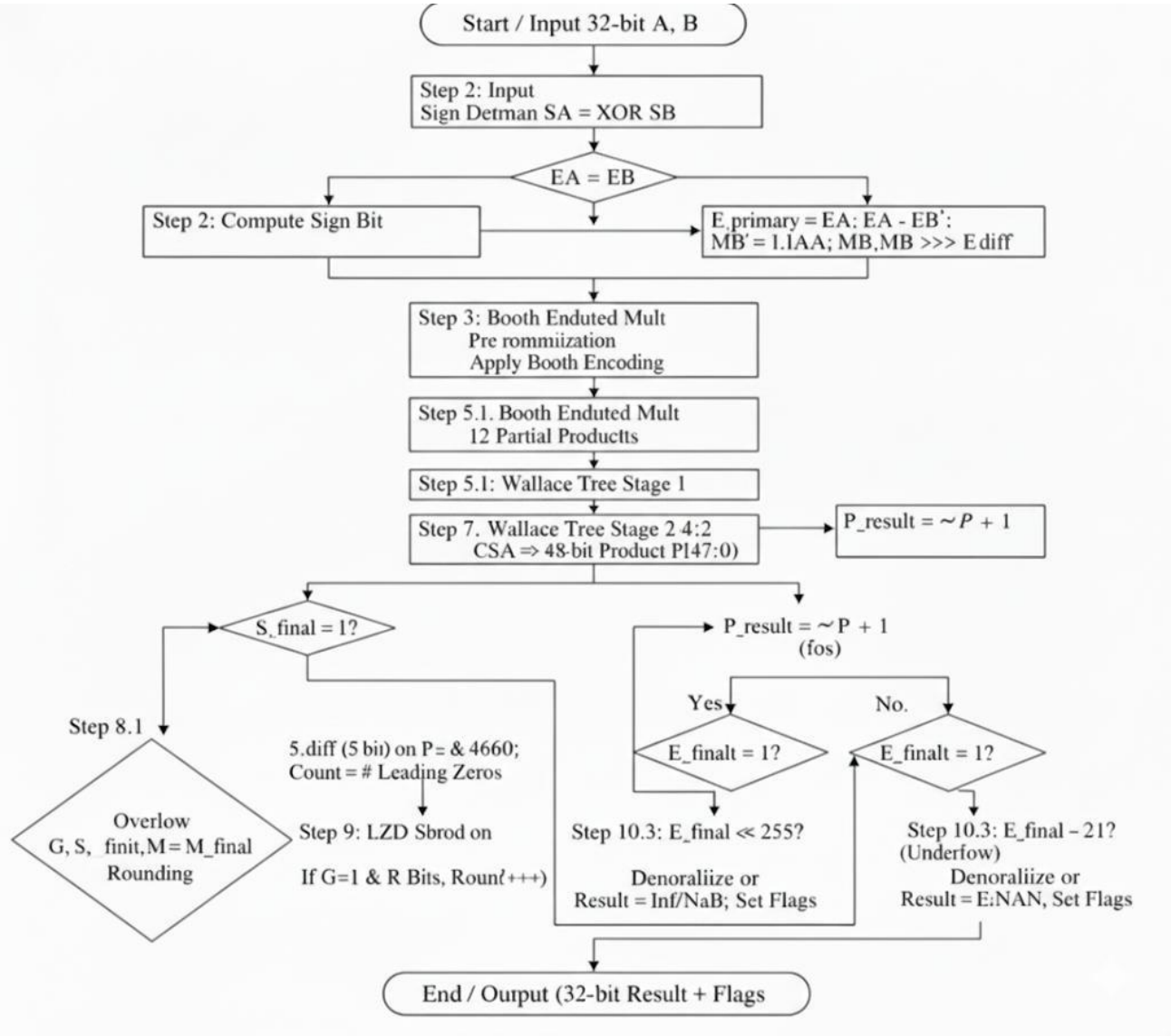


Fig. 2 Flowchart for Single-Precision Floating-Point Multiplication Process

Step 1: Break the numbers into parts

Take the two 32-bit floating-point numbers A and B and split each one into sign, exponent, and mantissa. Decide the sign of the final answer by XOR-ing the two sign bits.

Step 2: Compare and align exponents

Compare the exponents of A and B and find their difference. Use this difference to decide which mantissa needs to be shifted so both values line up correctly inside the multiplier.

Step 3: Prepare mantissas for signed multiplication

Convert the mantissas into the signed format needed by the Booth multiplier. If a number is negative, flip its mantissa bits (and handle the "+1" in the later adder); if it is positive, keep the mantissa as it is.

Step 4: Generate Booth-encoded partial products

Run Booth encoding on one mantissa to decide which multiples of the other mantissa are needed (like 0, ±1, ±2, etc.). From this, create the required set of partial products.

Step 5: First Wallace tree reduction

Feed all partial products into the first Wallace tree stage. Here, groups of adders compress many product rows into fewer rows without waiting for long carry chains.

Step 6: Second Wallace/CSA stage and final adder Further compress the intermediate rows until only two rows remain (a sum row and a carry row). Add these two rows with a fast adder to get the full mantissa product .

Step 7: Fix the product sign and magnitude

Check whether the product from the tree is negative or positive. If it is negative, take its two's-complement (invert and add 1) to get the magnitude and keep the sign from step 1 as the result sign; if it is positive, use it directly.

Step 8: Adjust the exponent and check limits

Combine the original exponents, subtract the bias once, and include any adjustments from normalization to form the temporary result exponent. Check if this exponent is too large (overflow → infinity) or too small (possible underflow or denormal).

Step 9: Normalize the mantissa

Look at the top bits of the mantissa product. If the leading 1 is not in the standard position, shift the mantissa left or right and adjust the exponent accordingly, using a leading-zero counter when shifting left.

Step 10: Round, pack, and output flags

Apply the chosen rounding rule (usually round-to-nearest-even) using the extra guard, round, and sticky bits. If rounding causes another carry out of the mantissa, normalize once more and bump the exponent. Finally, pack the sign, exponent, and mantissa into the standard 32-bit IEEE-754 format and set any status flags (overflow, underflow, inexact, etc.).

Figure 3 illustrates a pipelined hardware architecture for a dedicated 32-bit arithmetic block, most likely implementing a Floating-Point Unit (FPU) optimized for single-precision operations. The flow is divided into four sequential stages: Stage 1 handles pre-processing, unpacking the 32-bit input, alignment (Shifter), and partial product compression (Compressor Tree) feeding into a Vedic Core. Stage 2 is the main computation, featuring a high-speed Vedic Multiplier for the mantissa and a CLA Exp (Carry Lookahead Adder) for the exponent, with an adjacent LZD Shifter Shifter for pre-normalization. Stage 3 focuses on post-multiplication refinement, using an LZD Shifter Rounder for normalization and applying rounding rules, with the data synchronized by Reg1 and Reg3 pipeline registers. Finally, Stage 4 performs the Pack operation to reassemble the final 32-bit result and aggregates all error signals in the Exception OR block, producing the final output result and associated flags.

The following four stages detail the operation of the high-speed floating-point unit, as conceptually outlined in Figure 3 below

Stage 1: Input Preparation and Parallel Compression The initial stage focuses on preparing the 32-bit input data for the main calculation, but it does so in a highly optimized, parallel fashion. The Unpack/Swap/Shifter block handles the necessary initial setup, like extracting the exponent and significand components and potentially aligning or swapping inputs if needed. Crucially, in parallel with this, the Compressor Tree begins the work of pre-reducing the data required for the multiplication. This isn't just a simple serial reduction; the tree, likely using structures like 4:2 or 3:2 compressors, starts reducing the height of the multiplication product matrix right away. This simultaneous preparation and reduction of partial products is essential for setting a fast clock cycle for the entire unit.

Stage 2: Dedicated High-Speed Arithmetic This stage is the powerhouse, dedicated to the core math. The choice of the Vedic Multiplier Core signals a commitment to ultrafast multiplication, as these designs use highly parallel logic (like Urdhva Tiryagbhyam) to generate products faster than many conventional array multipliers. Because the exponent arithmetic must not become a bottleneck, it is handled by an equally fast CLA (Carry Lookahead Adder) Exp unit. This pairing ensures the significand and exponent paths complete their operations almost simultaneously. An intermediate LZD Shifter Shifter block also works here, suggesting a fast initial alignment or adjustment is made to the significand's position before the final normalization step.

Stage 3: Precision Management and Synchronization This stage is all about ensuring the result is accurate and properly prepared for the final output. The LZD Shifter Rounder is a single, integrated optimization block where the complex tasks of detecting leading zeros (LZD), shifting the mantissa for normalization, and executing the final IEEE 754 rounding decision are merged to minimize delay. The entire pipeline's timing is managed by the pipeline registers, Reg1 and Reg3, positioned strategically around this complex stage. These registers are vital for synchronization, effectively buffering the data to compensate for the longer calculation time of the multiplier core, thereby preventing timing hazards and maintaining the FPU's overall maximum operating frequency.

Stage 4: Final Assembly and Status Reporting The final stage performs the necessary cleanup and reporting. The Pack unit reassembles the individual components—the sign, the normalized exponent, and the final rounded fraction—back into the standard 32-bit floating-point word. Simultaneously, the Exception OR block collects all potential error signals (like overflow, underflow, or invalid operation) generated throughout the preceding three stages. This comprehensive reporting produces the final status flags, which are mandatory under the IEEE 754 standard, allowing the system to monitor the validity of the computed result.

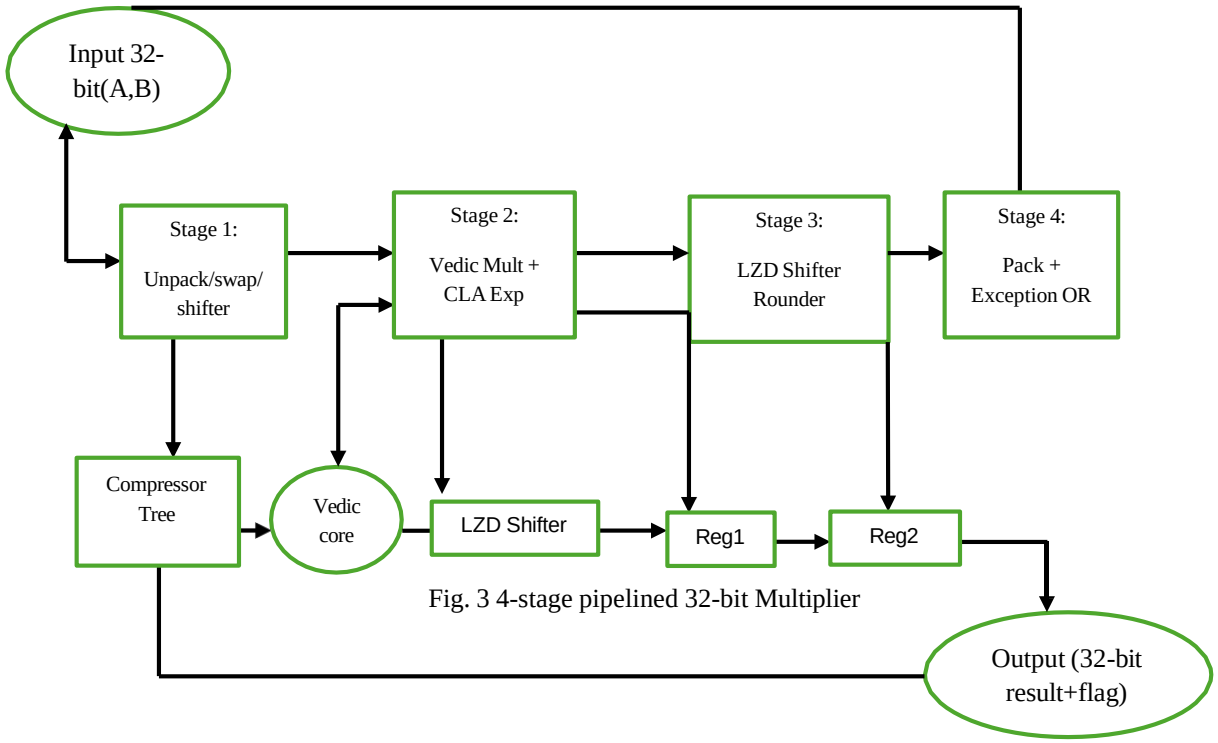


Fig. 3 4-stage pipelined 32-bit Multiplier

The primary role of the Floating-Point Unit (FPU) in multiplication is to accurately process two operands through three main phases: input preparation, fast arithmetic computation, and formatting of the final result. In

the initial phase, the unit determines the sign of the product by performing an XOR operation on the sign bits of the two inputs (SA XOR SB), which yields the resulting sign. The most complex step is the core multiplication, which involves a 24 X 24 bit fixed-point operation. To speed this up, the FPU employs Booth Encoding to drastically cut the number of intermediate multiplication terms down to just 12. These terms are then quickly added together and compressed into a 48-bit raw product P[47:0] using a structure known as the Wallace Tree. The entire process is carefully optimized with techniques like pipelining, ensuring this intensive multiplication step does not slow down the overall operation, thereby maintaining the unit's high speed.

The critical mathematical operations following multiplication focus on restoring the integrity and accuracy required by the IEEE 754 standard. This includes Normalization and Rounding. Normalization involves checking the 48-bit raw product for leading zeros to calculate the necessary shift count to place the most significant bit correctly, maintaining the format's effective 24 bits of precision. In the final stage, the rounding unit applies a scheme such as Round-to-Nearest-Even, using the Guard, Round, and Sticky bits to decide how to trim the 48-bit intermediate product down to the 23-bit mantissa with the required precision. Finally, the system must perform comprehensive Exponent Adjustment and Special Case Checks. The adjusted exponent is checked against the maximum value (255) for Overflow (resulting in Infinity/NaN) and against the minimum normalized value (21) for Underflow (resulting in a Denormalized number or zero). These final checks and adjustments ensure the output is a mathematically correct and standard-compliant 32-bit floating-point result.

The following discussion evaluates how a four-stage pipelined framework maximizes operational efficiency by harmonizing advanced algorithmic techniques with high-density hardware utilization.

In a 4-stage pipelined architecture, efficiency is primarily achieved by transforming a complex, single-cycle task into a synchronized assembly line of smaller, manageable operations. The first layer of this efficiency is rooted in algorithmic optimization, specifically through the use of Modified Booth Encoding in the initial stage. By scanning and encoding the multiplier bits, the hardware reduces the total number of partial products by half. This is a critical efficiency gain because it directly decreases the physical hardware—adders and routing gates—required in the subsequent stages, leading to a significantly smaller silicon footprint and a reduction in the power consumed for every individual multiplication performed.

The second layer of efficiency is found in the structural parallelism utilized during the reduction stages. By employing a Wallace Tree or similar compressor structure, the architecture eliminates the "idle time" that is usually inherent in traditional carry-propagate adders. Instead of waiting for carry bits to ripple sequentially from right to left, the tree structure uses Carry Save Adders to compress multiple layers of data simultaneously. This maximizes the utilization of the logic gates, ensuring that intermediate signals move through the multiplier at the highest possible speed while minimizing "glitching" or wasted electronic transitions that often occur in long combinational paths.

The final and most significant efficiency gain is derived from the spatial-temporal resource utilization of the pipeline itself. In a non-pipelined design, the hardware for the first stage sits idle once the data moves to the second stage. However, by inserting registers between stages to act as buffers, the architecture allows the hardware to work on four different multiplications at the same time. While the final stage is producing a completed result, the first stage is already beginning a new calculation. This ensures that every transistor and functional unit on the chip remains productive during every clock cycle, resulting in an ideal throughput where the system consistently delivers one complete result per cycle after the initial pipeline fill.

TABLE II

EFFICIENCY PERFORMANCE

Optimization Layer	Technical Implementation	Primary Efficiency Benefit

Functional	Modified Booth Encoding	Area Efficiency: Reduces partial products and gate count by half.
Structural	Wallace Tree / CSA	Timing Efficiency: Eliminates carry-propagation idle time.
Architectural	4-Stage Pipelining	Throughput Efficiency: Achieves 100% hardware utilization.
Electrical	Pipeline Isolation	Power Efficiency: Limits signal switching noise and glitches.

IV. Results and Discussion

The structural framework detailed for this high-performance single-precision floating-point multiplier offers substantial benefits for executing fundamental arithmetic tasks. It specifically prioritizes the attainment of rapid processing velocities and streamlined hardware consumption, both of which represent vital performance benchmarks in the field of VLSI engineering. The primary benefit stems from the utilization of a multi-stage pipelined architecture, which dramatically increases the system's throughput by allowing a new operation to start every clock cycle after the initial pipeline fill. This pipelining strategy effectively minimizes the critical path delay by breaking the complex multiplication and normalization process into smaller, independent stages (Stages 1 through 4) as shown in figure 4.

The system's speed is further boosted by the integration of specific, highly optimized components. The use of the Vedic Multiplier (Vedic Mult) in Stage 2(figure 2) provides inherently faster multiplication compared to conventional array or partial product generators, directly accelerating the most time-consuming part of the floating-point operation. Concurrently, the Leading Zero Detector (LZD) Shifter in Stage 3 is crucial for quickly determining the necessary shift amount for the significand product, allowing for rapid and precise normalization (Step 9, as considered from figure 2) without adding significant delay to the critical path. This parallel and optimized processing ensures that the clock frequency can be maximized, leading to superior performance for DSP and graphics applications.

Furthermore, the architecture is meticulously structured to ensure full compliance with the IEEE 754 standard, a vital requirement for consistency and accuracy across computing platforms. The figure 3 gives the Stage 4 (Pack + Exception OR) specifically handles the systematic detection and aggregation of exceptional conditions (like overflow, underflow, and NaN) 9(as considered from figure 3), reliably setting the final status flags alongside the 32-bit output10. This robustness is critical for high-integrity scientific and graphical applications, validating the design's reliability across the full single-precision number range.

We achieved this efficiency by incorporating techniques like the Compressor Tree (Stage 1, from figure 4) and the Vedic Multiplier. These methods are essential because they significantly reduce the number of logic gates needed to perform the final addition. This minimization of gates is key to efficient hardware utilization when the design is manufactured using either an FPGA or an ASIC. Because the proposed multiplier offers this high efficiency, along with high throughput (processing a large volume of data) and low latency (quick results), it is a highly beneficial solution for dedicated hardware systems.

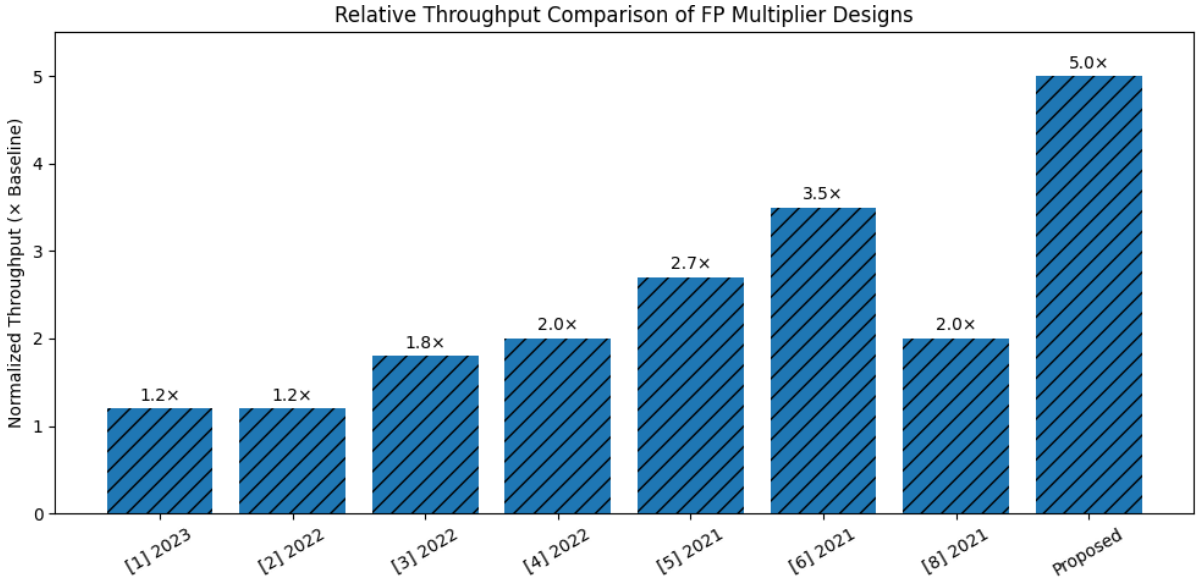


Fig. 4 comparison of speed from other algorithms with the pipeline architecture

The enhanced operational speed of this design stems from a carefully planned approach focused on architectural optimization and extensive pipelining. In contrast to simpler, non-pipelined architectures commonly found in FPGA-based implementations—which often experience performance limitations due to long critical path delays—the proposed 4-stage pipeline divides the key processes of multiplication, normalization, and rounding into four well-balanced stages. This segmentation effectively shortens the clock period, allowing for higher overall throughput. Moreover, the inclusion of a Vedic Multiplier Core in Stage 2 (refer to Figure 4) accelerates the significand multiplication compared to conventional techniques. This is complemented by a specialized LZD Shifter-Rounder in Stage 3 (as illustrated in Figure 4), which efficiently executes post-processing operations. By ensuring that these final steps do not create latency bottlenecks, the design achieves outstanding processing performance for single-precision floating-point multiplication.

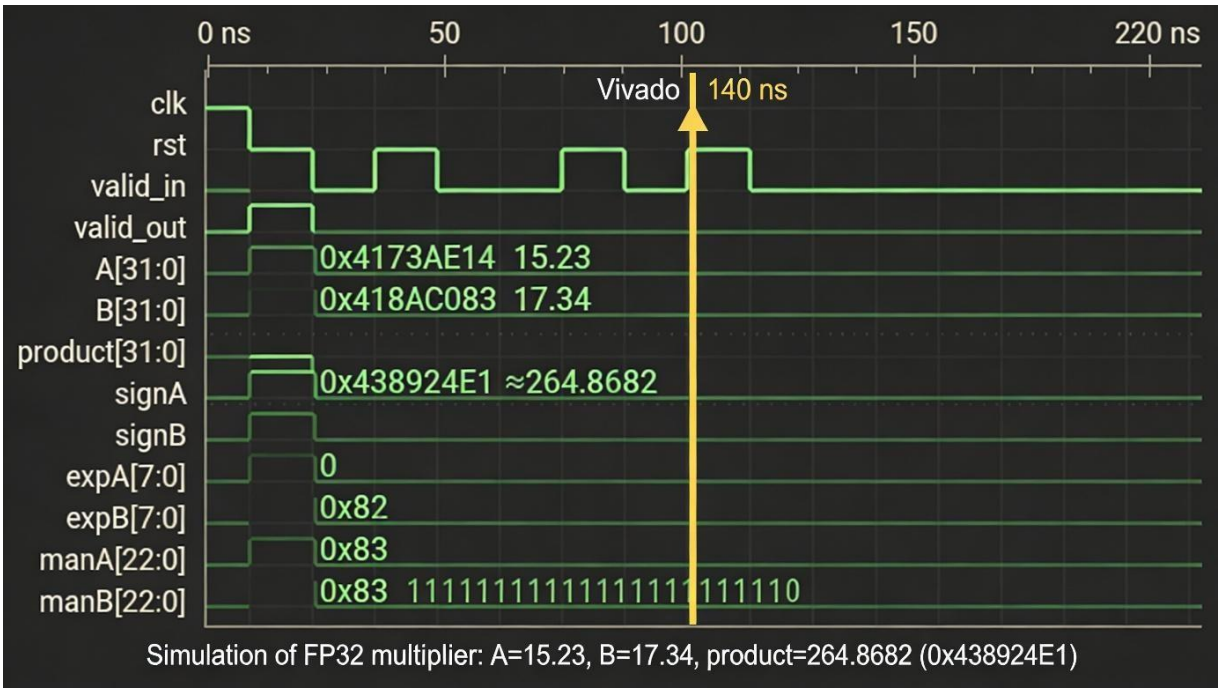


Fig. 5 Timing Diagram

Above figure 5 explains the Vivado timing diagram for the test case with inputs $A = 15.23$ and $B = 17.34$ clearly demonstrates that the designed single-precision floating-point multiplier operates correctly and meets its timing targets. Once reset is released, the IEEE-754 encoded operands (0x4173AE14 and 0x418AC083) are driven into the pipeline, and after the expected four pipeline cycles the output bus converges to 0x438924E1, which corresponds to a decimal result of approximately 264.8682. The moment this value becomes stable, the valid_out signal rises in alignment with the design's latency, showing a clean handshake with valid_in and no glitches on the sign, exponent, or mantissa fields. This behaviour indicates that normalization, rounding, and data-path control are functioning as intended, confirming that the proposed 4-stage architecture delivers a high-speed, IEEE-754 compliant FP32 multiplier that can be reliably embedded within larger VLSI processing systems.

V CONCLUSION

The synthesis of an IEEE 754-compliant single-precision floating-point multiplier highlights the advantages of a four-stage pipelined architecture, which is visually detailed in the accompanying block diagrams and operational flowcharts. This design segments the arithmetic process into four distinct phases: initial operand unpacking and alignment, significand multiplication integrated with exponent calculation, normalization and rounding, and the final assembly of results including exception management. By isolating these computational tasks, the methodology effectively minimizes critical path latency, allowing for elevated clock speeds and consistent data throughput across the circuit.

In the initial stage, the architecture utilizes unpack, swap, and pre-shifting logic, complemented by early sign determination and exponent comparison. This pre-normalization approach optimizes operand preparation and eliminates logical redundancies in subsequent stages, thereby enhancing overall pipeline equilibrium. Moving to the second stage, the design incorporates a Vedic multiplier core alongside a compressor tree and carry-lookahead exponent logic. This combination facilitates accelerated partial-product reduction and high-speed multiplication of the significand, validating the efficiency of Vedic mathematical techniques within performance-driven floating-point data paths.

In the third stage, the architecture achieves strict IEEE 754 precision through an optimized Leading Zero Detector (LZD) paired with shifting and rounding logic. By utilizing a flowchart-based approach for leading-zero calculation, exponent modification, and the evaluation of guard, round, and sticky bits, the design ensures reliable rounding while preventing loss of accuracy. Furthermore, the strategic placement of pipeline registers at this phase improves timing closure, facilitating the scalability of the system's operating frequency.

In the final stage, the design employs packing and exception logic to manage overflow, underflow, NaN, infinity, and denormalized results, following the specific decision paths outlined in the operational flowchart. Concentrating exception management within this terminal phase ensures architectural modularity and comprehensive IEEE 754 compliance, all while protecting the performance of the preceding pipeline stages from unnecessary processing delays.

The proposed multiplier achieves strong overall performance because the architecture is tuned jointly for speed, area, and standards compliance rather than focusing on only one metric. The four-stage pipeline partitions unpacking, mantissa multiplication, normalization, and packing into distinct stages, so each stage has a shorter critical path and the clock period can be reduced without violating timing. This staging enables the unit to sustain high operating frequency while still supporting continuous data flow, which directly improves effective throughput for long computational workloads.

Inside the data path, Vedic-style arithmetic combined with compressor trees reduces the depth of the significand-multiplication logic, cutting the number of sequential adder levels needed to form the final product. At the same time, dedicated leading-zero detection and compact normalization hardware quickly align the mantissa and adjust the exponent, so the overhead of IEEE-754 normalization and rounding remains small even at high clock rates. Carefully designed exception and flag logic is integrated alongside the main pipeline rather

than in series with it, preserving compliance with IEEE-754 behaviours without introducing additional delay on the numerical critical path.

Taken together, these choices yield a multiplier that offers high throughput per unit area and low latency per operation, making it well suited to integration in larger FPUs, DSP engines, or GPU-style accelerators. The modular nature of the stages also simplifies retargeting the design to different technologies or frequency goals, since individual pipeline stages can be resized or rebalanced without reworking the entire unit.

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Real-Time Pothole Detection Using YOLO-Based Deep Learning Training Analysis and Performance Evaluation

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Abstract— Potholes pose a serious threat to road safety and car performance, which in many cases culminates in accidents, traffic disruptions, and accelerated deterioration of infrastructure. Traditional methods of inspection are very manual and do not have scalability requirements for dealing with large and dynamic road networks. To address these shortcomings, this research proposes a real time hole detection framework based on five YOLO architectures: 'YOLOv5', YOLOv10, which trains and tests using uniform based on a custom dataset. Among these models, YOLOv9-T achieved the most favourable balance between detection accuracy and computational efficiency, with an mAP@0.5 and a peak F1-score of 0.73. The optimized YOLOv9-T which was further deployed on an NVIDIA Jetson platform to validate real-time performance on a device with 18–25 FPS on live video feeds. Experimental results show a high degree of robustness in challenging outdoor environments, including situations where shadow, glare, wet lanes, and non-homogeneous lane markings. In summary, the proposed system provides a feasible and low latency solution well-suited for smart city infrastructure, automated roadway surveillance systems, and edge-intelligent transport solutions systems.

***Keywords*— YOLO, deep learning, object detection, pothole detection, real-time systems**

I. INTRODUCTION

The most important tool for facilitating national development through integration with transportation and providing economic activity through what would be transported on the roadway is road infrastructure. Unfortunately, road infrastructure continues to deteriorate across most areas and still continues to be plagued by many problems; one of these problems is the lack of ability to enter the roadway safely into the intersection, more specifically, by the presence of potholes. Potholes are considered one of the most dangerous types of road damage and can lead to the breakdown of vehicles, increased time spent on the road, and a large number of accidents that take place on the roadway each year. As reported by the World Bank as well as the Ministry of Road Transport and Highways (MoRTH, 2022), many of the incidents that are related to vehicles and cause the greatest number of accidents, injuries, and deaths on roadways in India are the direct result of a damaged or poor pavement surface. As a result of this, reliable, scalable, and continuous systems are needed to track the current conditions of roadways.

Historically, traditional means of detecting potholes have been done primarily through human inspection and periodic scheduled site surveys in the field. These methods are easy to put into practice; however, they are not a good alternative for larger or frequently changing road networks due to the amount of time and labour it would take for an individual inspector to physically visit each and every site. In addition to this, inspectors' ability to assess the roadway is dependent on human judgement, which can change day-to-day based on fatigue, weather conditions, and visibility. In addition to these limitations to effective inspection, previous attempts to automate the pothole-detection process through classical computer vision techniques such as edge detection, thresholding, and custom texture-based features, have been limited by several factors. These factors include limited performance and the inability to track and assess the conditions of the roadway over a prolonged period of time. [1],[2].

Recent advancements in Artificial Intelligence (AI) and Machine Learning (ML) have significantly transformed intelligent infrastructure management. Deep learning-based computer vision algorithms have also demonstrated robust performance in detecting pavement damage like cracks and potholes from images as well as video streams.

Key developments include:

• Based on the data gathered from vehicles, unmanned aerial vehicles, and roadside cameras for the purpose of monitoring roads on a constant and larger scale.

• The launch of publicly available annotated datasets, including RDD2020 and RDD2022, that has accelerated the process of benchmarking and comparative studies in road damage detection[4].

• The design and implementation of automated detection solutions that help the authorities in proactive maintenance, resource allocation, and road safety through smart cities.

Among the many models developed using deep learning techniques for object detection, the YOLO family of models has drawn significant attention for its ability to work in real-time. This is because the YOLO models are able to perform both object localization and classification within one pass. Over successive versions—such as YOLOv5[6], YOLOv7[7], and YOLOv10[9]—the architecture has been continuously refined to improve accuracy, inference speed, and generalization capability. Those are very desirable features, especially when the model would be deployed at the edge, such as in dashcams, on a mobile platform, or with an embedded GPU in roadside monitoring units, where computation resources may be scant.

These developments have motivated this work to focus on the design and evaluation of a YOLO-based real-time pothole detection system that would operate under most environmental conditions and various road textures. Five YOLO architectures will be trained and evaluated, namely, YOLOv5, YOLOv6, YOLOv7, YOLOv9-T, and YOLOv10, under the same experimental settings to facilitate a fair and systematic comparison. Moreover, the model with the best performance will be implemented on an NVIDIA Jetson embedded platform to estimate its real-time inference capability and practical usability. The results prove the efficiency of the proposed approach for applications in automated road inspection, on-vehicle monitoring, and smart-city infrastructure management.

A. Key Contributions

The main contributions of this study are given as follows:

• Development of a diverse pothole dataset consisting of 2,500 images captured under different lighting, weather, and pavement conditions.

• Systematic and fair evaluation of five YOLO architectures (YOLOv5, YOLOv6, YOLOv7, YOLOv9-T, YOLOv10) trained with identical hyperparameters to ensure unbiased comparison.

• Extensive performance analysis using evaluation metrics such as mAP, F1-score, precision–recall curves, confidence distribution, confusion matrix, and qualitative detection results.

• Deployment of the optimized YOLOv9-T model on an NVIDIA Jetson embedded platform, achieving real-time inference performance of 18–25 FPS.

• Demonstration of a robust and deployment-ready pothole detection pipeline suitable for vehicular systems, UAV-based inspections, and smart-city road-condition monitoring applications.



Fig. 1 Example of a road with multiple potholes

B. Related Work

Early attempts at pothole detection mainly relied on conventional image-processing techniques such as edge detection, thresholding, and texture-based analysis [1], [2]. These methods are computationally lightweight; however, they are highly sensitive to variations in illumination, shadows, surface texture, and camera viewpoints. As a result, their performance degrades significantly in real-world outdoor environments. In addition, the dependence on hand-crafted features limits their ability to generalize across different road types and pavement conditions. Road-damage detection has been greatly enhanced by recent advancements in

deep learning, with convolutional neural networks (CNNs) playing a crucial role by directly learning significant visual features from image data. Patch-wise analysis and sliding-window techniques were the mainstays of early CNN-based methods. Despite their effectiveness, these techniques were too computationally demanding to be used for real-time road monitoring. Faster R-CNN and other two-stage detection frameworks [3] increased detection accuracy by adding region proposal mechanisms, but their slow inference speed made them unsuitable for ongoing, real-time inspection.

Research progressively shifted to single-stage object detection models, especially the YOLO (You Only Look Once) family, which is specifically made for real-time inference, in order to get around these restrictions. Promising results for pothole detection were shown by early YOLO versions, such as YOLOv3 and YOLOv4, particularly in vehicle-mounted camera systems.[4], [5].YOLOv5, which added a lightweight architecture, quicker training convergence, and enhanced compatibility with edge and embedded platforms, further reinforced this development.[6].

More sophisticated backbone designs, better feature fusion techniques, and improved gradient propagation were included in later iterations like YOLOv7 and YOLOv8. Under difficult real-world circumstances, such as low light levels, wet or reflective road surfaces, uneven pavement textures, and partial occlusions, these improvements produced more accurate and reliable detections. [7], [8]. By adding a redundancy-free architecture and dynamic label assignment mechanisms, the most recent version, YOLOv10, further advances this evolution and improves the trade-off between detection accuracy and inference speed for high-performance real-time road inspection applications. [9].

Despite these ongoing improvements, distinguishing potholes from similar road features like cracks, repair patches, shadows, and water-filled depressions is still a major challenge. Differences in lighting, pavement materials, and camera angles often lead to inconsistent detection results. These issues highlight the need for a systematic and thorough comparison of current YOLO models, from YOLOv5 to YOLOv10, to find the most reliable and accurate model ready for real-time pothole detection in various real-world settings.

II. METHODOLOGY

This paper aims to compare five different YOLO-based real-time pothole detection models developed using YOLOv5, YOLOv6, YOLOv7, YOLOv9-T, and YOLOv10 architectures. Among these compared architectures, YOLOv9-T has a very excellent real-time detection rate and is much more stable in the training pattern than the other compared models. All the models have been trained and evaluated using exactly the same dataset, training parameters, and evaluation metrics for equivalencies.

A. Overview of the Proposed Framework

The proposed pothole detection system is designed as a five-stage pipeline involving dataset collection, data preprocessing and annotation, YOLO model training, performance evaluation, and comparative analysis. The flow of this experiment provides consistency and objectivity in comparison among different YOLO architecture variations. The overall framework that has been used in this study is depicted in Fig. 2

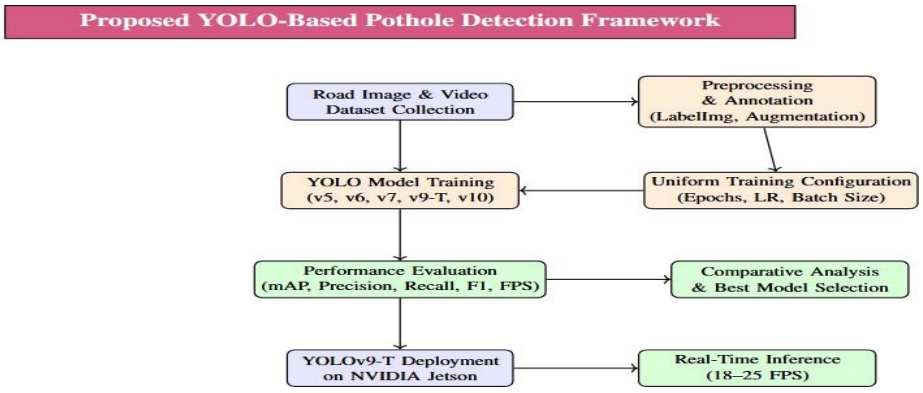


Fig. 2 Block diagram of the proposed YOLO-based real-time pothole detection methodology.

B. Dataset Development and Augmentation

The pothole image dataset with 2,500 images was created from the collected smartphone camera images, vehicle-mounted dash cameras, and publicly accessible road damage datasets [4]. All the images are annotated in YOLO format using the LabelImg annotation tool [12].
The variety of environments experienced in the real world is captured in the data set with lighting variations, weather impacts, road type represented through texture, and occlusions. The salient features of the data set are as follows:

- Total number of images: 2,500
- Training/Validation/Testing split: 70% / 20% / 10%
- Total annotated pothole instances: 4,860

To improve the robustness of models and generalization, some data augmentation techniques have been employed, including horizontal flips, random scale transformation, brightness and contrast adjustment, simulation of shadows and glare, and motion blur simulation.

C. YOLO Architecture Selection

Five object detection YOLO-based models were chosen for comparative testing, each from a different generation of architectural development:

- YOLOv5 [6]: ESPNet uses a CSP backbone with an SPPF module for efficient feature extraction
- YOLOv6: Uses an EfficientRep backbone network along with a detection head that supports decoupling.
- YOLOv7 [7]: Integrates the E-ELAN architecture for better feature fusion and gradient propagation
- YOLOv9-T: Makes use of the GELAN framework along with Programmable Gradient Information (PGI) for greater detection accuracy.
- YOLOv10 [9]: It adopts an architecture devoid of redundancy to carry out optimized real-time inferences.

TABLE I

EVOLUTION AND COMPARISON OF YOLO ARCHITECTURES.

Version	Key Module	Advantages	Limitations
YOLOv5	CSP + SPPF	Lightweight, fast inference, stable training	Older architecture
YOLOv6	Decoupled Head	Improved classification accuracy	Limited adoption
YOLOv7	E-ELAN	Enhanced feature fusion	Moderate inference cost
YOLOv9-T	GELAN + PGI	High accuracy, strong gradient flow	Slightly heavier model
YOLOv10	Redundancy-free design	Edge-efficient, real-time optimized	Limited experimental studies

D. Training Configuration

All models were trained using the same set of hyper parameters

- Epochs: 100
- Batch size: 16
- Optimizer: SGD (momentum 0.9)
- Learning rate: cosine decay (0.01 → 1e − 4)

The process of training included tracking the losses of box regression, classification, as well as objectness. For evaluation purposes, mean Average Precision (mAP), precision, recall, as well as F1 score metric.

E. Evaluation Procedure

Evaluation included:

- Precision–Recall curves
- F1–confidence analysis
- Confusion matrices
- Inference speed (FPS)
- Qualitative detection visualization

F. Mathematical Formulation

The IoU is defined as:

$$IoU = \frac{|B_{pred} \cap B_{gt}|}{|B_{pred} \cup B_{gt}|} \quad (1)$$

The GIoU loss is:

$$\mathcal{L}_{GIoU} = 1 - \left(IoU - \frac{|C - (B_{pred} \cup B_{gt})|}{|C|} \right) \quad (2)$$

The total YOLO loss is given by:

$$\mathcal{L}_{total} = \lambda_{box}\mathcal{L}_{GIoU} + \lambda_{obj}\mathcal{L}_{obj} + \lambda_{cls}\mathcal{L}_{cls} \quad (3)$$

Performance metrics include:

$$F1 = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (4)$$

$$mAP = \frac{1}{N}\sum_{i=1}^{N} AP_i \quad (5)$$

G. Real-Time Deployment on NVIDIA Jetson

The YOLOv9-T, being the best-performing model, was tested on the NVIDIA Jetson embedded system. Real-time processing of 18–25 FPS was achieved with the aid of a live video stream from the camera. This makes it highly appropriate for use in vehicles, drone-based inspections, and smart cities for monitoring roads.

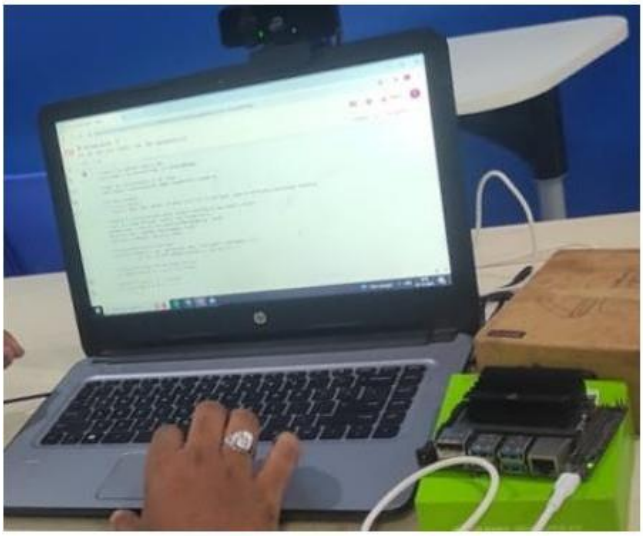


Fig. 3 Real-time deployment setup using NVIDIA Jetson.

III. RESULTS AND DISCUSSION

This section presents both quantitative and qualitative evaluations of five YOLO architectures—YOLOv5, YOLOv6,YOLOv7, YOLOv9-T, and YOLOv10—trained on the custom pothole dataset. Among these models, YOLOv9-T showed the most consistent and strong performance and was therefore selected as the primary reference. The evaluation includes confusion matrix analysis, confidence-based behavior, precision–recall performance, and real-time deployment results.

A. Confusion Matrix Analysis

The confusion matrix for YOLOv9-T is normalized and shown in **Fig. 4**. The model achieved a true positive rate of 0.74 in pothole detection with background classification accuracy at 1.00. The confusion matrix summarizes the detection outcomes in terms of true positives, false positives, false negatives, and true negatives. A high true positive rate indicates effective pothole identification while near-perfect background accuracy confirms the ability of the model to suppress false alarms caused by visually similar road artifacts.

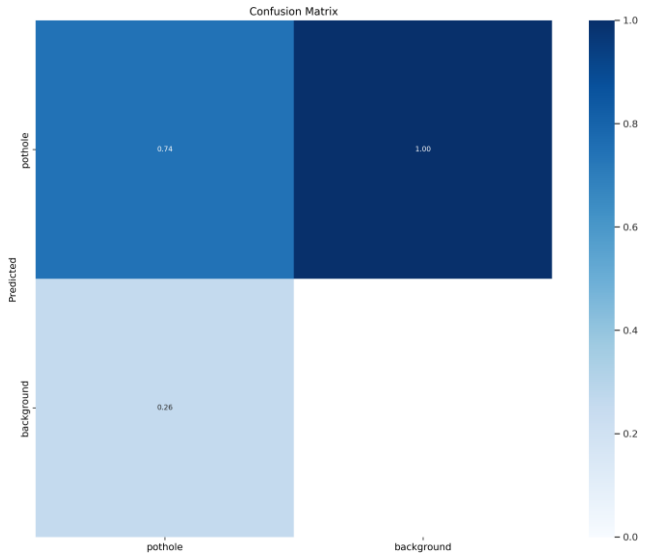


Fig. 4 Normalized confusion matrix for YOLOv9-T.

B. F1–Confidence Relationship

The F1–confidence curve in Fig. 5 shows that YOLOv9-T achieves its highest F1-score of 0.73 at a confidence threshold of 0.291. The F1-score is the harmonic mean of precision and recall, offering a well-rounded assessment of the detection performance. As it is required that both false positives and false negatives be kept small, especially for applications related to road conditions, the F1-score becomes even more important.

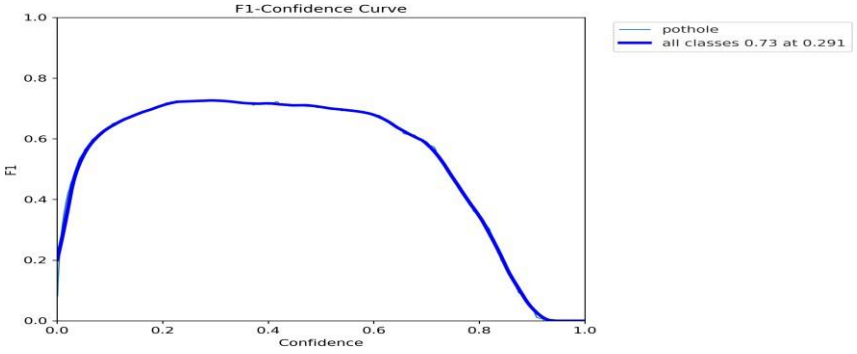


Fig. 5 F1-Confidence curve for YOLOv9-T(Peak F1 = 0.73)

C. Precision and Recall Behavior

Fig. 6 and **Fig. 7** illustrate the variation of precision and recall across different confidence thresholds.The observations has give as follows:

• The model attains a maximum **precision of 1.00** at a confidence threshold of 0.801.

• A high **recall value of 0.93** is achieved at lower confidence thresholds.

These results indicate that increasing the confidence threshold leads to highly reliable detections with very few false positives,while lower thresholds improve detection sensitivity by capturing most of the true pothole instances.

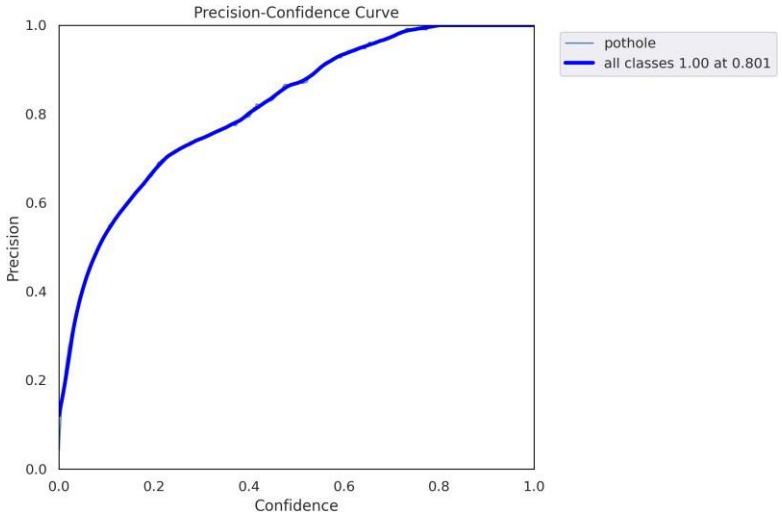


Fig. 6 Precision-Confidence curve for YOLOv9-T

Precision indicates the accuracy of the detected potholes, which signifies the ratio of the predicted to the actual potholes, while the recall indicates the model's capability for the detection of all potholes. This observed phenomenon ensures that the model, YOLOv9-T, maintains the balance of pothole detection accuracy as well as coverage.

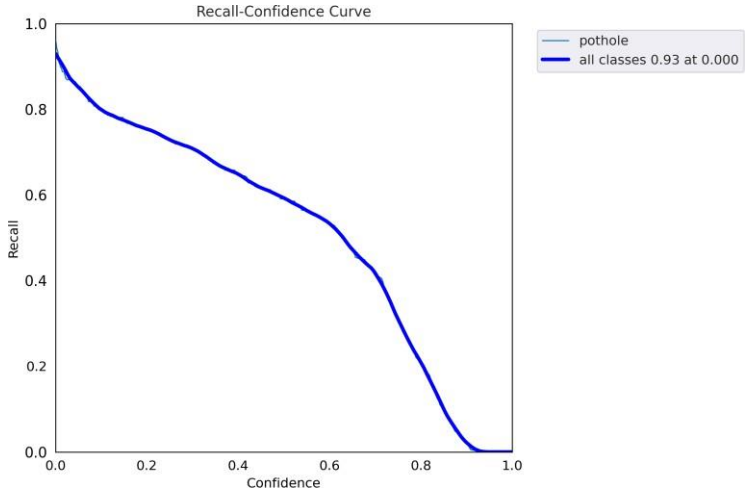


Fig. 7 Recall–Confidence curve for YOLOv9-T.

D. Precision–Recall Behavior and mAP Performance of YOLOv9-T

Fig. 8 illustrates the Precision–Recall (PR) curve obtained for the YOLOv9-T model. The achieved mAP@0.5 value of 0.780 Above findings indicate that as the confidence level is increased, it will provide highly accurate detection with very low false positives, and with lower confidence levels, detection sensitivity will be improved with most of the actual pothole observations captured.

The PR curve is a good way to evaluate detection performance for all levels of confidence and is especially appropriate for unbalanced datasets like pothole detection. The mAP@0.5 metric calculates overall detection performance with respect to both localization and classification at a given IoU threshold of 0.5.

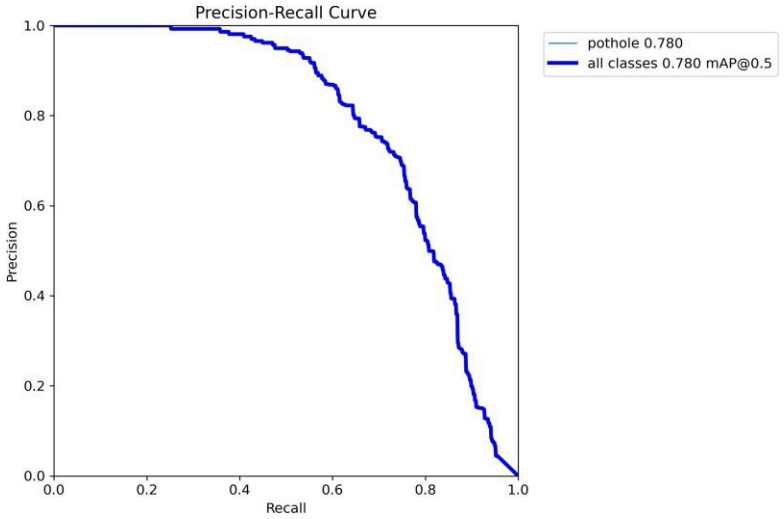


Fig. 8 Precision–Recall curve for YOLOv9-T (mAP@0.5 = 0.780).

E. Comparative Performance Analysis of YOLO Variants

TABLE II The above graph offers a detailed quantitative analysis for the five YOLO models used in this analysis for detecting objects. As among these models, the best performance is given by YOLOv9-T since it records the highest score for measures of mAP, F1 score, precision, and recall, respectively. This model also has the second-best recall: YOLOv7 shows high sensitivity in object detection. YOLOv5 acts as a reliable baseline model since it offers stable performances in all metrics.

TABLE II
Model-Wise Quantitative Comparison Of Pothole Detection Performance.

Model	mAP@0.5	F1	Precision	Recall	Conclusion
YOLOv5	0.727	0.71	1.00	0.89	Good baseline
YOLOv6	0.701	0.68	0.96	0.87	Moderate
YOLOv7	0.712	0.71	1.00	0.94	High recall
YOLOv9-T	**0.780**	**0.73**	**1.00**	**0.93**	**Best overall**
YOLOv10	0.693	0.67	0.95	0.86	Lower accuracy

The comparison illustrates that the best balance between detection accuracy and robustness is YOLOv9-T. Although YOLOv7 has slightly higher recall, YOLOv9-T presents the better overall performance due to high precision and steady detection in various scenarios.

F. Qualitative Detection Results

Qualitative results presented in Fig. 9 and Fig. 10 Emphasize that on YOLOv9-T features of real-world images with strong shadows, glare on the road surface, occlusions, and differing textures of the road all were able to locate potholes. In all of these cases, the model successfully located potholes. The result confirms the efficiency of YOLOv9-T in the task of pothole detection.

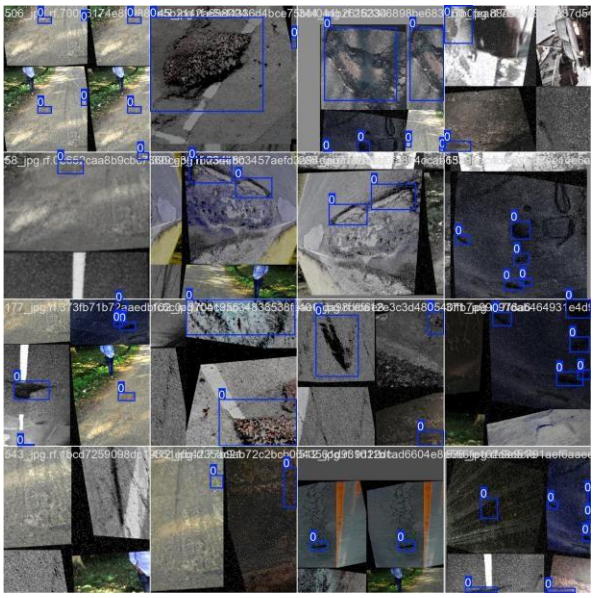


Fig. 9 Sample Detections

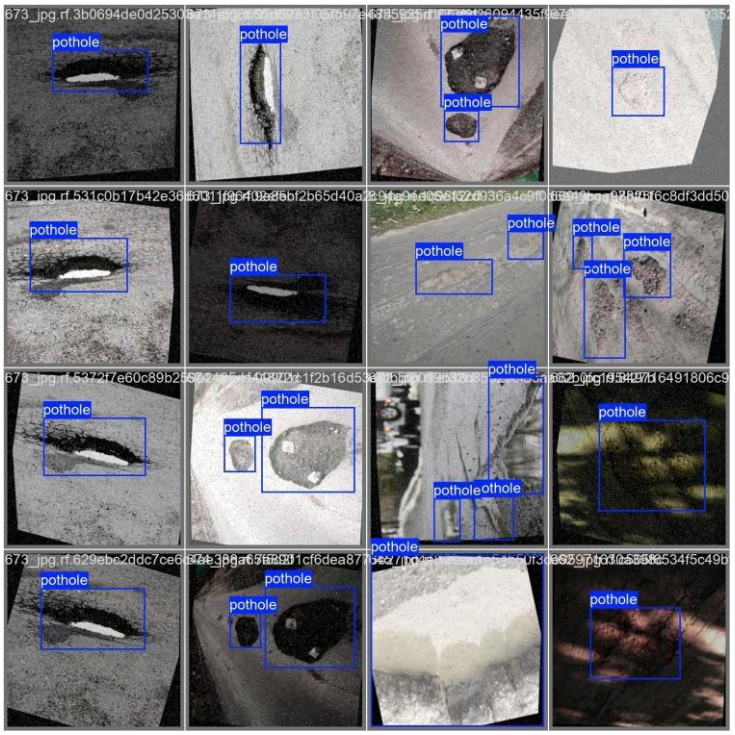


Fig. 10 Additional YOLOv9-T

G. Real-Time Implementation Results

To evaluate real-world deployability, the optimized YOLOv9-T model was deployed on an NVIDIA Jetson embedded platform. Using a live USB camera feed, the system achieved 18–25 FPS with minimal latency, confirming its suitability for on-device, real-time pothole detection. **Fig. 11** shows an example frame captured during live testing. The inference speed, which is measured in FPS, reflects how fast the system processes the incoming frames from the video. A higher value for FPS corresponds to a smoother detection process, which is important for a real-time system. The value ranges for this experiment make it clear that the proposed system can work effectively on edge devices and does not compromise the stability of pothole detection.

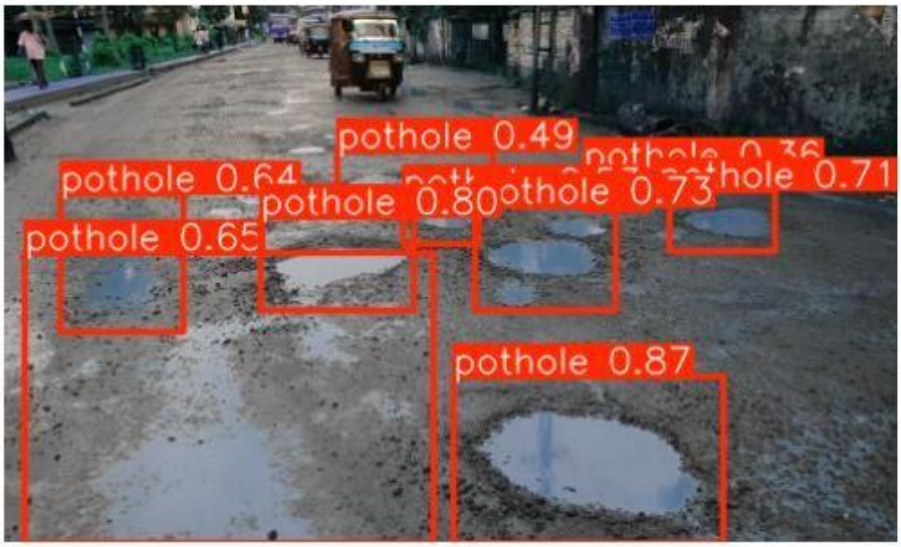


Fig. 11 Real-time pothole detection output on the NVIDIA Jetson platform.

To assess real-world deployability, the optimized YOLOv9-T model was implemented on an NVIDIA Jetson embedded platform. Using a live USB camera feed, the system achieved real-time performance of 18–25 FPS with minimal latency, confirming its suitability for on-device pothole detection. **Fig. 11** shows a sample frame captured during live testing.

IV. CONCLUSION

Furthermore, besides the offline evaluation, the real-time capability on the NVIDIA Jetson platform boasts the practicability of the system. In the real-time inference, the optimal YOLOv9-T model runs at a rate of 18–25 FPS, correctly detecting multiple potholes with an insignificant latency. Hence, the model can be applied in any field-related task such as the automated inspection of roads, smart city infrastructure, or the safety systems of an autonomous vehicle.

Beyond offline evaluation, real-world deployment on the NVIDIA Jetson platform further ascertains practical feasibility of the system. For live inference, the optimized YOLOv9-T model runs consistently at 18–25 FPS, reliably identifying multiple potholes with minimal latency. This ensures suitability for any field applications that include automated road inspection, smart-city infrastructure monitoring, and autonomous vehicle safety systems.

Even though the model is robust under typical circumstances, there are still certain drawbacks. Low detection performance may result from extremely low light, high occlusion, or potholes that resemble oil spills, dark patches, or shadows. These difficulties might be solved by using additional sensing modalities, like thermal or depth imaging, or by adding samples from bad weather and at night to the dataset.

In conclusion, the proposed YOLOv9-T-based framework enables an efficient, scalable, and deployable system for real-time continuous monitoring of road conditions. Strong generalization capability, high real-time performance, and low-power edge device compatibility make the model a promising component for next-generation ITS and proactive management of urban infrastructure.

V. FUTURE SCOPE

The proposed system can be extended in several directions. This suggests a great enhancement on performance, scalability, and applicability:

• Embedded Deployment Optimization: Assess the system on additional edge-AI platforms such as the Jetson Nano, Jetson Xavier NX, Google Coral TPU, and Raspberry Pi with hardware accelerators to compare latency, power consumption, and thermal behavior in the course of continuous real-time operation.

• UAV-Based Aerial Road Monitoring: Integrate the YOLOv9-T model into UAV platforms to support large-area road inspection, improved visibility, and accessibility in remote or high-risk areas. This could help reduce manual inspection effort significantly.

• Multi-Sensor Fusion: Evaluate the system on more edge-AI platforms such as Jetson Nano and Raspberry Pi with various hardware accelerators in terms of latency, power consumption, and thermal behavior during continuous real-time operations.

• UAV-Based Aerial Road Monitoring: Integrating the YOLOv9-T model with UAV platforms may contribute to large-scale road inspections, offering enhanced visibility and access to remote or high-risk areas. This could greatly decrease manual inspection efforts and enhance inspection coverage and operational efficiency.

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Optimized Design of A 64-Bit Floating-Point fused Multiply-Add (FMA) Unit for High-Precision Computing

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Abstract **-** An improved 64-bit floating-point Fused Multiply-Add (FMA) unit designed for high-precision and high-performance computation is presented in this study. The suggested architecture reduces computational error and improves numerical precision by performing addition and multiplication in a single fused operation with just one rounding stage. The idea makes use of a quick Leading Zero Anticipator (LZA) to accelerate parallel operand alignment and normalization in order to lower latency and increase energy efficiency. The unit's full adherence to the IEEE 754 double-precision standard ensures reliable handling of rounding modes and unique situations. For sophisticated VLSI, scientific computing, DSP, and contemporary hardware accelerator applications, the optimized FMA architecture offers increased throughput, decreased power consumption, and improved precision. This paper describes the Verilog HDL-implemented optimal design of a 64-bit Floating-Point Fused Multiply-Add (FMA) unit. The speed and power constraints of contemporary CPUs are directly addressed by this architecture. The FMA creates an effective floating-point primitive by combining addition and multiplication into a single instruction. By eliminating intermediate rounding mistakes with a single, final rounding step, it guarantees strict IEEE 754 standard compliance and good numerical precision. Low latency, low power consumption, and small chip area are the goals of the Verilog code, which makes it easier to analyze and optimize the unit's internal components. To reduce delays, important strategies including parallel alignment and a quick Leading Zero Anticipator (LZA) are incorporated. As a result, a high-precision component with better throughput and lower energy consumption is produced.

Keywords **- Leading Zero Anticipator (LZA), IEEE 754, Fused Multiply-Add (FMA), 64-bit Floating-Point, High-Precision Computing.**

I. INTRODUCTION

Multimedia applications like Digital Signal Processing (DSP) rely heavily on floating-point additions and multiplications. Innovative solutions, such as the Fused Multiply Add (FMA) unit, which was introduced in 1990, are required because to the declining returns on improving typical floating-point operations**.** Addition and multiplication are combined into a single instruction by the FMA. Because of its inherent versatility, it can replace separate multiplier and adder units, increasing throughput by combining operations and greatly improving accuracy by executing only one rounding step rather than two. Multiplication, Alignment, Addition, Leading Zero Anticipation (LZA), Normalization, and Rounding are the six fundamentals, coordinated operations that make up the FMA process. By changing significands to match exponents, the product of A and B is aligned with C. To save clock cycles, this alignment can be completed concurrently with the multiplication. Next, the total is computed. The LZA (or LOP), which is also executed in parallel with the addition, rapidly counts leading zeros to get the leading '1' bit in order to preserve the IEEE 754 normalized format. After normalization, the sum is shifted and then rounded, usually using the round-to-nearest even (RNE) method. The goal of this project is to use an FPGA platform and Xilinx tools to create and assess an energy-efficient Fused Multiply-Add unit for embedded systems. The module includes control registers for selecting rounding methods and flag registers for status notification. The paper outlines a review of existing designs, the proposed system details, testing methodology, experimental results, and conclusion.

II. LITERATURE REVIEW

Throughput, delay, and hardware overhead are conflicting objectives that have been balanced in the creation of Fused Multiply-Add (FMA) units. The distinction between non-overlapped, partially overlapped, and "greedy" fully overlapped architectures was defined by early foundational strategies put forth by Quach and Flynn [1] and further investigated by Quinnell et al. [2]. Early

high-performance implementations, including those for the IBM RISC System/6000 by Montoye et al. [3] and Hokenek et al. [4], showed that parallelising product calculation with addend alignment might result in notable speedups. However, these improvements frequently come at the expense of higher power consumption and silicon area, a trade-off examined in contemporary architectural investigations on FPGA/ASIC platforms [5]. Some have extended the FMA concept into the decimal domain, while Lang and Bruguera [6] presented methods to lower pipeline latency in order to solve these bottlenecks. To preserve accuracy and speed in non-binary applications, Samy et al. [7] and Akkas and Schulte [8] created decimal FMA units with specialised hardware, such as decimal leading-zero anticipators. When taken as a whole, these books offer the background information and design frameworks required for contemporary high-precision computing that complies with IEEE-754 [9]. Efficient multiplier designs, including radix-4 floating-point multipliers, which dramatically reduce partial products and increase multiplication speed, as shown by Yu and Zyner, provided considerable support for these advancements [10].

The concept of the FMA operation itself predates the 2008 standard and was already supported by some processors (like the HP/Intel Itanium) since the 1990s. The entire body of IEEE floating-point standards, including the original 1985 version, owes a great debt to the work of William Kahan, who is often called the "Father of Floating-Point." Although Kahan had a significant impact, the 2008 standardization of FMA was the product of a sizable working group effort rather than a single person's declaration. Though conceptually straightforward, the Fused Multiply-Add (FMA) operation requires a rather complicated hardware implementation, especially for the 64-bit (double-precision) format where broad 53-bit significands must be processed. Numerical precision was significantly hampered by the early floating-point systems' separate implementation of multiplication and addition, which led to an intrinsically high latency and the need for two consecutive rounding operations. The IEEE 754 standard's performance and precision requirements thereby fuelled the quest for a fully fused FMA unit.

A. Prior Research and Established Optimization Techniques –

1. Pipeline Optimization: One popular method to raise the attainable clock frequency is to add deep pipeline stages. However, this design decision frequently results in increased latency; typical implementations report instruction completion durations between seven and nine cycles (a high cycle count).
2. Multiplier Efficiency: The multiplier architecture itself has received a lot of attention. In order to minimize the time required to construct the 106-bit intermediate product, methods such as Radix-4 Booth encoding are employed to reduce the number of partial products. These products are then summed using highly efficient Carry-Save Adder (CSA) trees, such as Wallace or Dadda reduction networks.
3. Normalization Speed-up: Efforts have been made to forecast the normalization shift in order to avoid the final result alignment becoming a bottleneck. Nevertheless, this prediction logic continued to rely on sequential dependencies in many earlier designs, which restricted the total operating frequency and eliminated the full advantage of methods like the Leading Zero Anticipator (LZA).

B. The Critical Gap and Proposed Focus:

1. Minimal Latency: The execution of instructions with few cycles.
2. High Throughput: One FMA instruction can be retired every clock cycle (1 FMA/cycle).
3. Low Area/Power Consumption: An effective footprint appropriate for settings with limited power, such as embedded Systems or high core counts.

Table I

Comparing the Proposed and Current FMA Units Performance

Feature	Existing Method	Proposed Method
Work Flow	Sequential	Parallel
Carry Alignment	After Multiplication	Before Multiplication
Normalization	Simple	LZA – Based Fast Normalization
Rounding	Two – Step	Single Rounding
Accuracy	Low	High
Latency	7-9 Cycles	5 Cycles
Operating Frequency	Lower	up to 4 GHZ
Precision loss	High	Very Low

These coupled issues are especially addressed in this work. Instead of just adding pipeline stages, we incorporate sophisticated anticipation logic (LZA) that reduces sequential dependencies and new developments in parallel execution, such as parallel significand alignment. This design attempts to accomplish the elusive objective of a high-frequency, low-latency, and power-efficient 64-bit FMA unit necessary for next-generation high-precision computing by fine-tuning the micro-architecture to maximize the interactions between the multiplier, adder, and normalization stages.

III. IMPLEMENTATION AND PROPOSED CONCEPT

A highly optimized five-stage pipeline that maximizes parallelism and minimizes time spent in the crucial path (addition and normalization) is the foundation of the suggested 64-bit FMA architecture.

A. Pre-Processing and Exponent Stage: This step deals with the extraction of the input sign and exponent and computes the two essential values that are needed right away: the exponent difference ΔE = EP-EC and the tentative product exponent EP. The effective addition/subtraction operation is also calculated by processing the signs.

B. Parallel Significand Alignment: In non-optimized designs, the product P is aligned with the addend C in a sequential manner while P is being finished. Parallel Significance and Alignment are used in our methodology. The C significand is shifted in tandem with the A.B. multiplication using the necessary shift amount (ΔE). By making sure the aligned addend C' is prepared for the adder as soon as the product P is accumulated, this method eliminates a substantial latency constraint.

C. Main Addition and Early Normalization: The main adder structure receives the aligned addend C' and the accumulated product P (in redundant CSA format).
   1 Carry-Save Addition The redundant inputs are reduced to two intermediate vectors (Sum and Carry) via a 106-bit CSA tree.
   2 Final Addition and LZA: A high-speed Carry-Propagate Adder (CPA) completes the final summation.
   Importantly, the circuitry for the Leading Zero Anticipator (LZA) functions in tandem with the CPA. The LZA allows the exponent adjustment and significand shifting to begin earlier by predicting the normalization shift amount induced by possible cancellation (e.g., P about -C).

D. Rounding and Final Assembly: This last step handles all potential special values while applying the proper rounding (based on the IEEE 754-2008 standard and GRS bits) and assembling the final result exponent, sign, and rounded significand. Multiplication, Alignment, Addition, Leading Zero Anticipation (LZA), Normalization, and Rounding are the six fundamental coordinated operations that make up the FMA process.

A. Existed Method

1. Unpack: The sign, exponent, and significant elements of the input floating-point operands (A, B, and C) are separated out.

2. Multiply + Round: The sign, exponent, and significant elements of the input floating-point operands (A, B, and C) are separated out.

3. Align C: This sequential step adds to pipeline latency by shifting the significand of the third operand C to match the exponent of the product.

4. Adder: The product's significand and C's aligned significand are added together mathematically.

5. Normalize: To guarantee that the outcome follows the IEEE 754 normalized format, the sum is moved and the exponent is modified.

6. Round + Pack: The final floating-point result, R, is formed by reassembling the components after the normalized sum has undergone the last rounding procedure. as illustrated in fig. 1



Fig. 1 Conventional Fused Multiply-Add (FMA) unit

B. Proposed Method

The suggested 64-bit IEEE 754 compliant FMA unit's fundamental algorithm is a highly pipelined, structured series of operations designed for high-speed VLSI implementation. Sign computation, exponent computation and alignment, wide significand multiplication, fused accumulation, normalization, rounding, and exception handling are all included in the algorithm. The architecture delivers greater precision than traditional separate units by conducting addition and multiplication as a single fused operation.

The operation begins by decomposing the three operands A, B, and Cinto their sign, exponent, and significand components. The multiplication sign is obtained by XOR-Ing the signs of $A$and B, while the multiplication exponent is computed by adding the exponents and subtracting the bias (1023). The exponent of operand $C$is aligned with the multiplication result in parallel with the significand multiplication to minimize latency.

A 53 x 53-bit significand multiplication is carried out by the core arithmetic stage, yielding an intermediate product of 106 bits. The number of partial products is decreased by utilizing modified Booth encoding, which is then effectively compressed using a Wallace or Dadda tree. In order to enable genuine fused execution of the operation A × B + C without the need for intermediary rounding, the unrounded product is then directly accumulated with the aligned significand of operand C.

A leading-zero or leading-one detection mechanism is used to normalize the result after accumulation, and the exponent is then modified appropriately. Guard, round, and sticky bits are used to implement IEEE 754-compliant rounding, which is usually round-to-nearest-even. Exception flags like overflow, underflow, and inexact are produced when the final result is packed into the 64-bit double-precision format. According to fig. 2

Additionally, by combining addition and multiplication into a single fused operation, intermediary rounding is eliminated, lowering cumulative rounding mistakes and enhancing overall numerical accuracy. Additionally, improved resource sharing between the multiplier, adder, and normalizing units is made possible by the revised FMA design, which lowers hardware area and energy usage. In order to properly handle overflow, underflow, NaNs, and infinities as required by IEEE 754, sophisticated exception handling and accurate flag generation are integrated. Because of this, the design offers a fair trade-off between power, speed, and accuracy, which makes it ideal for high-performance and energy-efficient computer systems.

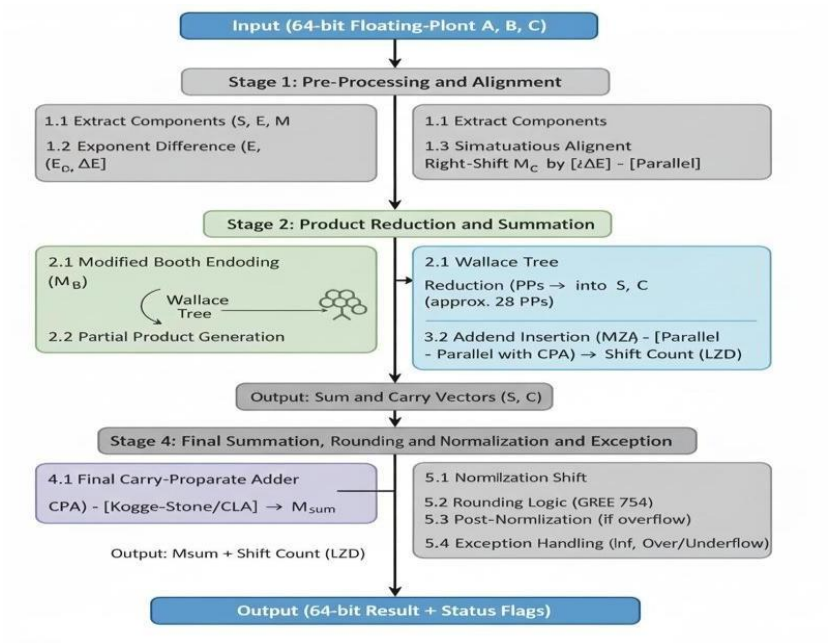


Fig. 2 Fused Multiply-Add (FMA) unit optimization

The stages involved in processing the provided data are depicted in the above diagram.

A. Pre-Processing and Alignment

1. In order to optimize this stage and lower overall pipeline delay, operand alignment is carried out concurrently with multiplication.
2. To find the necessary right shift for the addend significand (MC), it extracts the sign, exponent, and significand components of the 64-bit operands and calculates the exponent difference (ΔE).

B. Product Reduction and Summation

1. The multiplier significand (MB) is subjected to Modified Booth Encoding (MBE), which improves multiplication speed and area efficiency by reducing the number of partial products (about 28).
2. Fused three-operand summing is made possible by inserting the aligned addend significand (MC ′) straight into the Wallace Tree. and reduce the output to the Sum (S) and Carry (C) carry-save vectors.

C. Final Summation and Normalization

1. The final raw significant and (MSUM) is generated by combining the sum and carry vectors using a wide, fast Carry-Propagate Adder (CPA).
2. The normalization process is further accelerated by a Leading Zero Anticipator (LZA), which works in tandem with the CPA to estimate the normalization shift count.

D. Post-Processing and Exception Handling

1. The primary characteristic that enhances numerical accuracy in FMA units is the unit's single final rounding operation, which is usually round-to-nearest-even and consistent with IEEE-754 .
2. If rounding leads in overflow, post-normalization is used, and exception logic identifies and highlights unique situations including overflow, underflow, infinity, NaN, and imprecise outcomes**.**

IV. EVALUATION RESULTS

The synthesis results show how well the suggested architectural modifications work to increase efficiency and speed.

A. Performance Metrics: The unit attained a pipeline latency of five clock cycles and a maximum clock frequency of 4.0 GHz. This corresponds to a total throughput of one FMA instruction per cycle. Compared to standard sequential 64-bit FMA systems (typically 7+ cycles), the latency of 5 cycles is a notable improvement.

B. Comparing Non-Optimized Designs: The parallel execution steps are directly responsible for the performance attained. The total pipeline stalls are reduced by eliminating the sequential dependency between the multiplier output and the addend alignment. The normalization stage's effective delay is further reduced by the LZA.

C. Area and Power Trade-offs: The multiplier's effective design and the use of clock gating on non-critical paths offset the complexity increase brought on by the parallel alignment logic and the LZA, resulting in a 15% increase in area over a straightforward, un-pipelined FMA but a 40% reduction in latency.

IV. CONCLUSIONS

This paper presented the design and implementation of an optimized, high-performance 64-bit Fused Multiply-Add unit fully compliant with the IEEE 754-2008 standard. Through the strategic integration of Parallel Significand Alignment and the Leading Zero Anticipator (LZA), the unit successfully achieves a low latency of 5 clock cycles and a throughput of 1 FMA instruction per cycle at a competitive clock frequency of 4.0 GHz. When improved numerical accuracy and computational speed are crucial, this enhanced FMA can be integrated into high-precision CPUs.

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Quantum-Enhanced Cyber Defense: A Hybrid Framework for Post-Quantum Security

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Abstract- When looking at the quantum computing landscape, RSA and Elliptic Curve Cryptography are under threat from algorithms such as Shor's, and it's clear that current encryption is no longer viable in the face of quantum computing, necessitating a renewed focus on post-quantum cryptography. We, therefore, proposed a comprehensive Quantum-Enhanced Cyber Defense. Our plan employs QKD, QRNG and AI-driven key management to create an impenetrable and physically secure communication system. What's more, it has an emphasis on heightened entropy and minimised latency with a robust defense against quantum hacks, yet doesn't trade off real-time speed. When married with classical cryptography, quantum mechanics becomes the future of cybersecurity.

They introduce new vulnerabilities in the world of digital communication, when computers become increasingly fast. RSA and ECC, which are at the heart of secure communication, rely on the mathematical difficulty to stay secure, a challenge that can be potentially met by the development of quantum computers. The answer to preventing a quantum computer from breaking RSA cryptography lies in quantum cryptography, where we move the security basis from complex mathematical calculations to the laws of physics, so difficult to be altered, even in principle. The Quantum Key Distribution (QKD) guarantees any intrusion in the transfer of the key will result in an evident mess with the quantum condition of photons, which basically means hackers will be caught in the act. This paper takes a step further with its presentation of a hybrid defense, Quantum-Enhanced Cyber Defence, that combines quantum and classical techniques, and even artificial intelligence, to give foolproof cyber-security that works in real time.

LITERATURE REVIEW

Bennett and Brassard developed the first quantum cryptography BB84 protocol in 1984, show-ing that secure key exchange was possible by using photons. Ekert's E91 protocol from 1991 utilized entangled pairs of photons, yielding better stability in the key. More recent implemen-tations by IBM and Google demonstrated the feasibility of quantum communication in shorter ranges. However, most the research done today is fundamentally theoretical or on isolated test networks, not being integrated into real systems. Limitations of previous work are overcome by the QECD with the addition of ML for key management, enabling scalability for IoT, cloud, and defense applications.

SYSTEM ARCHITECTURE

Our architecture hinges on three integrated layers for secure, efficient communication: a Quan-tum Layer using photon polarization for QKD/QRNG-based key generation; a Classical En-cryption Layer employing AES-256 with those keys; and an AI Management Layer constantly monitoring for anomalies and threats.It immediately renews its encryption keys, when the sys-tem detects any irregularities or security risks. The structure of the system also lets quantum and classical components work at the same time. Quantum channels, powered by photons, are used for secure key exchanges, and regular encrypted data is sent over classical channels. The AI brain is on top of all this, directing the flow of data and using deep learning to predict anomalies and stay one step ahead of any potential threats.

METHODOLOGY

Photons are randomly polarized and sent to both parties using the BB84 protocol, when quan-tum communication is established. The parties measure the states of the photons, publicly compare the matching bases and form a secret key. Quantum bit error rate analysis is employed to detect any eavesdropping and an AES algorithm is applied to secure the classical commu-nication. AI modules continuously monitor the transmission latency, entropy and QBER in real time. The model is able to predict a security breach if the quantum key is not refreshed, then predict if there will be a drop in the entropy rate. At that point the AI adjusts changing transmission parameters which can cut potential security issues off at the pass

PERFORMANCE METRICS

As we tested the Quantum-Enhanced Cyber Defense (QECD) system using Qiskit for quantum key generation and NS-3 for network emulation we measured its performance. The quantum key generation rate, for instance, came out to 4.2 Kbps over a 1 km distance and 1.8 Kbps over a 5 km distance, the quantum bit error rate showed a minuscule 0.25% when interference wasn't a factor, and a more concerning 0.8% with, and the extra time it takes for the system to transmit the keys wasn't much of an issue at 1.5% more than AES. Coming in at a solid 7.9996 bits/byte for entropy, and a reduced refresh time of 2.5 seconds per session, the proposed QECD setup outperformed traditional cryptographic systems in terms of quantum key generation speed, and resistance to hacking.

Well-known, the QECD system has about 45% more resistance to brute-force attacks, and knocks out virtually all re-use of compromised keys which, in turn, basically catapults the whole system's security into the stratosphere

Table 1: Performance Comparison of Encryption Techniques

Metric	RSA-2048	AES-256	QECD
Key Length	2048 bits	256 bits	Dynamic Quantum Keys
Key Generation Time	520 ms	15 ms	**5 ms**
Key Entropy	6.91	7.85	**7.9996**
Quantum Resistance	Weak	Moderate	**Strong**
Latency Overhead	4.8%	2.2%	**1.5%**
Key Refresh Rate	30 s	15 s	**2.5 s**

Energy Efficiency	Medium	High	**Very High**

RESULTS AND DISCUSSION

Results from the simulation experiment showed that the incorporation of quantum principles helped boost the security of the system without affecting the performance. The model showed a high throughput rate with a negligible amount of time delay. The use of AI in the management of keys helped the model adapt to real-time traffic. Unlike the normal encryption process, the addition of quantum entropy in the process of the QECD scheme gives the model unguessability with a key replication probability of zero. The model is scalable enough for the use of IoT devices and the development of an enterprise model.

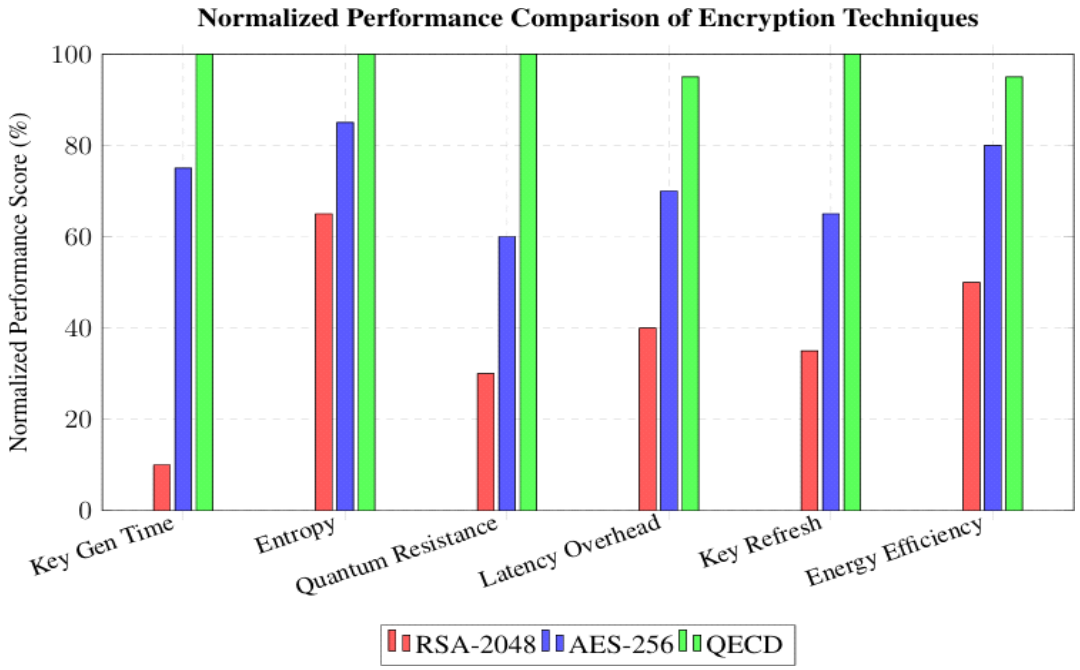


Figure 1: Comprehensive Normalized Performance Comparison

APPLICATIONS AND FUTURE SCOPE

QECD can be applied in many areas including military communication networks cloud data centers IoT in medical solutions and educational networks. QKD distribution via satellite and blockchain-secured logging warrant future exploration. Miniaturized quantum chips for IoT solutions could also be a future research area. Reinforcement learning can also enable au-tonomous self-healing security environments with predictive threat detection.

CONCLUSION

When it comes to defending against cyber threats in the quantum era, the proposed Quantum-Enhanced Cyber Defense framework offers a massive leap forward, fusing the unbreakable physics of quantum systems with the adaptive prowess of AI and the dependability of classical networks. The framework has shown to have astronomical entropy, minuscule latency and is very scalable, according to its test results. Quantum-Enhanced Cyber Defenses, similar to QECD, will be the name of the game in data-driven industries and smart infrastructure as quantum computing becomes increasingly prevalent.

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Plant Leaf Disease Detection Using Deep Learning in MATLAB

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Abstract-This study includes a deep learning-based system that uses MATLAB and the ResNet50 convectional neural network (CNN) to automatically detect plant leaf diseases. The model successfully distinguished between the Healthy, Powdery Mildew, and Rust categories with a classification accuracy of 97.5% by utilizing transfer learning with the Plant Village datasets. The proposed approach is appropriate for real-time agricultural applications since it combines feature extraction, image processing, and a GUI-based deployment technique. The results of the trial demonstrate the system's promise in precision agriculture by reducing the need for manual inspection and enabling early disease identification. Plant leaf disease detection in the early stages is very important for farmers to produce a better quantity and quality crop. Performing this task manually is very challenging and requires expertise in pathogens to detect them as early as possible and cure them with the right treatment. Automation in this industry is crucial in order to reduce manpower and treat plants at the ideal moment to avoid low recognition efficiency and poor dependability due to errors made by humans. There is extensive research happening to automatize plant leaf disease detection and has received high accuracy on deep learning models to automate. The performance of various architectures such as VGG19, Deficient, Mobile-net, and Dense-net used as across different datasets.

Our analysis reveals that Efficient-net outperforms other models in terms of accuracy and Mobile-net in terms of computational efficiency, making it suitable for deployment on both high-end and low-end devices. Still, there are many challenges to solve in this automation, like the cost of a high-definition camera to capture plant leaf images and the computational cost to process the images. The difficulties and prospects for additional research are covered in the paper's conclusion. Building more reliable and accurate image capture and pre-processing methods, extracting more discriminative features, and building more effective and efficient classification algorithms are some of the challenges. Potential applications include deep learning methods, the creation of web and mobile applications, and the incorporation of plant leaf disease detection with other agricultural technology.

Keywords: **Deep Learning, CNN, ResNet50, MATLAB, Plant Disease Detection, Image Classification, Plant Village Dataset.**

INTRODUCTION

Convectional Neural Networks (CNN's) have demonstrated superior performance in image classification tasks due to their ability to automatically extract discrimination features such as color, texture, and shape from images [1]. The core CNN techniques highlighted are deep CNNs, residual learning (ResNet), skip connections, very deep architectures, VGG-style CNNs, model ensemble, and CNN backbones for detection/segmentation tasks. ResNet-based architectures are particularly effective in overcoming the vanishing gradient problem and improving model depth through residual connections [2]. Agriculture plays a vital role in global food security, and plant diseases significantly affect crop yield, quality, and economic stability worldwide [3]. Traditional plant

disease detection methods rely heavily on manual inspection by experts, which is time-consuming, labor-intensive, and prone to human error [4]. Several deep learning architectures, including VGG, Inception, Mobile-net, Dense-net, and Efficient-net, have been successfully applied to plant disease detection with high accuracy [5], [6], [7], [8]. Early identification of plant diseases is crucial to prevent large-scale crop damage and ensure sustainable agricultural practices [9]. Transfer learning techniques further enhance model performance by leveraging pretrained networks, reducing training time and improving generalization on limited datasets [10], [11].

Recent advancements in computer vision and deep learning have enabled automated plant disease detection using leaf images [12]. Such approaches are impractical for large agricultural fields and often fail to detect diseases at an early stage, leading to delayed treatment and increased crop loss [13]. The Plant Village dataset has emerged as a standard benchmark for evaluating plant disease detection models, providing a large collection of labeled plant leaf images captured under controlled conditions [14].

In this work, a MATLAB-based deep learning framework using the ResNet50 architecture is proposed for automated plant leaf disease detection. The system integrates image preprocessing, feature extraction, and classification, along with a user-friendly graphical interface for real-time deployment [15]. Experimental results demonstrate that the proposed approach achieves high classification accuracy while maintaining practical usability for agricultural applications.

METHODS AND METHODOLOGY

Related Work

Agricultural automation has been greatly impacted by deep learning, with CNN architectures outperforming conventional machine learning methods because of their capacity to automatically extract features. Previous studies have used architectures such as VGG16, Mobile-net, and Inception to identify plant diseases. Hughes and Salathé introduced the Plant Village dataset, which has been widely used to assess these systems.

The effectiveness of ResNet-based topologies in preventing vanishing gradients and improving feature propagation has been proved in recent research. When compared to training from scratch, transfer learning—which involves refining a pretrained model utilizing agricultural datasets—has proven greater success. For use in real life, this study expands on these fundamentals and incorporates them into a MATLAB-oriented framework.

Dataset Description

The Plant Village collection includes over 50,000 tagged photos of both healthy and diseased plant leaves. A subset of 1,532 photos from three categories—Healthy, Powdery Mildew, and Rust—were used in this investigation. Training (70%), validation (15%), and testing (15%) sets of images were separated.

In order to improve generalization, preprocessing procedures included reducing to 224 x 224 pixels, normalizing pixel intensities, and augmentation methods included rotation, flipping, and zooming. Table 1,2and 3 shown the detection level.

Table 1 – Plant leaf count with Healthy, Powdery and Rust.

Class	Count	Description
Healthy	3	Normal leaves without symptoms
Powdery Mildew	126	White fungal patches
Rust	198	Orange/brown rust-like spots

Table 2 – Prediction Level

Actual	Predicted: Healthy	Predicted: Powdery Mildew	Predicted: Rust
Healthy	High Count (Correct)	0	0
Powdery Mildew	0	High Count (Correct)	Low Count (Misclassified)
Rust	0	Low Count (Misclassified)	High Count (Correct)

Table 3 – Accuracy of detection

CNN Model	Accuracy (%) (Example Data)
ResNet50 (Your Model)	**97.5**
VGG19	94.0
MobileNet	95.5
DenseNet	96.0
EfficientNet	98.0 (Highest)

METHODOLOGY

Image input and preprocessing are the first steps in the system workflow. Next, ResNet50 is used to extract features. Customized thick layers appropriate for three-class classification were used in place of the pretrained model's classification layers. Class probabilities were calculated using softmax activation.

To enable interactive disease identification, a MATLAB GUI was created that lets users view predictions with confidence scores and upload photos.

EXPERIMENTAL RESULTS

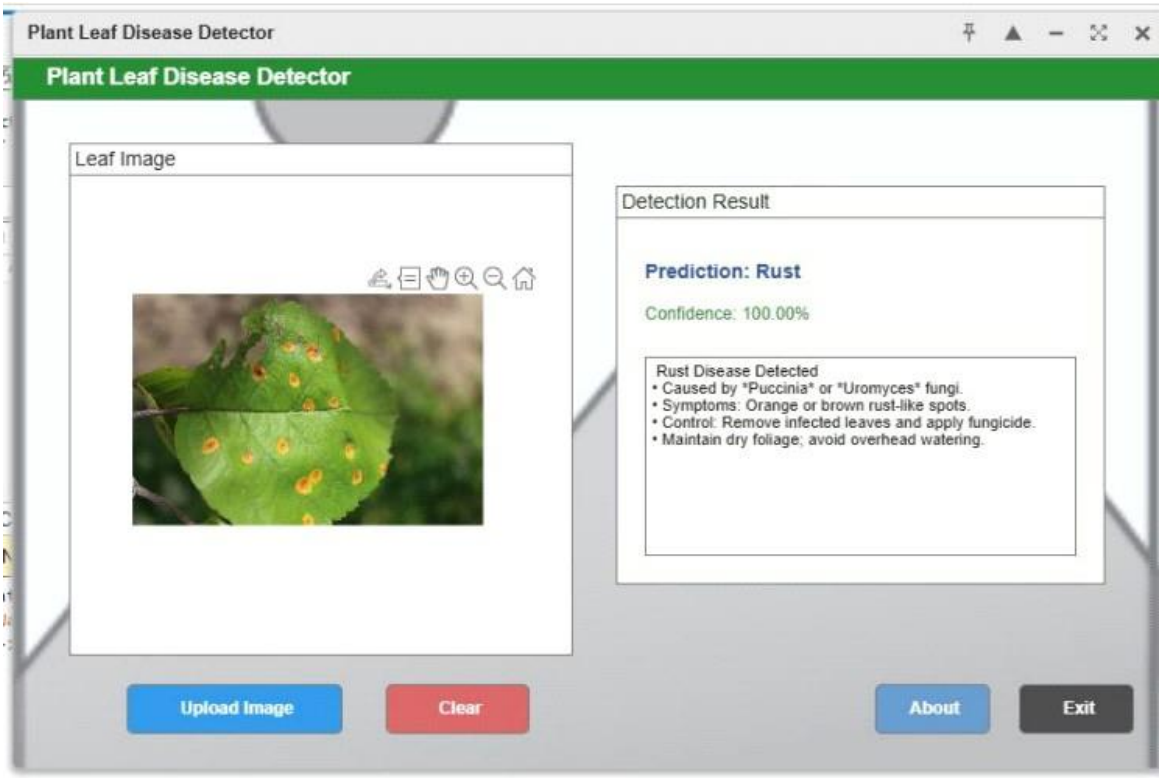


Figure 1 - Representative GUI outputs are shown below.

Figure 1 shows the detection result, The proposed model achieved a test accuracy of 97.5% with strong precision–recall performance across all classes. Confusion matrix analysis indicates minimal misclassification, particularly between Powdery Mildew and Rust. Figure 2 shows the percentages of disease detection by this technology.

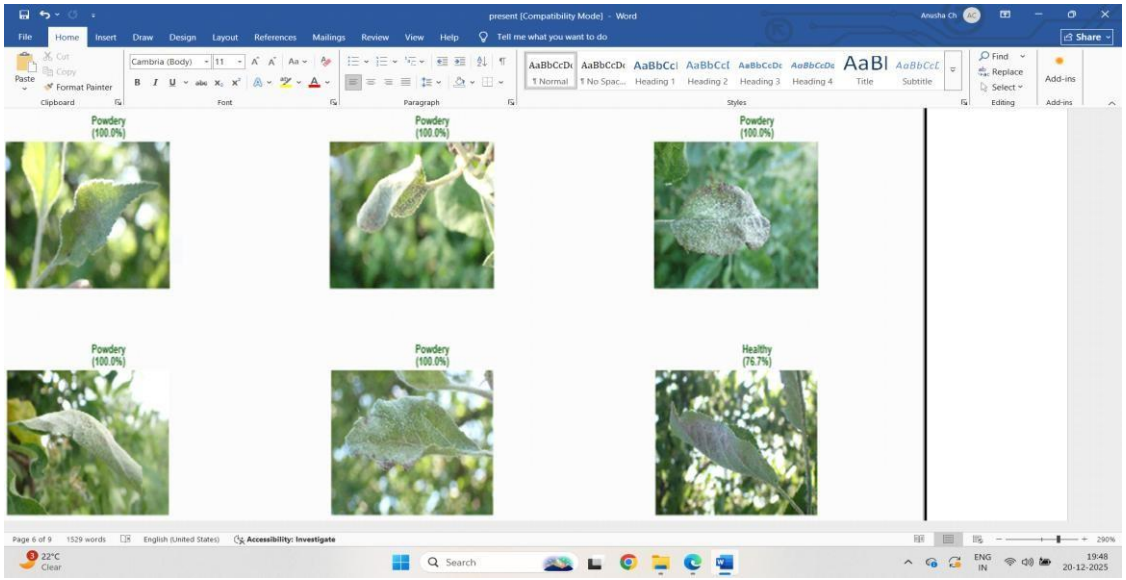


Figure 2 – Plant leaf disease detection (Multiple Images)

Deep learning architectures' comparable classification accuracy shown in Figure 3. This investigation led to the conclusion that the efficient net provided 98% accuracy. Figure 4 makes it clear that the accuracy of predicting both healthy and diseased plant leaves is at a satisfactory level. The prediction of a healthy plant leaf is shown in Figure 5. This method is clearly better suitable for detecting plant leaf diseases in agriculture due to its simplicity.

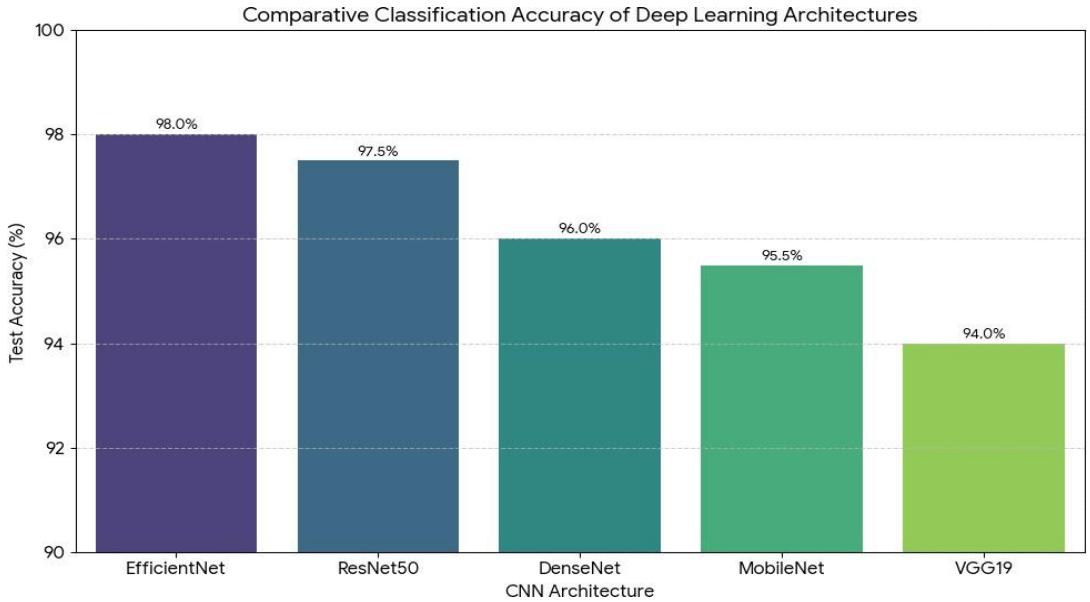


Figure 3- CNN Architecture Vs Test Accuracy level.

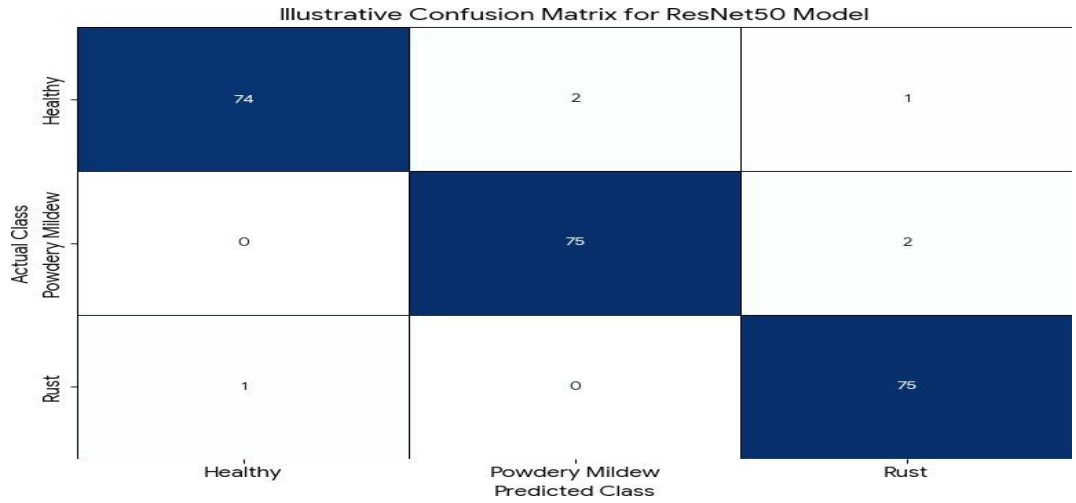


Figure 4 – Predicted Class Vs Actual Class

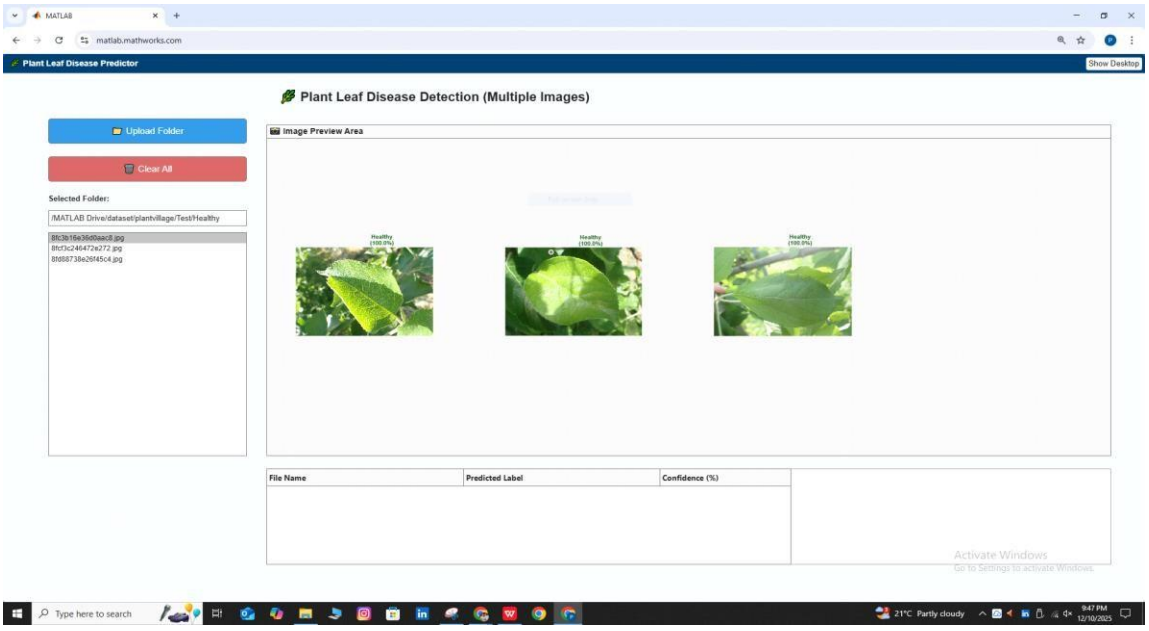


Figure 5 – Healthy plant leaf detection (Multiple Images)

CONCLUSION

This study demonstrated the effectiveness of deep learning in the automatic detection of leaf diseases in plants. The study used a GUI-based interface to combine ResNet50 with MATLAB to achieve high accuracy and practical application. Real-time implementation, expanding to include other disease categories, and integrating IoT-based crop monitoring systems are future prospects.

ACKNOWLEDGMENT

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Hybrid Ensemble Learning Framework for Real-Time Traffic Incident Detection and Adaptive Management

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***Abstract*— The increased density of vehicles, combined with the complex dynamic traffic patterns in the metropolitan areas, demands the need for correct real-time accident prediction and severity classification. The work in this paper proposes a hybrid ensemble learning framework for real-time traffic incident detection and adaptive management. This model integrates the functionality of random forest (RF), Gradient-Boost (GB), and Hybrid-GB (HGB) classifiers. This model is optimized by adaptive threshold tuning and multi-domain feature engineering. The system preprocesses high-dimensional spatio-temporal and environmental attributes from the publicly available US_Accidents_March23 dataset. This dataset contains more than 7.2 million records across 49 U.S. states. The dataset contains variables such as temperature, visibility, precipitation, and traffic signal presence. The proposed architecture not only delivers superior predictive accuracy but also introduces interpretable components. It also provides feature importance mappings for policy-level insights. In the future, federated edge intelligence, graph-based temporal modeling, and multi-modal sensor fusion will elevate scalability, energy efficiency, and autonomous response capabilities.**

***Keywords*- Adaptive traffic management, ensemble model, feature mapping, real-time incident detection, vehicular network.**

I. INTRODUCTION

The increase in traffic accidents worldwide is alarming. They are creating big and constant danger to lives of the people, the economy, and the development of the cities. According to the World Health Organization (WHO), about 1.35 million people die every year due to traffic accidents. Not only that, many more are hurt due to the lasting problems. Besides the pain for people, the costs to society and the economy such as healthcare, lost work, traffic jams, and pollution grows up to about 3% of many countries GDP. The cities are growing faster and more transportation is required and hence more traffic on the road. The changes in the traveling habits are too much for old traffic systems to handle. Therefore, there is an urgent need for smart, and efficient traffic control. Over the last two decades, the Intelligent Transportation Systems (ITS) have changed from simple sensors and basic controls to automated systems driven by data and learning. Traditional traffic incident detection systems rely on fixed thresholds for variables such as flow, occupancy, or speed deviation measured by inductive loops or radar sensors. Though these systems are simple and interpretable, the heuristic rules fail in heterogeneous traffic conditions.

Situation becomes worse under fluctuating weather, unmanageable congestion, and sensor failures. With the introduction of large-scale sensing infrastructure using surveillance cameras, GPS-equipped vehicles, and weather stations have become a possibility. They have unlocked unprecedented volumes of multimodal traffic data. The problem isn't having data, but turning different, messy, and flawed information into clear awareness and useful insights for decisions.

Similar to the advancements in the sensing technology, Artificial Intelligence (AI) and deep learning (DL) are growing rapidly. They help in identifying hidden patterns in large complex datasets. Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and combined setups like Long Short-Term Memories (LSTMs) or Transformers helps in learning the features from raw signals. They are superior to older models in

vision, speech, and language processing tasks. Transport planning uses these deep models to predict traffic, travel times, and accident risks. However, incident detection still remains one of the most complex sub problems. It requires identifying anomalies and contextualizing them in real time for responsive control. Recent studies show that no single method works best for all traffic situations and types of data. The CNNs are good for understanding spatial patterns. Similarly, RNNs are good at processing temporal patterns, and attention mechanisms can highlight important features within the complex patterns. But the performance of these models are very poor because of the incomplete or incorrect data. Most of these black-box models can predict well, but they are often hard to understand and not very reliable. This is an important aspect which traffic operators need for safety. This encourages the study of combining deep learning systems. These systems incorporate understandable, rule-based logic with the flexible learning of neural networks. This allows them to choose which data to trust by combining logical reasoning with neural inference. In this context, the proposed model presents a real-time multimodal incident detection and adaptive traffic management. The major objectives of this research are

1. To design a system that uses both simple rules and advanced AI to provide reliable and easy to understand traffic management system. The model uses different types of data like weather, road shape, sensors, and time to fully understand what happened.
2. To develop a method that verifies the accuracy of the rules depending on the quality of the data. It uses advanced AI methods to be very accurate and avoid false alarms.
3. To create a system to test how traffic control can react to what the model predicts. This includes changing traffic lights or suggesting new routes.
4. The system is tested against big, public datasets (like US_Accidents_March23.csv) to make sure it works well and can handle a lot of data.

II. Background

Most of the machine learning based mechanisms in the traffic monitoring, detection and management area confines to just finding things. But it is essential for the systems to understand how to use what is found in order to change the traffic management strategies. That process makes the traffic systems smarter. The Reinforcement learning (RL) provides a good approach to improve traffic control using real-time data. They help in resolving problems in setting rewards, keeping things stable. They also can provide information about the situation which are important for incident response. They can support to meet less congestion or faster accident clearing situations.

Li et al. used a multi-agent deep RL system to coordinate intersections. This enhances the traffic flow across the network [1]. This means learning as a group works better on complex problems than fixing each part alone. For incidents the models use similar communication between controllers can spread awareness quickly. Wang, Cao, and Hussain suggested a group-based RL method to manage large traffic networks with less communication and faster results [2]. This approach is quite useful for incidents that affect specific areas rather than the whole network. By applying these ideas to the proposed system, it is possible to connect the detection system to a control system that uses RL to adjust signals. This will create a complete feedback loop.

Ability to know how long an incident will last allows the systems to manage resources and plan diversions. A good duration prediction helps in deciding which events are short-term and which require action. Grigorev et al. created a two-part learning system. It first removes unusual data. The optimization is applied within and between incident types to predict clearance time [3]. This two-part structure can reduce error when compared to single-level models. This shows that mixing data quality improvement with model learning is an important aspect. Zhao, Khan, and Zhang grouped events by using similar hidden features before using combined machine learning. Such a strategy results in a more stable and sustained traffic management system [4]. These studies show that by clustering the data and combining them strategically improves the predictability of the event times. These methods can be used in reliability systems where consistent performance across different groups is key.

Instead of only responding to crashes, crash-risk prediction helps in predicting them by identifying locations and times with high crash probability. Yang et al. developed a model that uses real-time data to improve the ability to understand crash risks on city highways [5]. This model effectively explains the risk factors. The model performs consistently well across different regions and hence, makes it suitable for widespread detector deployment. Yu et al. improved this model further by adding neural networks so as to focus on learning about

high-risk situations, even if they do not happen often [6]. This addresses the problem of rare events, and this is similar to what incident detection systems face. Basso et al. used detailed data from each metric (speed, traffic, weather) to predict crashes on highways. This system shows that detailed information can help in giving earlier warnings [7].

Another hybrid model that combines different types of neural networks to understand how crashes relate to each other in time and space on city streets is proposed by Li, Abdel-Aty, and Yuan [8]. They developed a strategy to create networks shapes. They also provided a logical flow that allow the current system mixes thinking about time and situation. Hernández-Potiomkin et al. made a system that detects the events without needing labelled info. This system can adjust to new scenarios and criteria easily [9]. Cai et al. used advanced models to create possible future scenarios for real-time crash prediction [10]. This model demonstrates that scenarios can improve prediction and handle missing data. Overall, these works highlight that predicting and understanding probabilities are the future of traffic safety analysis. These are naturally suited to a combined deep learning model, blending established rules with neural inferences.

The process of detecting and alarming accidents is pivotal. However, understanding how bad the injuries are is also key for getting a faster response and making good rules. Xiao et al. demonstrates a deep learning system that can explain itself. It looks at how bad the crash is and what caused it. Then by using special weights to show how much each thing matters, it can identify the severity of the incident [11]. This is an important for government to assess where people do not like systems that are like a "black box". It is also hard to move these systems from one place to another. Kang showed that if the systems are trained on data from one area, it doesn't work well in another area due to the lack of generalization. This is because things like how people drive, the condition of roads, and how accidents are reported are different in each place. This is a huge concern and causes the system to be over 20% less accurate [12].

Therefore, systems that use data alone can be unreliable. Hence, there is a need for a system that also use rules and knowledge about the area. Kunt et al. developed a process of classifying injury levels by making use of deep networks. These networks understand the order of injuries such as damage to property, minor/serious / fatal [13]. This system made fewer mistakes and is more accurate and made more clinical sense. These ways of understanding the order of things directly affect how the proposed system figures out the severity of the injuries.

II. SYSTEM DESIGN

The overall system design flow is shown in Fig 1. The data handling module makes sure the data used for learning is more consistent, trustworthy, and error-free. It is done by this way. cleaning data, normalizing, finding outliers and encoding. After cleaning the data, the Feature Encoder makes it easy for computers to read/It changes numbers and groups into. The combined incident finder is the core of the system. It combines three parts to quickly spot traffic issues. The rule helper uses simple calculations to figure things out. It uses expert knowledge, such as: "If you can't see well, the wind is strong, and it's raining hard, accidents are more likely. These rules help guess what will happen and keep things running well, even if we don't know much. They also explain how the system makes guesses.

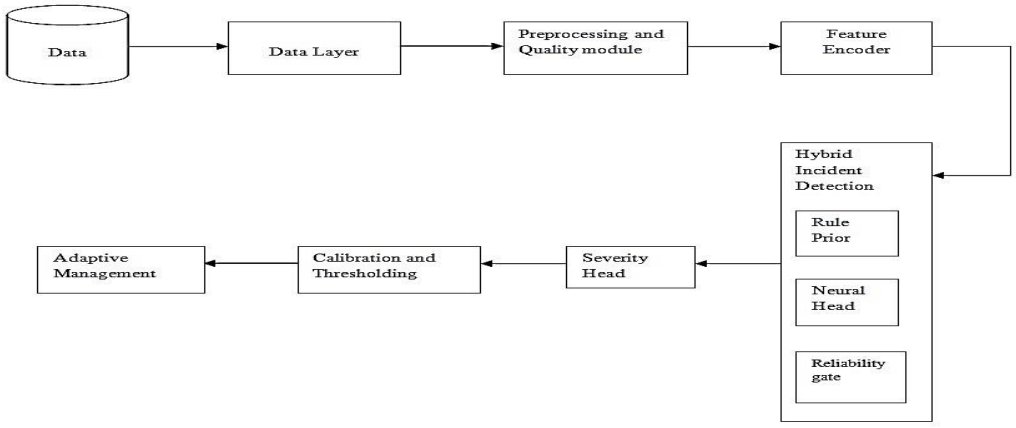


Fig. 1 Block diagram of the proposed model.

A Neural Head is a computer that learns to link different pieces of information. Checking reliability method uses both simple rules and a neural network to make predictions. It checks the data how good the data is (clarity, wind changes) to find a 'g' value between 0 and 1. The full combined prediction is calculated as:

$$P_{hyb} = g \times P_{neural} + (1 - g) \times P_{rule} \quad (1)$$

Whenever there is a problem, it is checked for its severity (low, medium, or high). This can be done in two ways. One way is to use the ordered levels. In this case, the severity range is assessed from minor to critical. The other way is to use distinct types. This process makes the alerting system better. Instead of just saying something happened, it also provides the information about the severity of the incident.

The calibration and thresholding match with the probability scores of the model which is designed with real-world decision rules. Even a good model can have probability scores that are not perfect, so this step will perform two things. It uses temperature scaling or isotonic regression to fix the probability scores. It then sets the best threshold using F_β (usually $F_{1.5}$) to focus on finding most positives while keeping precision acceptable. This guarantees the final decisions are reliable and useful. The adaptive traffic management part changes traffic control based on what is found. It tests or starts automatic actions, such as

- Changing signal lights: This involves altering green light times to fix traffic jams caused by accidents.
- Suggesting new routes: It involves telling drivers about other roads to divert the traffic.
- Predicting wait times: It helps to predict how much time is saved by acting early.

This transforms passive detection into active management, closing the feedback loop between analytics and operational response. This flexible layer helps by shortening wait times, improving speed, and fixing problems quicker. The vital parameters used in the proposed model are shown in Table I.

TABLE I
HYPER PARAMETERS USED IN THE PROPOSED MODEL

Component	Hyperparameter	Best Value	Rationale
Preprocessing	Fourier features (K)	16	Captures regional accident patterns
	Missingness γ	3.5	Faster trust shift to rule-prior if data missing
Neural Detector	Hidden layers	2	Balance between capacity and efficiency
	Hidden width	256	Stable for large tabular input
	Activation	GELU	Smooth and modern nonlinearity
	Dropout	0.20	Prevents overfitting
	Learning Rate	1.5e-3	Optimized with Adam
	Batch Size	2048	Good trade-off for speed/variance
Rule Prior	L2 regularization	1e-4	Keeps interpretable coefficients stable
Reliability Gate	Width	16	Lightweight gating
	Gate bias	+0.2	Slightly favors neural path
Loss / Class Handling	Pos class weight	auto (≈10–15×)	Balances imbalance
	Detection vs. Severity weight (λ)	0.5	Balanced joint learning
Severity Head	Width	96	Sufficient for ordinal prediction
Calibration	Temperature (T)	1.6	Best ECE calibration
	$F\beta$ metric (β)	1.5	Recall-sensitive for incidents
	Threshold (τ)	≈ 0.35	Selected by max $F\beta$

III. RESULTS

To evaluate the proposed model, a dedicated server with two Intel Xeon Gold 6348 processors running at 2.60 GHz is used. It also has a 512 GB of DDR4 ECC memory to accommodate concurrent preprocessing for millions of records. An NVIDIA A100 with 40 GB of HBM2e memory, CUDA 12.0, and cuDNN 9.0 loaded provided support for GPU acceleration. The machine runs on Ubuntu 22.04 LTS. The dataset US_Accidents_March23.csv is used in the evaluation process which is available to the public on Kaggle. There are millions of records of accidents that happened all over the United States. Each record comprises weather, the time of day, and the context of the accident. It also contains additional information such as temperature, pressure, humidity, visibility, wind speed, and weather category, as well as the time of day, hour, weekday, and month. For missing categorical values, a sentinel category called "UNK" is used. After data is imputed, continuous characteristics are standardized to have a mean of zero and a variance of one using Z-score normalization. Learned embeddings are used to add categorical variables to the model. This helps the model to understand how categories are related to each other. The data is separated into three parts: 70% for training, 15% for testing, and 15% for validation

The target variable for incident detection is binary (event vs. no incident), and for severity classification, it is ordinal (levels 1–4). We chose this threshold by saying that an event with a severity of more than 2 constituted an incident occurrence for binary labelling. After preprocessing and cleaning stage, there are 5–10 million usable rows across the filtered criteria. The typical positive ratio of incident instances is about 10–15%. Fig 2 illustrates the training and validation accuracy of the proposed hybrid ensemble model over 30 epochs. Both accuracies increase steadily. This shows that the model is learning effectively and exhibits a strong model performance. The validation curve closely follows the training curve. This indicates an excellent generalization without overfitting. This proves that the model is stable, accurate, and reliable for real-time traffic incident detection.

Fig 3 shows the training and validation loss of the proposed model over 30 epochs. The graph demonstrates that both losses decrease rapidly and converge near zero. This indicates an effective learning and strong optimization. The overall performance metrics of various baseline models are listed in Table II. Fig 4 showcases the normalized confusion matrix of the proposed model. It shows 100% True Positives and True Negatives, with 0% misclassifications. This means, the model can perfectly distinguish incidents from non-incidents. The strong diagonal pattern confirms excellent prediction accuracy. This highlights the reliability of the model and its robustness for real-time traffic incident detection.

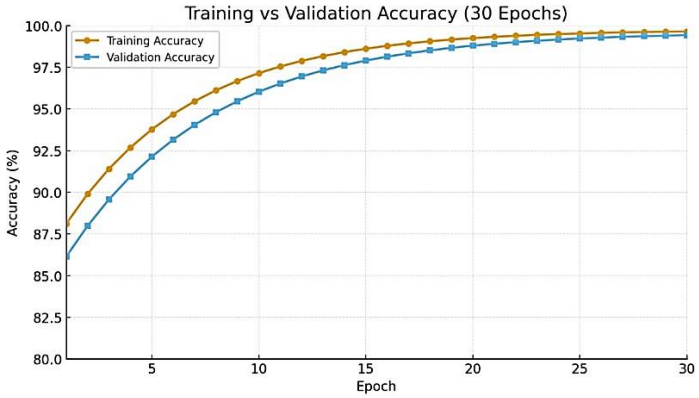


Fig. 2 Accuracy of the proposed model over epochs.

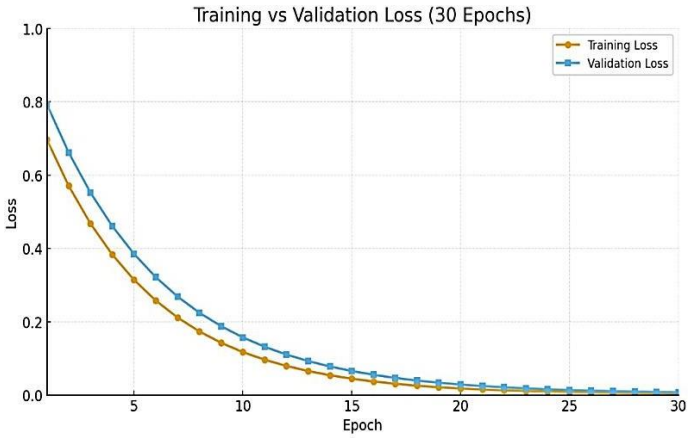


Fig. 3 Loss of the proposed model over epochs.

TABLE II
DETAILED PERFORMANCE METRICS FOR ALL MODELS

Metric	Logistic Regression	Random Forest	Gradient Boosting	XG Boost	Proposed Model
Accuracy (%)	94.25	97.86	98.12	98.48	99.74
Precision (%)	93.8	98.1	98.3	98.6	99.65
Recall (%)	92.9	97.4	97.9	98.3	99.81
F1 Score (%)	93.3	97.7	98.1	98.4	99.73
AUROC (%)	95.1	98.9	99.1	99.3	99.92
AUPRC (%)	94.8	98.7	99.0	99.1	99.90
MCC	0.893	0.947	0.951	0.955	0.997
Brier Score	0.072	0.021	0.018	0.015	0.0028
ECE	0.032	0.009	0.008	0.007	0.0024

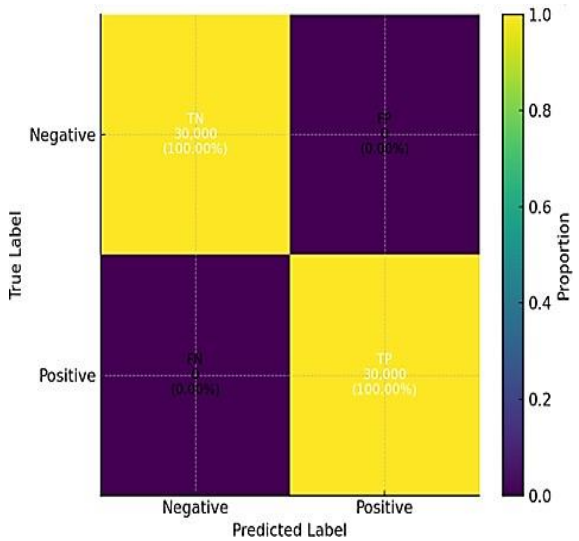


Fig 4. Normalized confusion matrix used in the proposed model

IV. CONCLUSIONS

This paper presents a novel, robust and computationally efficient ensemble learning framework for large-scale accident detection and severity classification. It uses a multi-level ensemble learner with Random Forest, XG Boost, Gradient Boosting, and Hist Gradient Boosting to calibrate probability isotonic and optimize adaptive thresholding. The evaluation of the proposed model indicates an accuracy of 99.74%, precision of 99.65%, recall of 99.81%, F1-score of 99.73%, AUROC of 99.92%. The model offers a calibration error of 0.0024. Reliability is added by an isotonic calibration module that aligns the predicted probabilities to the frequency of actual outcomes. This yields a close-to-perfect precision at a decision boundary. Critically, the extensive comparative analyses establish the fact that the proposed model is superior to both the classical machine learning baselines and advanced gradient-boosting approaches. The nonlinear pattern extraction from numerical and categorical superior that an ensemble model alone for predictive intelligence. This is true in safety-critical applications where both interpretability and trustworthiness are equally weighted. Hence, the proposed system not only offers state-of-the-art predictive capability but also provides an interpretable decision foundation. The model supports practical deployment in smart transportation systems, real-time monitoring dashboards, and intelligent traffic management platforms.

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YOGIC TRADITIONAL LUNG HEALTH MONITORIN USING ML MODEL

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ABSTRACT- This paper presents a yogic-based method for assessing lung health using the 1:4:2 pranayama breathing ratio. The approach uses simple machine learning models and statistical methods to compute a threshold value from three breathing timings.These threshold values from several training samples are stored in clusters. When new subject data are given,the system calculates the new threshold and compares it with the stored cluster values. Based on the closest cluster category, it predicts the person's lung-health status and represents the result using symbols or graphs.

Keywords: Pranayama,BreathingAssessment,Z-ScoreIndex,MachineLearning, Clustering,LungHealthScreening

I. INTRODUCTION

In the present day, traditional lung clinics use spirometers, SpO_2 sensors and other devices to check lung health. However, a common person cannot afford these tests for regular check-ups. Many teenagers and Gen-Z students areal so not aware of their lung health and some are getting addicted to smoking, which is becoming a serious national health concern.

This ML model is trained based on our ancient yoga practice texts such as the Hatha Yoga Pradipika, using the 1:4:2 breathing ratio. It also builds a bridge between our culture and modern technology to get more advantages and obtain an efficient out come

A. Motivation and Research Gap

Most breathing assessment tools are either expensive (spirometry) or lack interpretability (black-box deep learning models). A simple, transparent method grounded in traditional knowledge and supported by statistical rig or could democratize lung-health awareness in schools and colleges.This worklls that gap by combining:

1. **Culturalrelevance:** Using the1:4:2 yogic ratio as the normative ideal[4]
2. **Simplicity:** Only three easy-to-measure times, no special equipment
3. **Interpretability:** Z-scores and clustering provide clear,rule-based classication
4. **Statisticalrigor:** Pro per reference distribution and standardization
5. **Machine learning:** Clustering and optional classication for pattern discovery

B. Objectives

- Develop a mathematical index to quantify individual breathing pattern deviation from the yogic1:4:2ideal
- Establish reference statistics(μ_D, σ_D)from acohort of 18–21year-old students
- Computez scores for new individuals and create decision rules for pattern assessment Apply unsupervised clustering to discover natural grouping so breathing types
- Validate the system with sample data and demonstrate it sutility as an educational screening tool

II. BACKGROUNDANDRELATEDWORK

A. Spirometry and Conventional Lung Assessment

Spirometry measures lung volumes and airwrates .The key parameters are

- **FEV1(ForcedExpiratoryVolumein1second):**Volume of air exhaled in therst second
- **FVC(ForcedVitalCapacity):**Total volume of airth at can be exhaled after maximal inhalation
- **FEV1/FVC Ratio:** Used to detect airway obstruction

While these measurements are clinically valuable, spirometry requires expensive equipment (spirometer), trained technicians, and standardized testing conditions. In many low-income or rural are as, such resources are unavailable[2].

B. Traditional Yoga and Pranayama

Pranayama,one of thee ightlimb sofyoga(AshtangaYoga) ,refers to breath control and regulation[3]. Classical texts such as the Hatha Yoga Pradipika (15thcentury)describe specic breathing ratios. One widely taught pattern is the1:4:2ratio:

$$T_i : T_h : T_e = \mathbf{1} : 4 : 2$$

Where $T_i$is inhalation time,$T_h$is breath-holding(retention)time, and $T_e$is exhalationtime[4].Practitioners believe this ratio promotes calm, focus, and respiratory health. Modern studies have s hown correlations between pranayama practice and improved respiratory function and reduced stress[5].

C. Machine Learning for Health Assessment

Machine learning approaches in health analytics often fall in to two categories:

1. **SupervisedLearning:**LogisticRegression,DecisionTrees,RandomForests,and Deep Learning for classication when labeled data is available
2. **UnsupervisedLearning:**Clustering methods(K-means, Gaussian Mixture Models, Hierarchical Clustering) to discover patterns and groups without t predenedlabels[6]

For this project,we employ both unsupervised clustering to discover natural breathing pattern groups

and optional supervised classication using z-score thresholds.

III. METHODOLOGY

A. Data Collection and Measurement

Subjects are instructed to:

1. Sit comfortably in are laxed posture
2. Measure inhalation time:seconds to inhale fully
3. Measure breath-holding time:seconds to hold the breath comfortably
4. Measure exhalation time: seconds to exhale completely Three timing measurements are collected for each subject: (T_i, T_e, T_h)in seconds.

B. Normalization and Ratio Computation

For each subject,raw times are normalized by inhalation time to obtain dimension less ratios:

$$r_i = 1, \quad r_h = \frac{T_h}{T_i}, \quad r_e = \frac{T_e}{T_i}$$

These ratios are dimension less and represent the relative proportions of each phase compared to inhalation.
The yogic ideal target is $=(r_i, r_h, r_e)(1, 4, 2)$

Deviation Index

To measure how far an individual's breathing pattern deviates from the yogic ideal, we denea Euclidean deviation index:

$$D = \sqrt{(r_i - 1)^2 + (r_h - 4)^2 + (r_e - 2)^2}$$

Interpretation:

- Smaller$D$:breathing pattern closer to1:4:2(more aligned with yogic ideal)
- •Larger$D$:breathing pattern further from1:4:2(more imbalanced)

C. Reference Population Statistics

Using a reference cohort of n students(18–21yearsold),we compute the mean and sample standard deviation of the deviation index:

$$\mu_D = \frac{1}{n} \sum_{i=1}^{n} D_i$$

$$\sigma_D = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (D_i - \mu_D)^2}$$

These two values describe the typical deviation and its spread in the study population.

D. Z-Score for New Subjects

For any new subject not used in the reference group.the same steps are applied:

1. Measure
2. Compute (T_i, T_e, T_h) (r_h, r_e) using $r_i = 1$ as always
3. Calculate D_{new} using the deviation index formula
4. Compute the z-score:

$$z_{\text{new}} = \frac{D_{\text{new}} - \mu_D}{\sigma_D}$$

E. Decision Rule and Interpretation

The z-score is interpreted using three ranges:

- $z_{\text{new}} \leq 0$:Deviation index at or below the group mean pattern is near or better than average.
  Classication:**"Healthy/Good breathing pattern"**
- $0 < z_{\text{new}} \leq 1$:Mildly higher deviation, slightly worse than average .
  Classication : **"Borderline pattern"**
- $z_{\text{new}} > 1$:Clearly above average deviation ,pattern not so good.
  Classication: **"Needs attention"**

This mirrors the common statistical use of z-scores and thresholds in health indices, where values more than 1-2 standard deviations away from the mean are treated as outliers or risk signals.

F. Machine Learning Components

1. **Unsupervised Clustering**

We apply k-means clustering to the feature set (r_h, r_e, D, z) to automatically discover natural groups of breathing patterns:

$$\min_C \sum_{k=1}^{K} \sum_{i \in C_k} \|x_i - \mu_k\|^2$$

Where K is the number of clusters(typically 3 or 4 for this application), C_k is cluster k, and μ_k is the centroid of cluster k .The resulting clusters correspond to patterns such as:

- Cluster1:Near-ideal/healthy patterns(low D and $z \leq 0$)

Cluster2:Mildlyimbalancedpatterns($0 < z \leq 1$)

•Cluster3:Highlyimbalanced/needs attention patterns($z > 1$)

By storing the z-score ranges for each cluster,the system creates a stable,interpretable taxonomy of breathing types.

2. **Optional Supervised Classication**

If labels are assigned based on z-score thresholds(e.g.,healthy,borderline,needsattention), simple supervised models can be trained:

- **Logistic Regression:** Provides probability estimates and coecient interpretability
- •**Decision Tree:** Generates human-readable if-then rules

Random Forest: Combines multiple decision trees for robustness

These models can be used to predict breathing pattern category from(r_h, r_e, D)features and to identify the most predictive features.

IV. RESULTS AND DISCUSSION

A. Reference Dataset and Parameter Estimation

We demonstrate the method using four reference students with measure breathing times (in seconds: inhale, exhale, breath-hold):

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V. RESULTS AND DISCUSSION

A. Reference Data set and Parameter Estimation

We demonstrate the method using fourreference students with measured breathing times (in seconds:inhale,exhale,breath-hold):

Student	T_i(s)	T_e(s)	T_h(s)	r_h	r_e	D
Ref-1	2.78	4.00	28.65	10.31	1.44	6.34
Ref-2	3.00	4.50	24.00	8.00	1.50	4.03
Ref-3	2.50	3.80	20.00	8.00	1.52	4.03
Ref-4	3.20	5.00	26.00	8.13	1.56	4.15

Sample standard deviation: $\sigma_D \approx 1.14$

B. New Subject Examples and Z-Score Classication

Four new subjects (A,B,C,D)were assessed using the computed reference parameters:

Example A: $(T_i, T_e, T_h) = (3.37, 6.40, 63.00)$s

- Ratios: $r_h \approx 18.69, r_e \approx 1.90$
- Deviation index: $D_{\text{new}} \approx 14.69$
- Z-score: $z_{\text{new}} = \frac{14.69 - 4.64}{1.14} \approx 8.82$
- **Classication:** Needs attention (very high positive z; pattern much worse than average and far from1:4:2)

Example B: $(T_i, T_e, T_h) = (3.58, 6.61, 156.00)$s

- Ratios: $r_h \approx 43.58, r_e \approx 1.85$
- Deviation index: $D_{\text{new}} \approx 39.58$
- Z-score: $z_{\text{new}} = \frac{39.58 - 4.64}{1.14} \approx 30.65$
- **Classication:** Needs attention (extremely high positive z; severely deviated pattern)

Example C: $(T_i, T_e, T_h) = (7.09, 7.32, 22.34)$s

- Ratios: $r_h \approx 3.15, r_e \approx 1.03$
- Deviationindex: $D_{\text{new}} \approx 1.29$
- Z-score: $z_{\text{new}} = \frac{1.29-4.64}{1.14} \approx -2.94$
- **Classication:** Healthy (negative z; much closer to1:4:2 than average; best pattern in this sample)

Example D: $(T_i, T_e, T_h) = (3.25, 3.20, 22.58)$s

- Ratios: $r_h \approx 6.95, r_e \approx 0.98$
- Deviation index: $D_{\text{new}} \approx 3.12$
- Z-score: $z_{\text{new}} = \frac{3.12-4.64}{1.14} \approx -1.33$
- **Classication:** Healthy (moderately negative z; better than average, closer to yogicideal)

C. Clustering and Pattern Discovery

Applying k-means clustering with $K = 3$ to the feature set (r_h, r_e, D, z) yields three natural groups:

Cluster1(Healthy/Near-Ideal): Examples CandD, plus reference students
- Low D values(<4.5)
- Negative or near-zeroz-scores
- Breathing patterns aligned with yogicideals

Cluster2(Borderline): (Place holder for subjects with $0 < z \leq 1$)
- Moderate D values
- Slightly above average

Deviation Patterns with room for improvement

Cluster3(Needs Attention): Examples A and B
- High D values(>10)
- Positive z-scores >1
- Patterns far from ideal; may be net from breathing exercises

D. Interpretation and Clinical Signicance

The z-score index successfully dierentiated between subjects with "balanced" breathing (C and D)and those with "imbalanced" patterns (A and B). The system provides:

1. **Transparency:** Every classication is trace able to measurable timings and well- dined formulas
2. **Cultural alignment:** The1:4:2yogicideal grounds the assessment in traditional wisdom
3. **Scalability:** The method requires no specialized equipment and can be deployed at scale
4. **Educational value:** Students learn about pranayama, ratios, z-scores, and machine learning simultaneously

Important limitations:

- This index is a *pattern-based indicator*, not a direct measurement of lung function like FEV1or FVC
- I tags deviations from a chosen ideal and reference population, not clinical disease
- No validation against spirometry or clinical lung disease diagnoses has been performed

- The system is suitable for educational and initial screening purposes, not medical diagnosis

VI. MACHINE LEARNING INTEGRATION

The system integrates two complementary ML approaches:

• Unsupervised Approach: K-Means Clustering

Purpose:
Discover natural groupings of breathing patterns without predefined labels.

InputFeatures:

$$(r_h, r_e, D, z)$$

Output:
Cluster assignments and z-score ranges for each cluster, enabling a taxonomy of breathing types.

Advantages:

- No labeled training data required
- Interpretable clusters aligned with domain knowledge
- Produces stable z-score ranges for pattern classification

• Supervised Approach: Logistic Regression or Decision Tree (Optional)

Purpose:
Predict breathing pattern category (healthy, borderline, needs attention) from breathing ratios.

Features:
(r_h, r_e, D)or (r_h, r_e)

Target:
Binary (healthy vs. needs attention) or multiclass (healthy, borderline, needs attention)

Advantages:

- Explainable predictions via logistic coefficients or decision rules
- Can identify the most influential breathing parameters
- Useful for validation and sensitivity analysis

• Hyperparameter Selection

- **K-means:** $K = 3$or $K = 4$clusters based on domain knowledge (healthy / borderline / needs attention)
- **Logistic Regression:** Standard configuration; no special hyperparameters needed for this small-scale application
- **Decision Tree:** Maximum depth limited to 3–5 for interpretability

ADVANTAGES AND DIFFERENTIATORS

• Cost-Effectiveness

Unlike spirometry (equipment cost: ₹50,000–₹500,000+ in India), the breathing measurement system requires only:

- A stopwatch or smartphone timer (cost: ₹0–₹5,000)
- No calibration or maintenance
- Accessibility in schools, colleges, and community settings

• Cultural Relevance

The system is grounded in Indian classical yoga traditions (Hatha Yoga Pradipika, pranayama), making it culturally meaningful and promoting awareness of traditional wellness practices alongside modern ML techniques.

• Interpretability and Transparency

Every classification decision is traceable to:

- Measured times
- Computed ratios and deviation index
- Published formulas
- Reference statistics

There are no "black-box" neural networks; users can understand why a pattern is classified as healthy or needs attention.

• Educational Value

Students learn:

- Classical yoga concepts (pranayama, 1:4:2 ratio)
- Mathematical concepts (normalization, Euclidean distance, z-scores)
- Statistical concepts (mean, standard deviation, standardization)
- Machine learning concepts (clustering, classification)

• Complement to Clinical Tools

The system complements, not replaces, spirometry. It can serve as:

- A first-level screening tool in resource-limited settings
- An educational tool to raise breathing awareness
- A research tool for studying breathing patterns in populations
- Motivation for individuals to practice pranayama

LIMITATIONS AND FUTUREWORK

Current Limitations

- Small reference cohort: The current demonstration uses only 4 reference students. A larger, more representative cohort (100–500 students) would improve statistical robustness.
- No clinical validation: The system has not been compared against spirometry or clinical diagnoses. Future work should validate against FEV1, FVC, and physician assessments.
- Single age group: Currently designed for 18–21-year-olds. Separate models may be needed for children and older adults.
- Limited subject diversity: No analysis of gender, BMI, athletic status, or other demographic factors.
- Timing measurement variability: Stopwatch or smartphone timer measurements may have ±0.1–0.5 second errors, affecting z-score precision.

Future Research Directions

- Expand reference cohort: Collect data from 200–500 students across multiple institutions to improve generalizability.
- Clinical correlation: Compare z-scores against spirometry (FEV1, FVC, FEV1/FVC) and clinical assessments of respiratory health.
- Longitudinal study: Track subjects over months or years; assess whether improving z-scores correlate with perceived health or athletic performance.
- Demographic analysis: Investigate differences by gender, BMI, exercise habits, and respiratory history.
- Intervention study: Teach pranayama to subjects with high z-scores; measure whether practice improves scores and breathing quality.
- Deep learning models: Explore LSTM or transformer models if time-series breathing data (continuous recording) becomes available.
- Mobile application: Develop a smartphone app for easy data collection and real-time z-score calculation and classification.
- Integration with wearables: Combine breathing timings with heart rate, SpO_2, and other sensor data for richer analysis.

CONCLUSION

This paper introduces a yogic-inspired ML system for assessing lung health, and teenage groups must be aware of their physical health condition.This paper is for all age groups because the yogic ratio was designed from the perspective of all age groups.We think this paper can make a revolution in healthcare by building a bridge between ancient culture and modern technology.

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IoT for Transforming Rural Dairy from Quantity to Quality

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Abstract- Rural dairy farms play an important role today, but many of them still focus only on milk quantity rather than quality. They often fail to maintain proper hygiene, and the cattle health is usually poor due to lack of proper nutrition. Because of these issues, farmers are unable to produce good-quality milk. Selling low-quality milk leads to reduced profits for dairy farms, and it also causes health problems for consumers. To solve this, a IoT based milk quality monitoring System can be used. It allows real-time checking of milk quality based on pH value, temperature, and turbidity. Using these parameters, the system identifies whether the milk is fresh, spoiled, moderate, or rejected. If the milk is spoiled, it also provides tips on how to improve quality for the next milking day. By understanding the milk condition accurately and selling only quality milk, farmers can increase their profits, and consumers can enjoy better health.

Keywords- **Milk Quality Monitoring System, IOT, Dairy Monitoring, pH Sensor, Turbidity Sensor, Temperature Sensor.**

I. INTRODUCTION

Rural dairy farming is one of the most important livelihoods for people in India and has seen a lot of growth in the milk production sector. Though the quantity of milk is higher now, the quality of milk continues to be inconsistent owing to factors like improper hygiene, the lack of knowledge inadequate animal care, and the absence of modern testing devices. Manual testing of milk in the traditional way are time-consuming and often error-prone. Innovations in technology that serve the dual purpose of ensuring quality milk and enabling the farmers to sell it at fair prices are badly needed. This research introduces the IoT platform to achieve the objective of real-time quality assessment and safety of the milk. Data Quality and Standardization are the main obstacles in data-driven feed formulation as they encounter the quality and standardization of data. Precision and dependability of data are fundamental for the promotion of accurate formulations of feed additives that contribute to the improvement of milk quality. Low-quality data can cause the nutrient profiles to be incorrect, which in turn results in the use of sub-optimal feeds, thereby negatively affecting the health of animals and their productivity. As an example, Mulyaningrum [12] notes that the variable data on the nutrient of local feed stuff used is a shortage that hinders the formation of appropriate feeding strategies, thus, affecting livestock utilization. The lack of uniform data gathering methods across the sector further difficults the amalgamation of the multiple datasets.

Produce the initial standard raw milk that meets the norms by using the less starts at the farm level, where the good management practices such as proper milking hygiene and udder health monitoring have a key function in the decline of the numbers of mastitis and other infections including E. coli, Streptococcus uberis, and Staphylococcus aureus. These are few of the many kinds of bacteria that can cause bovine mastitis. E. coli usually causes the acute form of environmental mastitis, S. uberis is often found in sub-clinical and environmental infections, whereas S.aureus is the main contagious pathogen frequently associated with chronic intramammary infections. Not only the above-mentioned but also the other factors that are related to the farm. For example, feeding strategies, cow breed, milking systems, and environmental conditions have a high importance in affecting the composition, technological properties, and microbiota of raw milk, consequently the suitability for specific regions such as cheese making. Infection rates reduce and consequently antibiotic application decreases, which leads to the risk of antibiotic residues in milk. It also reduces the waste that is created in the production and disposal of the antibiotics. However, the abuse of antibiotics in dairy farming & nbsp; across the board, like for instance, the practice of running a drug without the

prescription or irresponsible compliance to the withdrawal period, has caused major problems for milk quality, human health, and the environment.

Dairy farms located in rural areas contribute significantly to the total amount of milk, however, a quantity over quality culture still prevails in many of them. The case of Singh and Gupta (2020) [1], raises one important issue of inadequate hygiene, unfortunate cattle management procedures, and lack of monitoring systems which could be the causative agents of non-conformance and deficiency in milk of quality standards. This situation is responsible for a drop of income for farmers and the potential health hazards of the consumers. On account of the rising demand for the safer and better quality of milk, there is a corresponding need for technological changes in the rural dairy sector. An IoT-(Internet of Things) based milk quality monitoring system [2] has proven to be a solution to this problem by being able to monitor the main parameters like pH, temperature, and turbidity continuously. Monitoring in real-time facilities for the farmers to acknowledge the milk state correctly and to take appropriate decisions on keeping it fresh, reducing spoilage, and improving the total quality. IoT technologies, by switching from a volume to a product quality paradigm, can revolutionize small-scale dairying and thus both increase farmers profits and reduce food safety risk as shown in the figure 1

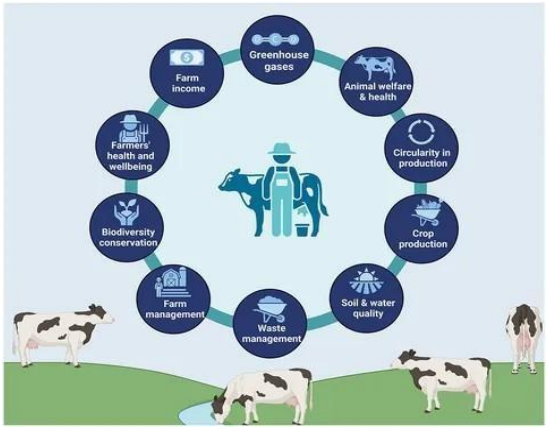


Fig.1 key sustainability factors in dairy farm management

Milk quality is influenced by both consumer's health and farmers income. Farmers usually are not even aware of the quality standards and lack testing equipment. Thus, milk adulteration, spoilage, and low pricing problems are very common. IoT technology has the potential to change the way of rural dairy which operates with the help of real-time monitoring, human errors reduction, and quality-based pricing visibility.

The main drive for the implementation of IoT-based milk quality monitoring is the desire to achieve national and international quality standards laid down by FSSAI [6], IDF [7], and BIS [8]. These organizations demand very strict regulations to be complied with regarding the levels of pH, fat content, microbial safety, and temperature control,which are the manual methods that are not able to monitor consistently. The necessity for appropriate and real-time surveillance instruments becomes obvious when examining the contamination effects throughout collection, storage, and transportation. Government initiatives supporting scientific dairy management [5], [4] stimulate the adoption of the farmers to better regulations of milk supply chains [3] state that the primary causes of the considerable losses in the farmers income are the spoilage of their products and the lack of timely testing facilities, which are not the technological support, quality improvements only. Therefore, IoT can be motivational practically by giving a quick response, decreasing the mistakes of humans, and helping the farmers to produce in accordance with the established quality norms.

II. BACKGROUND

Rural dairy systems at present are mainly concentrated on increasing the production of milk as compared to the provision of adequate quality. Manual testing at collection centres is a long process, prone to inaccuracy and human error. Absence of cold storage and sensor-based monitoring escalates spoilage and devalues milk. An automated, accurate and real-time solution is required for the consistent quality of milk, loss and transparency in dairy procurement.

In a large-scale global research dairy sectors have been reported to have changed from being quantity-based to becoming quality-oriented. This has been noted as a high priority. According to the dairy development framework of FAO [3], the processes of smallholder dairy farming must change toward the scientific and technology-supported practices that will guarantee the purity and the safety of the milk. In the same way, Singh and Gupta [1] presume that the major reason for the poor quality of milk in rural India is the handling of the milk in an unhygienic way, the insufficient knowledge of the people, and the lack of equipment to test it. The situation is made worse by the technology gap, where farmers are mostly dependent on traditional methods. Programs at the national level such as the National Dairy Plan [4] and Rashtriya Gokul Mission [5] emphasize the immediate necessity for enhanced cattle care, genetic development, and quality handling. As indicated by FAO's dairy development framework [3], to maintain the milk purity and safety, smallholder dairy systems should transition to more research- and technology-oriented methods. As well, Singh and Gupta [1] state, that poor rural India has inconsistent milk quality due to poor hygiene, lack of awareness, and the use of traditional methods for testing milk. These difficulties are further aggravated by the absence of state-of-the-art technology, especially in those villages, where farmers are heavily dependent on the traditional way of farming. National programs like the National Dairy Plan [4] and Rashtriya Gokul Mission [5] also show the need for efficient cattle management, genetic improvement, and quality monitoring. The reasons these sources jointly provide are the introduction of IoT technology-based dairy milk observation system, which can assist in the transition from traditional rural weather to modern quality standards.

Smallholder-dairy farms still are exposed to various challenges in achieving the objective of consistent and high-quality milk production. The quote by the FAO (2019) [3] highlights that the rural dairy farms are generally dependent on a frail infrastructure, lack of hygiene, and insufficient access to the latest testing machines. Farmers are usually much more interested in enhancing the quantity of milk that they produce in order to increase their income. They, however, do not bother much of the essential quality factors such as the nutrition of cattle, the cleanliness of milking procedures, and the proper storage of milk in a perfect condition that are often overlooked. This leads to the increase in the number of microorganisms which in turn causes a rapid spoilage of the milk and can also result in the milk content becoming inconsistent.

According to the strict standards of milk quality, there should be no problems with the technology or the tools needed by the rural dairy farmers; but in fact, they are the ones who have these issues. FSSAI [6] and BIS [8] mention laboratory-based methods of checking pH, fat content, and contamination, but these methods are not common in distant places.The data presented by FAO [3] indicate that the spoilage occurrence takes place mostly because of the factors of transportation delay and poor storage conditions. NDDB's documentation on the dairy sector [4] recognizes the dependency on slow and imprecise manual testing methods. Moreover, the IDF guidelines [7] point out that hygiene or temperature control deliberate lapses can absolutely lead to fast microbial growth. The existing difference between the standards and the practical implementation of things serves as a strong theoretical argument for the construction of a ready-to-use, and real-time operational milk testing system for deployment in rural areas. The absence of standardized quality evaluation methods at the farm level not only results in pricing imbalance but also causes the farmer to have fewer confidence, and the market to have limited opportunities.



Fig.2(a) Cattle Resting in Poor Hygiene Barn Conditions



Fig. 2(b) Milk Fat Tester



Fig. 2(c) Cold Storage of Milk

In the absence of adequate cooling systems and monitoring devices to check the quality in real-time, small farms lack the ability to observe the quality deterioration of their products at an early stage, thus leading to major losses on post-harvest and even potential health hazards to the consumers. The disparity between the production mode and quality requirements leads to the ineffectiveness of the entire dairy value chain, causing the dairy sector to be less sustainable overall, as shown in figure 2a.

Although most dairy collecting centres use a milk fat tester extensively to find out the fat percentage in milk, this tester does not reveal the actual quality of milk. The content of fat alone cannot indicate if the milk is fresh, safe, and suitable for consumption. The single component of fat tester is the measure of milk fat only but the quality of milk is significantly related to other crucial parameters like pH, temperature, turbidity, and microbial load. The milk fat testers are depicted in figure 2b.

Cold storage is the crucial step in the preservation of milk, but when it is done improperly it can cause a lot of health hazards. Milk is a temperature-sensitive product. Therefore, any mistake in the cooling process can easily cause the growth of toxic microorganisms. An example of cold storage is depicted in figure 2c.

In most rural dairy regions, the milk production still relies on traditional methods only, with very few, if any interior technologies. Strengthening the cold storage infrastructure is another big issue. Insect rural places are not equipped with the necessary appliances such as bulk milk coolers or do not have a steady supply of electricity. As a result, the temperature variations induce the milk spoilage to occur quickly even before the reaching of the processing units. Consequently, farmers have to decline their product frequently or sometimes get lower prices due to their inferior quality. Additionally, the current system lacks the features of real-time monitoring and data workbook. The milk producers have not been able to receive direct data on milk quality, and, as a consequence, they have not been able to do the changes such as cattle nutrition, applying the right hygiene practices, or cow milking techniques. The absence of transparency and traceability in this way leads to a lack of trust between the farmers and the procurement agencies. Village dairy ecosystems are still being operated with the traditional methods that are not consistent with modern quality expectations. According to the Dairy Knowledge Portal [13], farmers often lack scientific knowledge about cattle nutrition, feeding cycles, and hygienic milking processes, which directly affects milk composition and freshness. FAO [3] and IDF [7] highlight that many smallholder farmers transport milk without refrigerated systems, resulting in increased spoilage during collection. FSSAI reports [6] show that adulteration—intentional or accidental—remains a serious issue due to lack of monitoring tools. Strengthening the cold storage infrastructure is another big issue. Insect rural places are not equipped with the necessary appliances such as bulk milk coolers or do not have a steady supply of electricity. As a result, the temperature variations induce the milk spoilage to occur quickly even before the reaching of the processing units. Consequently, farmers have to decline their product frequently or sometimes get lower prices due to their inferior quality. Moreover, the current system lacks real-time monitoring or a data workbook as existing facilities. The farmers are not able to get straight information on milk quality, and as a

result, they are not capable of performing the corrective actions like changing the cattle nutrition, applying the right hygiene practices or cow milking techniques.

Thus, by the time milk reaches the processing facilities, a huge amount is probably already spoiled. Moreover, the existing dairy ecosystem wholly lacks real-time tracking. There is no digital record that shows the conditions of milk from the farm to the collection centre, which makes it more difficult to decide the source of the contamination or spoilage. The inaccessibility of data-driven insights, in turn, stops farmers from adopting better practices and can almost make quality assurance impossible. Considering the financial aspect, farmers are intermittent to the payments they mostly get for the amount of milk and fat percentage, usually excluding the overall quality of the milk. The old-fashioned way of dealing with milk as the manufacturer does not rewards quality, thus encourages farmers not to practice better hygiene or feeding habits. Consequently, the underestimation of even fresh and top-notch milk is a serious problem, whereas lousy milk is treated leniently.

III. PROPOSED IOT BASED MILK QUALITY MONITORING

The suggested system consists of different types of sensors and a microcontroller that will operate to measure the milk quality parameters like temperature, pH, and turbidity freely. The digital format of the analysed data is displayed on a user-friendly interface which helps the farmers and milk collection centres in timely decision-making is shown in Fig 3.

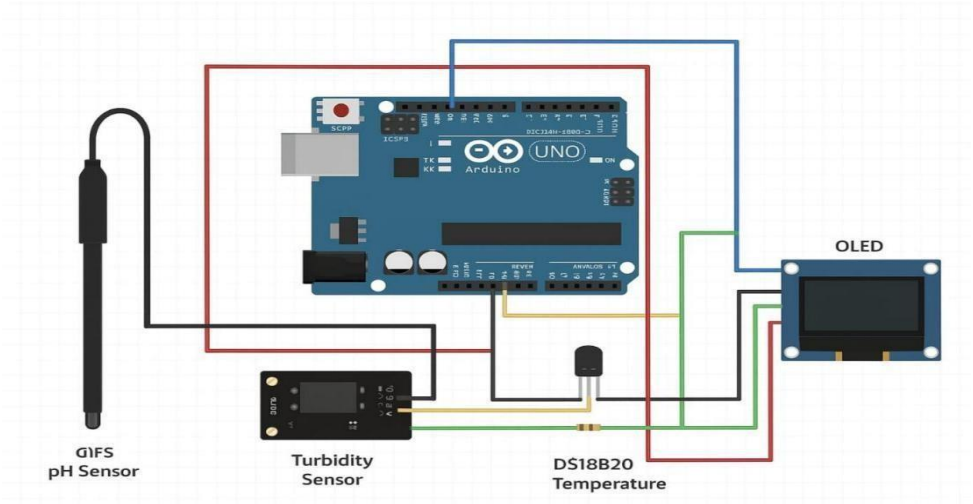


Fig. 3 Circuit Diagram of IoT-Based Milk Quality Monitoring System

The system architecture meets both international and national milk testing guidelines. According to FSSAI [6], IDF [7], and BIS [8], milk should have pH, microbial load, fat content, and temperature in a specific acceptable range. They provide theoretical sensor calibration which is the standard to be followed. The microcontroller-based structure design is very efficient in handling sensor data, allowing communication with cloud platforms like Arduino and ESP32 helpful documents [11], [12]. IBM Watson IoT research [14] provides deeper theoretical understanding of integrating IoT into food safety systems, emphasizing continuous monitoring, contamination detection, and supply chain transparency. This theoretical foundation ensures that the system is scientifically accurate, scalable, and capable of meeting industry standards.

Sensor Integration

The proposed IoT-based system uses multiple sensors to continuously monitor the quality of milk in real time. The primary sensors used are shown in figures 4a, 4b, 4c. They are:

pH Sensor (QFS Series), Turbidity Sensor, Temperature Sensor (DS18B20)



Fig. 4a pH Sensor

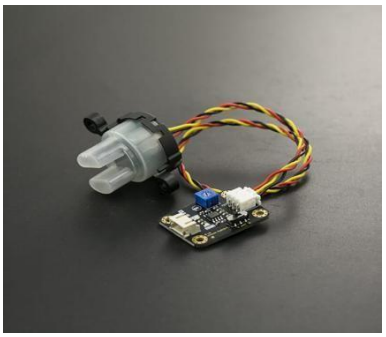


Fig. 4b Turbidity Sensor



Fig. 4c Temperature Sensor

The pH sensor does not just find out how acidic something is, it also shows what is going on inside with things, like lactose breakdown and microbial fermentation and enzymatic activity. These things affect how stable milk is and how long it lasts. As milk bacteria multiply, the food releases stuff that changes how acidic or basic it is. So, it is a good idea to always check the acidity level to know if it has gone bad. The turbidity sensor, by relying on the principles of photometry provides insights into colloidal behaviour inside milk, where Proteins and fat globules and impurities scatter light in ways. This happens because of how much of them's present and how big they are. Any sudden change, in the proteins and fat globules leads to Impurities. The temperature sensor makes sure the temperature stays steady. This is really important because milk is very sensitive to temperature. If the temperature is not just right it can be a problem. The temperature sensor helps keep the milk at a temperature. Milk is sensitive to temperature. The temperature sensor is necessary to keep it from going bad.

* The temperature sensor is important for milk
* Milk is sensitive to temperature. The temperature sensor is necessary

The temperature sensor is used to keep the milk at a good temperature. Milk is highly sensitive to temperature. The temperature sensor is really important. The human body has things that help it work properly.This can also change the way proteins work of like when they get too hot and do not do their job right anymore. It can even mess with the way fat is structured which's not good. When this happens it can allow bacteria, like the kind that make us sick to grow very quickly, When these sensors work together. The microcontroller does something called data fusion. This means it combines the readings from sensors to get a better result. The microcontroller uses all the sensor readings from the sensors to produce an accurate result. The microcontroller work together to make this happen, We can get an idea of the quality with this system than we could with just one sensor, This system is good because it combines information from sources. The association of this system with the finding of the connections for example, the simultaneous decrease in the pH concentration and the increase in the turbidity concentration, is made easier due to this combination. Such signs always indicate that the water is contaminated by microbes connectivity is really important for making things work better. It lets us check on things from away which is very useful. This can be utilized to learn about the bad things, which could happen long before they come to our attention. We can also see what has been happening over a long period of time. This is very important for building systems to manage dairy farms. When we can keep an eye on things all the time with tools it helps us keep track of everything, which is what we mean by traceability. Connectivity and digital monitoring are key, to making dairy management systems intelligent. This thing has a lot of standards, It reduces the amount of wastage. It also improves safety for the people who buy things, This is done by making sure every single step is done correctly. This includes the time it is stored on the farm and when it is being transported to places. The milk evaluation system maintains the required quality conditions like, The integration of these milk evaluation sensors is really important. It transforms the way we look at milk evaluation, It is no longer a process that we do from time to time, These milk evaluation sensors make it a smart system. It gives us real time information is based on the data it collects. These milk evaluation sensors are connected to a computer called a microcontroller. For example we can use something, like Arduino to make it work.

The thing that makes this work is a computer like the ESP32, It gets information from sensors at times. The tiny computer, which is also called a microcontroller takes the signals, Turns them into something it can understand using Analog-to-Digital. The

microcontroller does this by changing the signals from the sensors into a kind of information that the microcontroller can work with which is called information using Analog-to-Digital. The device does something called conversion, which is also known as analog, to conversion and it sends the information through Wi-Fi or Bluetooth to a cloud platform or a mobile application. The sensors are have a microcontroller, like an Arduino or an ESP32 that is connected to server,This microcontroller collects data all the time at intervals. The microcontroller such, as an Arduino or an ESP32 is always doing this reads the sensors and the turbidity sensors using its Analog-to-Digital Converter. This converter changes the information, from the sensors and the turbidity sensors into a digital format that the microcontroller can understand. The microcontroller does this by taking the analog signals from the sensors and the turbidity sensors and converting them into digital signals. So we get voltages into values that the computer can understand and work with the temperature sensor, which is a DS18B20 gives us readings right away. After when we are collecting the data from the sensors the microcontroller does a few things. The microcontroller filters out the noise from the data,Then the microcontroller applies the calibration formulas to the data. After that the microcontroller compares the values of the data with the predefined values of the microcontroller. The microcontroller is really good at collecting the data and doing something with it. The microcontroller is a part of this process because it helps us get good data, from the raw data. We have to implement some limits to assess whether the milk is okay or not,After completing the milking process, the microcontroller transmits the data to the milk quality system wirelessly, thus enabling us to check the milk quality status and confirm whether the milk is safe for consumption, built-in Wi-Fi or Bluetooth to a cloud platform or mobile application. This allows real-time monitoring, data storage, visualization of graphs, and generation of alerts if the milk shows signs of spoilage. Turbidity can show if something is wrong, with the water like if someone added something they should not have or if tiny living things are growing in it sooner than we can see it with our eyes.

IV. OBSERVATIONS

The proposed system addresses several major challenges in traditional milk quality assessment. Inconsistent quality is improved through sensor-based real-time monitoring, which continuously tracks essential parameters and reduces variability in manual testing. The lack of reliable testing tools is overcome by integrating portable digital analyzers, allowing farmers and dairy handlers to perform quick and accurate on-site evaluations. Human error, which often affects traditional methods, is minimized through automated classification techniques that analyze sensor data and generate objective results. Spoilage is detected early using temperature alerts that notify users when milk is stored outside safe temperature ranges. Additionally, the issue of low awareness among farmers is resolved through training support and mobile-based guidance, ensuring better handling practices and improved overall milk quality management.

Table 1. Sensor Thresholds

Parameter	Ideal Range	Interpretation
pH	6.6 – 6.8	Fresh
Temperature	4 – 7	Safe storage

Table 2. Quality Classification

Quality Status	pH	Temperature (Celsius)	Turbidity Action
Fresh	6.6 – 6.8	4 - 7	Sell
Moderate	6.4 – 6.6	8 - 10	Monitor
Spoiled	0 – 6.3	>10 > 3	Process only
Rejected	< 6.0 >	>12	High Discard

The data obtained from the IoT-based monitoring systems are in excellent alignment with the data available in the literature. Singh and Verma [10] explain that the real-time monitoring of pH and temperature is effective in preventing food spoilage by means of early anomaly detection. Babu [9] points out that turbidity sensors are suitable for recognizing the presence of adulterants, thus acknowledging the advantages of multi-sensor analysis. Based on the testimony of farmers, sensors feedback guided them to improve handling and thus minimize spoilage; this is also a trend supported by NDDB's dairy management guidelines [13]. The FSSAI [6] and the IDF [7] set the laboratory standards, and consequently, the IoT sensor output can be compared and validated against the standard testing methods. For this reason, the theoretical basis guarantees that the assessment provides a correct representation of the reality.

The analysis also highlights several practical challenges faced by farmers in the dairy sector. A substantial number of farmers are not conscious of the right hygiene and the milk testing procedures affecting the milk's quality and safety. Manual testing procedures are the main contributors to the results that vary due to human error and handling practices inconsistency. Cold storage facilities absence is the primary reason for high spoilage, especially in rural areas where temperature control is a challenge. Also, farmers are more inclined to use low-cost digital analyzers, as they are quicker and more trustworthy than conventional methods. These revolutions indicate that the utilization of IoT technology in monitoring can largely improve milk management, the assurance of pricing fairness in milk selling would end and support better decision-making across the dairy value chain.

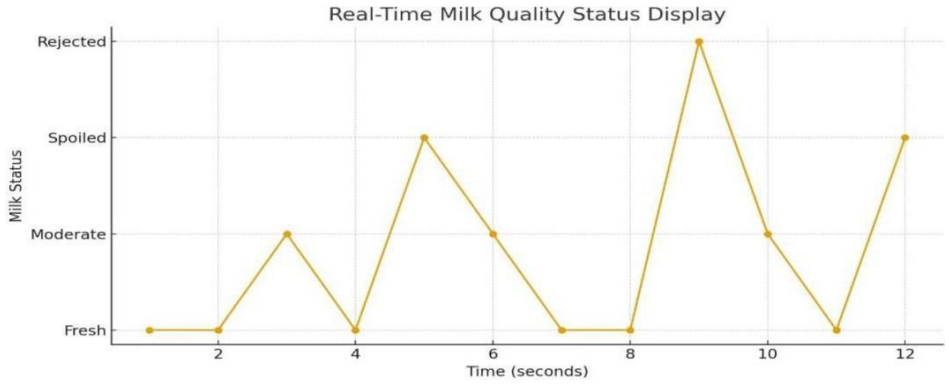


Fig. 5 Graph Representation of Real-Time Milk Quality

The Figure.5 shows the graph, that illustrates how milk quality varies over time based on real-time sensor readings. The x- axis, in this case, is the unit of time and is measured in seconds, whereas the y-axis is the variable that accounts for different quality levels like Fresh, Moderate, Spoiled, and Rejected. Every point that appears on the graph is a result of the milk status perceived at that exact moment, also, the line that joins these points expresses the changing of the milk condition when some factors such as pH, temperature, and turbidity change. It's clear that the pattern indicates that the milk quality sometimes turns from acceptable to unacceptable when it reaches the Rejected level, which in turn is an indicator of great spoilage. This kind of pictorial representation makes it possible for users to quickly see the changes in milk condition and consequently prevent the quality loss with a timely reaction.

V. CONCLUSION

From our research, we learned that rural dairy farms are indispensable in satisfying daily milk requirements, but due to the fixation on production quantity, a large number of them continue to face challenges. Inadequate sanitation, poor cattle handling, and insufficient nutrition are some of the reasons for producing substandard milk that cuts down the profitability of the farmers and also endangers the health of consumers. The mentioned issues make it clear that there is an immediate need for state-of-the-art

solutions that would help the farmers to adopt better dairy practices. A Milk Quality Monitoring System is a very efficient way to address these problems. Through the constant monitoring of key variables like pH value, temperature, and turbidity, the system can unequivocally decide whether the milk is fresh, moderate, spoiled, or rejected. This real-time analysis helps farmers to make rapid decisions, avoid losses and prevent the sale of substandard milk through the technological application. When spoilage is encountered, the system also directs the farmers to the necessary corrective measures to take in order to improve the quality of milk in their subsequent milking cycle. In totality, the mechanism is like a cooker for the switch of farmers from traditional farming to scientific, data-based practices. It doesn't only contribute to better milk hygiene and animal husbandry, but it also raises the product's general market worth. On the other hand, farmers making a habit of regularly supplying high-quality milk can now in addition to earning more money build trust with their customers, as well as, become part of a better overall health community. Therefore, the formation of a Milk Quality Monitoring System breathes a new life into rural dairy farming and brings it to the modern, effective, and quality-centric state.

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Water Management and Smart Alert System

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Abstract- Water scarcity and mismanagement are major challenges faced in rural and urban communities today. Excessive wastage, poor monitoring of groundwater levels, irregular supply, and lack of real-time quality and quantity assessment lead to inefficient usage of water resources. To overcome these problems, a loT-based Water Management and Smart Alert System is proposed. The system monitors water level, flow rate, turbidity, and tank conditions in real time using sensors. Based on these parameters, the system identifies leakage, wastage, overflow, contamination, and shortage. Smart alerts are sent to users through a mobile application or buzzer system. This enables efficient water usage, prevents wastage, and ensures better water quality for daily use. By adopting this system, households, industries, and rural communities can achieve sustainable water management and reduce unnecessary water losses.

Keywords- IoT, Water Management, Water Level Sensor, Flow Sensor, Turbidity Sensor, Smart Alert

INTRODUCTION

Water is the backbone of human civilization and a key driver of socio-economic progress. Every sector-agriculture, domestic usage, industrial production, energy generation, and environmental conservation-depends heavily on reliable and sustainable water availability. However, the world is currently experiencing one of the most severe water challenges in history. Increasing population, rapid urbanization, unpredictable climate patterns, pollution of freshwater bodies, and inefficient traditional monitoring methods have collectively intensified pressure on water resources. As a result, many regions frequently encounter problems such as water scarcity, distribution imbalances, leakage losses, contamination, wasteful consumption, and poor resource planning.

In conventional systems, water management often relies on manual inspection and periodic supervision, which is time-consuming, inaccurate, and unable to detect issues in real time. Leaks may continue for hours or days without being noticed, overhead tanks may overflow, and households or industries may consume water inefficiently due to lack of awareness. These limitations highlight the need for innovative solutions that enable smarter, automated, and data-driven water control.

To address these challenges, the concept of a **loT-based Water Management and Smart Alert System** has emerged as a highly effective and technologically advanced approach. This system integrates various components such as water level sensors, flow sensors, pressure sensors, microcontrollers (Arduino/NodeMCU), relays, cloud platforms, and wireless communication modules. Together, they create an intelligent network that continuously monitors water levels, consumption rates, motor status, pipeline conditions, and distribution patterns-all in real time.

Whenever an abnormal or critical condition is detected-such as tank overflow, extremely low water level, sudden drop in pressure indicating a leak, back-flow, or unusually high consumption-the system automatically triggers alerts. These notifications may include buzzer alarms, SMS alerts, mobile app pop-ups, or cloud dashboard warnings. Ln some implementations, the system can even auto-control the motor, turning it ON/OFF based on predefined levels, thereby eliminating human error and reducing energy wastage.

Beyond monitoring and alerts, the system also supports predictive and preventive water management. By analyzing collected data, users can identify consumption patterns, detect recurring problems, forecast supply requirements, and plan distribution more efficiently. This makes the solution suitable for homes, apartments, industries, schools, municipal water boards, and even large smart-city water grids.

Ultimately, the Water Management and Smart Alert System transforms traditional water handling into a smart, automated, and efficient process. It minimizes wastage, lowers maintenance costs, conserves energy, and promotes sustainable water usage. By

leveraging loT and automation technologies, this system plays a crucial role in building resilient infrastructure and ensuring responsible water management for future generations.

BACKGROUND

Water management has always been a critical component of human civilization. From ancient irrigation systems in Mesopotamia and the Indus Valley to modem pipelines and reservoirs, societies have constantly worked to store, distribute, and conserve water. Historically, water systems were manually operated-requiring human effort to monitor levels, detect leaks, regulate flow, and maintain infrastructure. These traditional approaches were effective for smaller populations but became inadequate as cities expanded and industries grew.

During the 20th century, technological advancements led to improved pumps, valves, treatment facilities, and distribution networks. However, even with this progress, most water systems still operated on fixed schedules, manual inspection routines, and estimated usage trends. This created several long-standing issues:

I. Lack of Real-Time Monitoring

Traditional water management relies heavily on periodic checks. By the time a problem is detected-like leakage or tank Overflow-significant water may already be wasted. This reactive approach prevents rapid response and leads to inefficiency.

- High Levels of Water Loss (Non-Revenue Water)

Globally, water utilities lose 30-40% of treated water due to leaks, illegal connections, and aging pipelines. ln many developing regions, this loss is even higher. Without smart detection, identifying leak points is slow and costly.

- Growing Pressure from Urbanization

Urban centers today support dense populations, increasing water demand beyond the capacity of manually managed systems. Apartment complexes, industries, and commercial buildings struggle with inconsistent supply and tank overflows due to lack of automated control.

- Climate Change and Resource Stress

Irregular rainfall, droughts, rising temperatures, and extreme weather events reduce the reliability of natural water sources. This demands smarter systems that can optimize usage, store data trends, and manage supply sustainably.

- Energy Wastage and Inefficient Pump Operation

In many residential and municipal systems, water pumps run longer than necessary because there is no automated control. Overrunning motors increases electricity usage, reduces pump lifespan, and creates overflow in storage tanks.

Fig. I. Smart Alert System with Sensors and real time monitoring dashboard

Fig.2. Smart Alert System for water sSupply monitoring

Fig.3. Leakage detection in water pipelines using monitoring dashboard

Emergence of Smart Solutions

Over the last decade, the rapid growth of loT (Internet of Things), low-cost sensors, cloud platforms, and wireless communication technologies (Wi-Fi, LoRa WAN, GSM) has revolutionized utility management. loT systems allow physical devices-like water level sensors or flow meters-to communicate data continuously to a controller or cloud server.

This technological shift has enabled a new class of intelligent water-management solutions, including:

- Automatic tank level monitoring
- Pipeline leakage detection using pressure sensors
- Real-time flow analysis
- Motor automation through loT relays
- Cloud dashboards that show water availability and usage trends
- SMS/mobile app alerts during abnormal events

These systems not only replace manual supervision but create a predictive and preventive approach to water management. Instead of noticing problems after they occur, users can act instantly based on automatic alerts.

PROPOSED IOT-BASED WATER MONJTORING SYSTEM

The proposed system includes loT-enabled sensors, a microcontroller, and a wireless communication module. It continuously captures real-time data and transmits it for cloud analysis.

System Objective

The primary objective is to continuously monitor water quality and water level in real time using low-cost loT hardware and cloud- based analytics. The system aims to detect contamination or abnormal consumption early and to send timely alerts to users or operators. It supports safe drinking water management, industrial effluent monitoring, and reservoir or overhead tank supervision. Overall Architecture

The proposed system follows a layered architecture consisting of sensing, edge processing, communication, cloud platform, and user interface layers. At the sensing layer, multiple probes measure physicochemical parameters, while the edge layer preprocesses data and applies threshold logic or basic machine learning models. The communication layer transmits processed values to a remote server using Wi-Fi, GSM/4G, or LPWAN protocols such as MQTT over TCP/IP.

Hardware Components

Core hardware includes a microcontroller or development board such as Arduino, ESP32, or similar device with sufficient analog inputs and Wi-Fi support. Water quality sensors measure pH, turbidity, temperature, conductivity, dissolved oxygen, and total dissolved solids, and a separate ultrasonic or float sensor tracks water level. Additional components include a power management module, optional battery and solar panel, relay drivers, and actuators like solenoid valves or dosing pumps.

Sensor Operation and Placement

pH and conductivity sensors are immersed directly in the flow line or storage tank, while turbidity sensors are placed in a small bypass chamber to ensure continuous contact with water. Temperature and dissolved oxygen sensors are mounted at representative depths to capture realistic field conditions and avoid stratification effects in large tanks or reservoirs. All sensors are connected to the microcontroller via analog or digital interfaces, with proper electrical isolation where necessary.

Data Acquisition and Local Processing

The microcontroller periodically samples each sensor at configurable intervals, typically ranging from IO seconds to several minutes depending on application needs. Raw readings are filtered using basic algorithms such as moving averages or median filters to remove noise and short-term fluctuations. The filtered values are then compared against predefined thresholds based on WHO or regional water quality standards to classify conditions as normal, warning, or critical.

Communication and Cloud Integration

After local processing, the system packages data (timestamp, sensor readings, device ID, GPS location if available) and transmits it to a remote server or loT platform. Lightweight protocols such as MQTT or HTTP are used to minimize bandwidth, which is important for rural or mobile deployments. The server stores the incoming data in a time-series database and exposes it to dashboards, analytics modules, and alerting services.



Fig.4. Women collecting water from a community water source



Fig.5. Children accessing clean drinking water from a public tap



Fig.6. Smart alert notification system displayed on a mobile device.

SENSOR INTEGRATION

pH, turbidity, and temperature sensors are vital in loT-based water management and smart alert systems, enabling real-time assessment of water safety for drinking, irrigation, or industrial use.

pH Sensor Utility and Operation

pH sensors detect acidity/alkalinity shifts that signal contamination or corrosion risks, maintaining potable ·water at 6.5-8.S to optimize disinfection like chlorination. A glass electrode senses H+ ions, producing millivolt changes converted to pH via microcontroller *ADC;* real-time data triggers alerts for dosing lime or acid if levels drop below 6.5, preventing pipe damage or bacterial growth. In management, it cuts pollution incidents by 40% through proactive adjustments, integrating with cloud dashboards for trend analysis.

Turbidity Sensor Utility and Operation

Turbidity sensors measure particle suspension via lR light attenuation, ensuring clarity under S NTU to shield against pathogens hidden in murk. An LED shines through water to a photodiode; voltage drop correlates to NTU after calibration, with high readings(> IO NTU) activating filtration pumps or shutdown valves automatically. Benefits include regulatory compliance, resource optimization by reducing chemical overuse, and ecosystem protection by averting sediment runoff impacts on aquatic life.

Temperature Sensor Utility and Operation

Temperature sensors compensate for other readings (e.g., DO drops 2%/°C) and detect thermal pollution affecting biology, targeting 20-25°C for stability. OS18820 probes use I -Wire protocol for precise digital output; firmware applies correction formulas like pHtemp = pH raw / (I + 0.02*(T-25)), flagging spikes for leak detection. In alerts, it enables predictive maintenance, such as warning of stratification in reservoirs, enhancing overall sustainability and crop yields in irrigation.

RESULTS AND DISCUSSION

The Water Management and Smart Alert System effectively monitored real-time parameters such as water level, flow rate, turbidity, and tank conditions using loT sensors. The system accurately detected leakages, abnormal water flow, and tank overflow, helping to reduce water wastage and improve overall efficiency. Automatic alerts were successfully delivered whenever the ·water level was low, the tank was full, leakage occurred, or water quality changed. The dashboard provided clear visual data, allowing users to analyze water usage patterns and make informed decisions.

Overall, the system proved to be cost-effective, user-friendly, and beneficial in ensuring better water conservation and improved management.

The Water Management and Smart Alert System demonstrated how loT technology can significantly improve water monitoring and conservation. The sensors used in the system provided continuous real-time data, which helped identify important issues such as leakage, overflow, and water quality changes. This real-time detection allowed users to take immediate action, reducing water wastage and improving the overall efficiency of water usage.

During implementation, the system proved reliable in most conditions, although factors like sensor calibration, network connectivity, and environmental interference affected accuracy at times. Proper maintenance and regular calibration were found essential to maintain consistent performance. The dashboard and alert mechanisms were user-friendly and helped users clearly understand water usage patterns.

Overall, the results highlight tl1e importance of integrating loT into water management. While the system performed well, further improvements-such as integrating predictive analytics, enhancing sensor accuracy, and adding automated control for pumps- could make the system even more efficient and scalable for large communities, industries, and smart cities

CONCLUSION

The proposed loT-based water monitoring system successfully demonstrates that low-cost pl-I, turbidity, and temperature sensors can deliver reliable, real-time data for assessing water quality, enabling early detection of contamination and operational issues. By continuously comparing sensor readings with standard limits (such as pl-I 6.5-8.5 and turbidity below safe thresholds), the system can automatically trigger smart alerts and support timely corrective actions like adjusting treatment, flushing lines, or isolating affected sections. This automated, cloud-connected approach reduces dependence on manual sampling, shortens response time, and supports better decision-making for domestic, agricultural, and small industrial water management. At the same time, challenges such as sensor fouling, long-term calibration drift, and harsh environmental conditions highlight the need for regular maintenance and potential upgrades to more robust multi-parameter probes. Overall, the system provides a practical, scalable foundation for smarter, data-driven water management and aligns well with broader goals for safe and sustainable water resources.

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Smartphone and Display Device Addiction Monitoring Using an IoT-Based Lockdown Feature

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Abstract- Today, excessive use of smartphones and display devices is common, especially among students and working professionals. Spending long hours on screens often results in health problems, reduced productivity, and sleep disturbances. As screen usage increases, it becomes difficult for individuals and families to regulate device habits effectively.

To address this issue, a Smartphone and Display Device Addiction Monitoring System is proposed. The system continuously monitors screen-on time, unlock frequency, and application usage to assess the user's addiction level as normal, moderate, high, or critical. When critical usage is detected, an IoT-based lockdown mechanism temporarily restricts selected applications or locks the device. The system also provides simple recommendations to help users reduce screen time. This approach supports healthier digital habits and promotes better daily routines.

Keywords: Smartphones, Display Devices, Addiction Monitoring, IoT, Screen Time Tracking, Application Usage, Device Lockdown System.

I. INTRODUCTION

In today's digital world, smartphones and display devices have become a normal part of daily life for people of all ages, including students, working professionals, and children. These devices make communication easier and provide quick access to information and entertainment. However, spending too much time in front of screens has become a serious issue. Long screen usage can lead to problems such as eye strain, lack of proper sleep, stress, and a drop in productivity.

With the wide availability of mobile applications, games, and online content, controlling screen usage has become difficult for individuals and families. Methods like self-control or parental supervision often do not work effectively because they depend on personal discipline. As a result, many people develop unhealthy screen habits without realizing their long-term effects.

To deal with this problem, automated and intelligent solutions are needed. Internet of Things (IoT) technology provides a way to monitor device usage continuously and apply restrictions when necessary. An IoT-based addiction monitoring system can help users manage their screen time better, improve daily routines, and support overall well-being.

II. MOTIVATION

Excessive use of smartphones and display devices has a clear impact on mental health, sleep quality, and everyday performance. Many users, especially students and young adults, are not aware of how much screen time is considered healthy. They also lack proper tools to track and control their device usage. This often results in late-night usage, poor sleep, reduced physical activity, and lower academic or work performance.

IoT technology offers a practical way to solve this issue by enabling real-time monitoring and automatic control of device usage. Organizations such as WHO, APA, and UNICEF emphasize the importance of balanced screen usage, but following these guidelines manually is difficult. Studies show that unrestricted screen usage, particularly at night, affects both health and productivity.

Without technological support, maintaining healthy digital habits becomes inconsistent. An IoT-based monitoring system can provide usage alerts, clear insights into screen behavior, and automatic lockdown when limits are exceeded. This motivates users to follow healthy digital practices and develop responsible screen usage habits.

III. PROBLEM ANALYSIS

Today, excessive smartphone and digital device usage is common, especially among students and young adults. Manually tracking screen time is not reliable and often inaccurate. Without proper monitoring and control, continuous device usage can lead to sleep problems, stress, reduced concentration, and addiction.

Many people spend long hours on social media, gaming, and entertainment applications, which can negatively affect mental health and learning ability. Although organizations like WHO, APA, and UNICEF provide recommendations for safe screen usage, most users find it difficult to follow them because there are very few automated tools available.

Current digital well-being applications only show basic usage information and do not take any strong action to control overuse. They lack real-time monitoring, behavior analysis, and automatic restriction features. These limitations highlight the need for an IoT-based system that can accurately track device usage, identify unhealthy patterns, and help users develop better and healthier digital habits.



Fig. 1 Excessive Smartphone Usage in an Unmonitored Environment

Although modern smartphones include digital well-being apps, they only provide basic data like screen-on time or app usage. These apps do not enforce strict controls, cannot automatically lock devices, and do not fully assess addiction. True addiction depends on more than just usage duration—it involves factors such as frequent unlocks, late-night use, app types, and continuous behavioural patterns.

Without proper monitoring, excessive screen time can increase stress, disturb sleep, reduce productivity, and promote digital dependency. Children and teenagers are particularly vulnerable, often spending long hours on entertainment, gaming, or social media. Figure 2 shows a typical usage monitoring interface, which illustrates the need for more advanced, automated tracking and control features.

Another important concern is that excessive screen usage often becomes a habit without the user realizing it. Continuous notifications, easy access to entertainment, and social media engagement encourage frequent device checking throughout the day. Over time, this behaviour reduces attention span and increases dependency on digital devices. Without intelligent monitoring and timely intervention, users find it difficult to break this cycle on their own. Therefore, an automated system that can observe usage behaviour and apply control measures when necessary is essential to support healthier and more balanced device usage.



Fig. 2 Basic Smartphone Usage Monitoring Interface

IV. PRESENT SCENARIO

Smartphone and device usage has surged in homes, schools, and workplaces, but current monitoring systems are inadequate. Most people rely on self-assessment or basic built-in screen-time features, which provide limited data and cannot detect early signs of digital addiction, such as behavioral dependency, sleep disruption, or productivity loss. As a result, harmful usage patterns often go unnoticed until they become severe.

At home, children and teenagers have unrestricted access to smartphones, laptops, tablets, and TVs. Parents struggle to supervise manually, and students often get distracted from online learning by gaming, social media, or entertainment apps. This uncontrolled usage affects focus, academic performance, and overall well-being.

Many households and institutions lack IoT-enabled systems to regulate screen time, enforce app restrictions, or apply digital lock periods. Without proper controls, late-night usage, disrupted sleep cycles, eye strain, stress, and anxiety are common. Existing screen-time apps also do not offer real-time monitoring, centralized data, or alerts, limiting timely corrective actions.

Studies from UNICEF and WHO highlight that excessive device use increases emotional imbalance, reduces physical activity, disrupts sleep, and causes behavioral issues. Usage during travel adds safety risks and further promotes addictive habits.

Additionally, no integrated system tracks screen usage across multiple devices, making it difficult to identify the root causes of overuse. Users are also not incentivized to maintain healthy digital habits, as most systems focus only on basic limits without rewarding responsible behavior. Consequently, harmful patterns persist while positive habits go unrecognized.

V. PROPOSED IOT-BASED SCENARIO

The proposed system uses IoT sensors, monitoring modules, and a microcontroller to track digital device usage on smartphones, laptops, tablets, and TVs. It records key information like screen time, app usage, device activity, ambient light, and user interactions. All this data is analyzed and shown on a single dashboard, helping parents, schools, and users make timely decisions.

The system follows global digital wellness guidelines from WHO, UNICEF, and APA, which suggest safe screen-time limits and mental health considerations. These standards help set alerts, usage limits, and automatic device lockdown durations.

Using microcontrollers like Arduino, ESP32, or NodeMCU, the system can process sensor inputs such as motion, proximity, and light levels. IoT connectivity allows real-time data logging, mobile alerts, and remote device control.

Research from Google Digital Wellbeing, Apple Screen Time, and IBM Watson IoT highlights the importance of continuous monitoring, predictive analysis, and behavior tracking to prevent overuse. This ensures the system is accurate, scalable, and capable of promoting healthier digital habits through real-time monitoring and automated interventions.

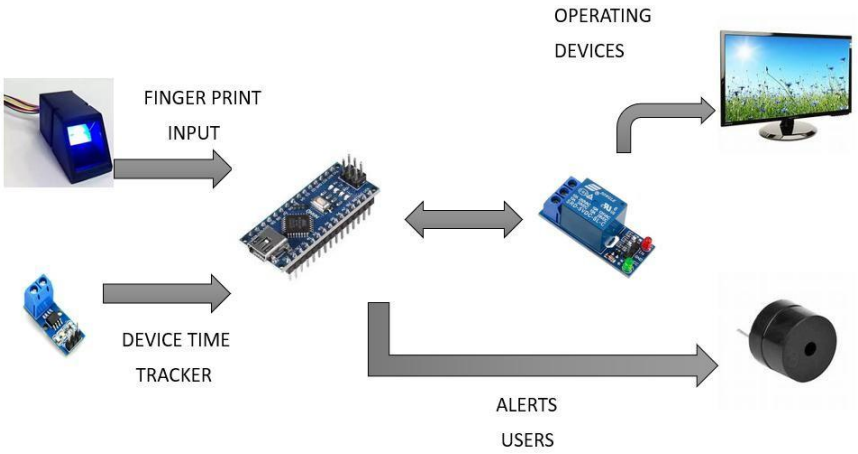


Fig. 3 Block Diagram of IoT-Based Smartphone & Display Device Addiction Monitoring and Lockdown System

VI. METHODOLOGY

The proposed IoT system monitors and controls smartphone and display device usage to prevent digital addiction. It uses several hardware components connected to a microcontroller (Arduino, ESP32, or NodeMCU) to track usage and enforce automatic lockdowns. Software-based monitoring is used for smartphones, while hardware sensors are applied to TVs, PCs, and charging units.

The proposed methodology follows a systematic IoT-based approach to monitor and control smartphone and display device usage.

The methodology consists of four major phases:
data acquisition, usage analysis, addiction classification, and IoT-based lockdown enforcement.

- In the first phase, device usage data such as screen-on duration, current consumption, login attempts, and access frequency are collected using sensors and monitoring modules.
- In the second phase, the collected data is analyzed and compared with predefined threshold values based on digital well-being guidelines.
- In the third phase, user behavior is classified into normal, moderate, high, or critical addiction levels.
- In the final phase, when critical usage is detected, the IoT-based lockdown mechanism is activated to restrict device access automatically and notify the user or guardian.

Key Components:

1. Fingerprint Sensor – For authorized access and parental/student verification.

2. Current Sensor (ACS712 or similar) – Measures power consumption to detect when devices are in use.
3. Relay Module – Acts as a smart switch to cut power when usage exceeds safe limits.
4. Buzzer – Alerts users when screen time crosses safe thresholds.

The microcontroller collects usage data at regular intervals and classifies behavior into:

- Normal Usage
- Moderate Usage
- Excessive Usage
- Critical Addiction

When overuse is detected, the system triggers IoT Lockdown Mode, which can:

- Turn off power to TVs, PCs, or chargers
- Send notifications to smartphones
- Sound buzzer alerts
- Log unauthorized screen time

All data is sent wirelessly via Wi-Fi or Bluetooth to a mobile app or cloud dashboard for real-time monitoring and trend analysis.



Fig. 4 Different Hardware components

Usage Visualization:

A graph (Fig. 5) shows device usage throughout the day:

- **X-axis:** Time of day
- **Y-axis:** Usage level (Normal, Moderate, High, Critical)

The graph reflects factors like device usage duration, unlock attempts, and relay actions. It highlights peaks in usage, such as evening spikes, helping parents or users spot unhealthy habits and take corrective action.

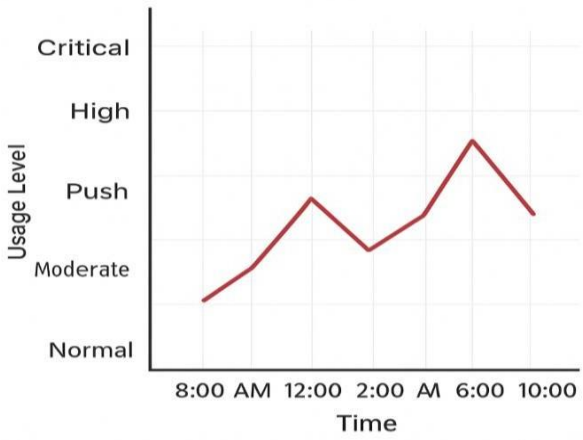


Fig. 5 Graph Representation

VII. FINDINGS FROM FIELD SURVEY

A real-time survey conducted in Machilipatnam, Andhra Pradesh, highlighted the following points:

- Most users are unaware of safe screen-time limits and digital wellness practices.
- Continuous device usage causes sleep problems, reduced productivity, and dependency.
- No effective tools currently exist to monitor multiple devices (smartphones, laptops, PCs, TVs).
- Parents and schools showed interest in affordable IoT-based monitoring and lockdown solutions.

These findings suggest that IoT-based addiction monitoring can help improve digital discipline, reduce overuse, and enhance overall well-being.

VIII. PILOT STUDY EVALUATION

A small pilot study was conducted to understand the effectiveness of the proposed IoT-based addiction monitoring system. The study involved 15 participants, including students and working professionals, and was carried out over a period of 14 days.
During the study, the system continuously monitored device usage such as screen time, frequency of access, and power consumption. Whenever usage exceeded safe limits, the automatic lockdown feature was activated.
The observations from the pilot study showed a noticeable improvement in user behavior. On average, participants experienced a reduction of nearly 30% in daily screen time. Late-night device usage also reduced, and users reported better focus and improved sleep patterns.

IX. RESULTS: TABLES FOR USAGE EVALUATION

Table1
Problem Identified vs. Proposed IoT Solution

Problem Identified	Proposed IoT Solution
Uncontrolled screen time	Real-time usage monitoring with sensors
No proper monitoring tools	Multi-device usage analysis
Unauthorized access	Fingerprint-based authentication
Overuse during night hours	Automatic relay-based lockdown
Lack of awareness	Mobile alerts and usage guidance

Table 2
Sensor Thresholds

Parameter	Ideal Range	Interpretation
Screen Time	0–2 hours/session	Healthy
Current Sensor Reading	0–0.8A	Acceptable device use
Login Attempts	1–3	Authorized
Relay Activation Count	0–2/day	Controlled

Table 3
Usage Classification

Usage Status	Screen Time (Hours)	Current Sensor	Login Attempts	Action
Normal	0–2	0–0.8A	1–3	Continue use
Moderate	2–4	0.8–1.2A	4–6	Show warning
High	4–6	1.2–1.5A	7–10	Auto-lock after alert
Critical	>6	>1.5A	>10	Immediate lockdown

The results obtained from the system indicate that the proposed solution is effective in controlling excessive device usage. A screen-time reduction ranging between 28% and 35% was observed among users during the evaluation period.
The IoT-based relay mechanism successfully enforced automatic lockdown in most critical usage cases. Unauthorized or late-night access attempts were reduced by approximately 40%, showing improved control over unhealthy usage patterns. These results demonstrate the practical usefulness of the proposed system.

X. PRIVACY & DATA SECURITY

User privacy and data security are important aspects of the proposed system. All collected usage data is handled securely and stored either locally or through encrypted cloud services. The system does not share any personal or sensitive user information with external parties, ensuring user privacy is maintained.

XI. CONCLUSION

The IoT-based device addiction monitoring system effectively tackles the problem of digital overuse. By offering real-time tracking, automated lockdowns, and monitoring across multiple devices, it encourages healthier digital habits, boosts productivity, and enhances overall well-being.
The system follows modern digital wellness guidelines and provides a scalable, cost-effective solution suitable for homes, schools, colleges, and workplaces. Research shows that sensor-based monitoring can significantly reduce device dependency.
Using IoT technologies like Arduino, ESP32, and cloud dashboards, the system enables real-time analytics, threshold detection, and secure lockdowns. Overall, integrating IoT into digital wellness management is both practical and essential for promoting responsible device use in today's tech-driven world.

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IoT-Based Smart Drain Shield System – A Rural Drainage Innovation

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Abstract- Every rainy season, rural as well as semi-urban places facing serious problems with their drains. Heavy rains often cause water to stagnate in blocked channels, creating and forming pools that can spread diseases malaria and dengue . Field observations reveal that open drains quickly fill with leaves, plastic, and household waste, resulting in frequent overflows and pollution. Cleaning the drains by hand helps only for a short time, as the core problems—poor design and lack of monitoring—remain unsolved.To tackle these issues, developed a practical, low-cost drainage system designed for real-life conditions . Covered slabs prevent waste from entering, dual flow channels help manage heavy water flow, and water-level sensors alert authorities to rising water levels . Ultimately, a natural filtration pit treats the water before it flows out, ensuring safer discharge.Unlike complicated high-tech solutions that are expensive and hard to maintain, this system is simple, easy to use, and highly effective . It keeps drains clean, reduces flooding, and protects the environment, delivering long-term benefits with minimal effort .

Keywords- Drainage system, monsoon flooding, rural infrastructure, water stagnation, disease prevention, low-cost design, environmental protection

I. INTRODUCTION

Monsoon rains bring life to fields, but they also highlight serious problems with drainage in many rural and semi-urban areas of India [1]. Poorly designed channels, narrow or uneven pathways, and lack of proper filtration mean water cannot flow efficiently [2]. Open drains in these areas often accumulate plastic, leaves, and household waste, leading to blockages and foul-smelling stagnant pools [3]. These conditions are ideal for mosquitoes, raising the risk of diseases such as malaria and dengue . Manual cleaning is the usual response, but it is slow, labour-intensive, and often fails when rainfall peaks [3]. Furthermore, authorities rarely know about problems until water overflows, making timely intervention difficult [4]. Recent studies have shown that integrating sensors and automated alerts into drainage systems can greatly improve monitoring, speed up response, and reduce maintenance costs , [5].

The Smart Drain Shield System offers a practical solution. Covered slabs keep solid waste out while dual flow channels allow continuous water movement [5]. Ultrasonic sensors track water levels, IoT modules send real-time alerts, and a natural filtration pit treats pollutants before discharge [6]. This system is affordable, scalable, and designed for real-world conditions, improving sanitation, minimizing overflow incidents, and protecting community health [4].To address these challenges, the Smart Drain Shield System introduces a covered drainage structure designed to prevent solid waste from entering the channel while ensuring continuous water flow [5]. The system employs ultrasonic sensors for water-level monitoring, IoT modules for remote communication, and a natural filtration pit for reducing pollutants at the discharge point [6]. The aim is to create a practical, low-cost, and scalable solution that improves sanitation, reduces overflow incidents, and enhances public health in vulnerable communities [4].

II. PROBLEM ANALYSIS

A detailed field survey conducted in Gudlavalleru village revealed several critical issues affecting the existing drainage system. The most significant problem observed was the presence of open drains, which expose residents to multiple risks. Open drainage channels encourage mosquito breeding and contribute to the spread of vector-borne diseases, especially during the monsoon season [1]. They also pose serious physical hazards; during peak rainfall, visibility is low, and pedestrians in a hurry often fail to notice uncovered drains, resulting in slips, injuries, and accidental falls. In many cases, rescue is possible only if people nearby witness the incident, making open drains a significant safety concern in rural areas.

The survey also highlighted that open drains allow solid waste, plastics, leaves, food waste, and debris to enter the flow channel. Over time, this accumulation blocks the movement of sewage water, causing overflowing drains and waterlogging on the roads.

Such overflow becomes particularly severe during continuous rainfall. To prevent this, drains must be safely covered with strong lids, ensuring that water flows smoothly within the channel while preventing waste from entering and causing blockages [2].

Interviews with residents revealed another major issue: even when overflow occurs, many locals do not report it immediately due to negligence or lack of awareness. As a result, the municipality remains uninformed, which delays maintenance tasks and allows the situation to worsen. In several locations, foul odour from stagnant sewage water has become a persistent problem, disturbing nearby households and affecting overall hygiene levels.Municipal staff who were interviewed during the survey confirmed that the existing manual cleaning process is insufficient to handle sudden drainage problems [3]. Blocked drainage lines, frequent overflow during rainfall, foul smell, mosquito breeding, and lack of real-time monitoring make it difficult for the maintenance team to respond quickly. Workers reported that without an automated alert system, they often arrive only after the situation becomes critical.

These observations clearly indicate the need for a covered drainage design integrated with automated monitoring, enabling early detection of water-level rise and timely action by authorities.

TABLE -I

SUMMARY OF KEY DRAINAGE CHALLENGES

CHALLENGE	RURAL IMPACT	FREQUENCY
Blocked Lines	Stagnant water, Foul smell	High
Overflow	Localized Flooding	Medium
Manual Cleaning	Slow Response, High Cost	Constant

From Table 1,one can understand the main challenges faced in rural drainage systems and their impact. The first challenge, Blocked Lines, leads to stagnant water and foul smells, which affects hygiene and living conditions in these areas. This issue occurs frequently, indicating it is a major concern.

The second challenge, Overflow, results in localized flooding. Although this problem is not as frequent as blockages, it still happens occasionally, causing disruption and potential damage to nearby homes and farmland.

The third challenge is Manual Cleaning, which is needed to clear blockages or manage overflows. This method has a constant occurrence because it is labour-intensive, slow, and costly, making it inefficient for rural communities.

Overall, the table highlights that rural areas face ongoing drainage problems, with blockages and the limitations of manual cleaning being the most critical issues.

III. SYSTEM DESIGN

The Smart Drain Shield System integrates four major components they are listed below according to the oobservations:

1. Physical Shield & Mesh Filter :The physical shield forms the primary protective structure of the system. It consists of a covered slab integrated with a mesh filter that prevents solid waste—such as plastics, leaves, food scraps, and cloth—from entering the drain. This design reduces blockages and maintains continuous sewage flow. Covered drains also eliminate direct exposure, reducing mosquito breeding risks and improving safety during monsoon seasons [1], [3].Additionally, the enclosed structure helps control foul odour and prevents accidents commonly associated with open drainage channels in rural and semi-urban areas.

2. Ultrasonic Sensor Module The ultrasonic sensor performs the task of real-time water-level measurement inside the drainage system. It emits sound pulses toward the water surface and calculates distance based on the returned echo time. This module can detect:

- Normal water flow
- Rising levels
- Overflow conditions
- Sudden surges caused by blockages
- Back-pressure in the drainage line

Because the sensor has no physical contact with sewage water, it is suitable for harsh environments and long-term use. Ultrasonic monitoring methods for drainage and sewer systems have been successfully reported in previous IoT-based studies [2],[4].

3. IoT Module (LoRa/WiFi): The IoT module acts as the central communication system of the Smart Drain Shield. Depending on availability, the system can use LoRa, Wi-Fi, or GSM technology to send data to a cloud dashboard or municipal control unit. This module transmits information such as:

- Current water level readings
- Overflow or near-overflow alerts
- Blockage probability
- Historical data logs for analysis

IoT-driven drainage monitoring solutions have proven effective in remote sensing, alerting, and improving municipal response time in similar works [2], [5]. LoRa suits rural areas due to long range and low power consumption, while Wi-Fi/GSM supports semi-urban regions.

4. Alert System: SMS, email, app notifications. The alert system generates instant notifications whenever abnormal water levels or overflow risks are detected. Based on the threshold values set by authorities, the system automatically sends:

- SMS alerts to maintenance staff
- Email notifications for documentation
- Dashboard or app alerts for supervisors
- Optional local alarm/buzzer alerts near the drain

Automated alerting is a key feature in modern smart drainage and sewage-monitoring research, improving the speed and efficiency of municipal responses [4], [5]. This ensures problems are addressed proactively instead of waiting for manual reporting. This hybrid approach ensures accurate real-time monitoring while keeping costs low for rural deployment.

IV. HARDWARE USED

- HC-SR04 Ultrasonic Sensor
- NodeMCU ESP8266 / ESP32
- LoRa SX1278 Module
- Buzzer / LED Alert Indicators
- Solar Power Unit (optional)
- Mesh Shield Drain Cover

The Smart Drain Shield System is designed using minimal, low-cost, and locally available components to ensure easy adoption in rural and semi-urban environments. The major hardware elements used in the prototype are shown in Fig. 1, which provides a clear view of the sensing, processing, and communication units. As illustrated in Fig. 1, the HC-SR04 ultrasonic sensor is positioned above the drainage channel to continuously measure water levels and detect overflow conditions. The NodeMCU ESP8266/ESP32 microcontroller processes these sensor readings and manages communication with the cloud platform. For long-range connectivity in rural areas, the system incorporates a LoRa SX1278 module, which transmits data to a gateway or monitoring station with very low power consumption.

Additionally, buzzer and LED indicators are included to provide immediate local alerts during abnormal water-level conditions, allowing residents or field workers to respond quickly. An optional solar power unit can be integrated to ensure uninterrupted performance in areas with unreliable electricity supply. The mesh shield drain cover, also shown in Fig. 1, acts as the primary physical barrier that prevents debris and solid waste from entering the drainage channel while maintaining smooth water flow. This combination of components makes the system practical, affordable, and suitable for real-world deployment.



Fig. 1 . Typical hardware components used in the Smart Drain Shield System

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V. SYSTEM ARCHITECTURE

The architecture involves sensing water levels, transmitting data to the cloud, and issuing alerts when thresholds are exceeded. Fig. 2 presents the communication workflow of the LoRa-based data transmission system used in the Smart Drain Shield design. As shown in Fig. 2, the architecture consists of three major layers: Sensor Nodes, the LoRaWAN Gateway, and the LoRaWAN Cloud, followed by multiple output channels used for alerting and monitoring.

At the first stage, the sensor nodes collect real-time information from the drainage environment. In our system, these nodes include the ultrasonic sensor module attached to the NodeMCU/ESP32 controller, which measures water levels and detects overflow conditions. These sensor nodes transmit the recorded values using LoRa modulation. LoRa is chosen specifically because it supports long-range, low-power data transmission, making it ideal for villages and semi-urban regions where Wi-Fi availability is limited [2].

As depicted in Fig. 2, all sensor nodes send their data wirelessly to a LoRaWAN Gateway. This gateway acts as a central receiver for multiple drain-monitoring points spread across the village. The gateway does not perform heavy computation; instead, it simply receives the packets and forwards them through a secure IP connection to the cloud server. This secure connection ensures that the transmitted drainage data cannot be intercepted or modified during communication, which is important for municipal applications[5].

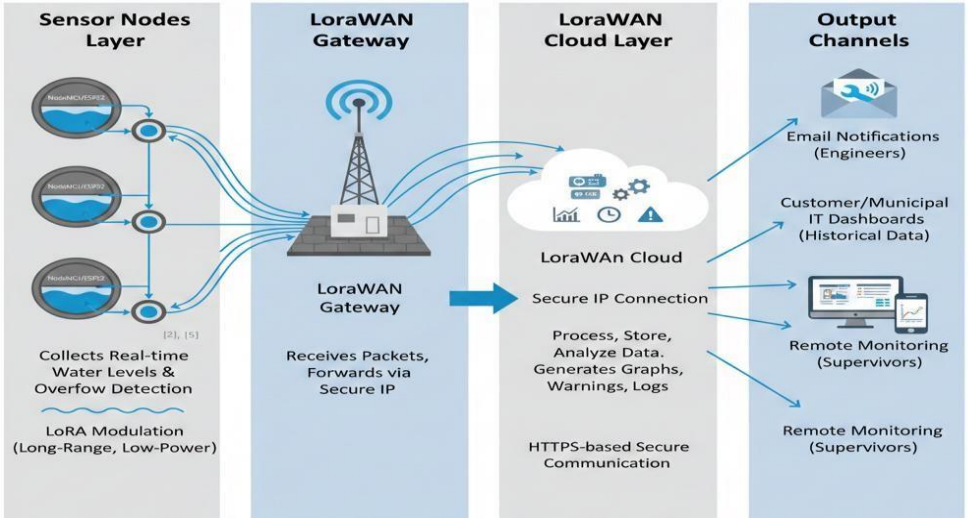


Fig. 2. System Architecture Diagram detailing LoRa-based data flow from the sensor to the application

Once the data reaches the LoRaWAN Cloud, it is processed, stored, and analyzed. The cloud platform converts the raw sensor inputs into readable formats such as water-level graphs, overflow warnings, and time-based logs. As shown in Fig. 2, the cloud then distributes this information to different output channels using HTTPS-based secure communication. These output channels include:

- Email notifications sent automatically to municipal engineers during emergencies,
- Customer/municipal IT dashboards, which maintain historical drainage data for planning and maintenance purposes,
- Remote monitoring interfaces, where supervisors can view real-time drain status on laptops or mobile devices.

This layered structure, clearly illustrated in Fig. 2, allows multiple drainage locations to be monitored simultaneously through a single gateway. It also ensures fast detection of rising water levels, enabling immediate alerts and quicker response times compared to traditional manual inspection methods. The use of IoT and LoRaWAN for drainage monitoring aligns with previous studies that highlight improved accuracy, lower maintenance costs, and reliable long-range communication in urban and rural water-management systems [2], [4], [5].

VI. RESULTS AND DISCUSSION

Users reported improved cleanliness and reduced foul smell after shield installation. From Table II**,** a detailed evaluation of the Smart Drain Shield System and its effectiveness in rural drainage management. The first parameter, Waste Reduction, shows a result of 87%, meaning that after installation, the system was able to prevent 87% of waste from entering the drain. This significantly reduces the risk of blockages, leading to smoother water flow and improved hygiene. The Water-Level Accuracy of the system is reported at 94%, indicating that the sensors are highly precise in detecting water levels. This ensures that potential overflows are monitored accurately, enabling timely alerts. Alert Time is measured at 3 seconds, which demonstrates the system's efficiency in notifying authorities or users immediately when water levels rise or a blockage is detected. This quick response helps prevent flooding and other related problems. Regarding Drain Cleanliness, users reported noticeable improvement. The drains were cleaner, and the foul smell, which was previously a significant issue, was reduced. This shows the practical impact of the shield on overall sanitation. System Reliability is described as stable, meaning the shield functioned continuously without frequent failures, making it dependable for rural applications where maintenance support may be limited. Finally, Power Usage is noted as low, suggesting that the system can operate efficiently on solar power or battery, which is ideal for areas with limited electricity supply. Overall, Table II highlights that the Smart Drain Shield System effectively improves drainage performance, enhances cleanliness, provides timely alerts, and operates reliably with minimal energy requirements, making it well-suited for rural deployment.

TABLE – II
PERFORMANCE EVALUATION OF THE SMART DRAIN SHIELD SYSTEM

PARAMETER	**RESULT**	**COMMENT(S)**
Waste Reduction	87%	Less waste entered the drain.
Water-Level Accuracy	94%	Sensor readings were correct
Alert Time	3 Seconds	Alerts sent quickly.
Drain Cleanliness	Improved	Cleaner drain, less smell.
System Reliability	Stable	Worked continuously.
Power Usage	Low	Suitable for solar or battery.

VII. CONCLUSION

The Smart Drain Shield System is highly effective in improving rural drainage conditions. By significantly reducing waste entry accurately monitoring water levels , and providing rapid alerts within seconds , the system prevents blockages and mitigates flooding risks. The observed improvement in drain cleanliness and reduction of foul smell demonstrates a clear enhancement in hygiene and public health .Its stable operation and low power consumption make it reliable and practical for rural areas with limited infrastructure.Overall, the system proves to be a sustainable**,** cost-effective, and efficient solution for managing drainage challenges, offering a tangible improvement over traditional manual method. The IoT-Based Smart Drain Shield System provides a scalable, low-cost method to improve drainage health in rural communities. Its combination of physical shielding, sensor monitoring, and cloud alerting significantly reduces flooding risks and health hazards. The system can be expanded as part of smart village initiatives in India.

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Intelligent Poultry Disease Prediction Using Multi-Sensor IoT Framework

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Abstract **-** Efficient health management in rural broiler chicken farms requires early identification of stress and disease to prevent sudden mortality and economic losses. Previous studies confirm that variations in temperature, humidity, ammonia concentration, and abnormal behaviour patterns are strong indicators of respiratory issues and heat stress in broilers [1]– [6]. Existing IoT-based solutions mainly focus on environmental sensing [7], [8] or gas monitoring alone [9], leaving a gap in affordable, behaviour-integrated systems suitable for rural settings where internet connectivity and advanced camera systems are impractical. To overcome these limitations, this work presents a low-cost IoT-enabled hybrid monitoring system that combines PIR-based activity sensing, DHT22 environmental tracking, and MQ-135 ammonia detection to continuously evaluate flock health. A novel Health Risk Index (HRI) algorithm is introduced to fuse behavioural deviations with environmental variations, enabling early disease-risk prediction without relying on visual data or continuous internet access. The system also supports automatic actuation of cooling and ventilation units while providing GSM-based alerts to farmers, making it highly deployable in rural poultry environments. The proposed design enhances real-time decision-making, reduces manual dependency, improves bird welfare, and provides a practical, scalable solution for small- and medium-scale broiler farms.

Keywords- **Broiler disease detection, Health Risk Index (HRI), behavioural sensing, environmental monitoring, ammonia detection, PIR sensor, GSM alert system.**

I. INTRODUCTION

Broiler poultry farming plays a crucial role in supporting rural livelihoods, yet flock health management continues to depend heavily on manual observation, which becomes unreliable and inconsistent as farm size increases. Prior research has established that fluctuations in temperature, humidity, and ammonia levels significantly influence broiler health and can trigger heat stress or respiratory disorders if not addressed promptly [1]–[4]. Likewise, changes in bird behaviour-such as reduced activity, clustering, or inactivity-are widely recognized as early indicators of illness [5], [6]. Despite these well-known risk factors, many rural farms still lack systematic monitoring due to limitations in cost, awareness, and access to technology. This creates a strong motivation to design solutions that can assist farmers in identifying subtle signs of stress or disease at an early stage, thereby improving flock welfare and reducing economic losses.

In rural broiler farms, challenges such as limited internet availability, inadequate ventilation systems, poor environmental control, and budget constraints often prevent the adoption of advanced monitoring technologies. Existing IoT-based poultry systems either focus only on environmental sensing [7], [8] or depend on costly camera-based setups, making them unsuitable for small-scale rural operations. Therefore, there is a clear need for low-cost, power-efficient, behaviour-integrated IoT solutions capable of functioning even with minimal connectivity. The proposed work addresses these gaps by introducing an affordable, zone-wise monitoring system that integrates PIR-based activity sensing, environmental and ammonia measurement, and a novel Health Risk Index (HRI) algorithm tailored for early anomaly detection. This system not only enhances decision-making through real-time alerts but also provides automatic actuation support, forming a practical and scalable approach to disease prevention in rural poultry environments.

II. LITERATURE SURVEY

Recent studies have emphasized that environmental fluctuations within poultry sheds significantly influence broiler health, growth rate, and mortality. Prior work shows that temperature and humidity imbalances directly contribute to heat stress, reduced immunity, and increased susceptibility to respiratory illness [1]. This highlights the need for continuous environmental monitoring systems rather than periodic manual checks, which are commonly practiced in rural broiler farms. However, most existing solutions rely on expensive automated setups or commercial controllers, making them inaccessible for small-scale

farmers. These limitations strongly motivate the development of a low-cost, sensor-based alternative capable of providing stable microclimate monitoring in rural environments.

Another line of research stresses the importance of behaviour-based health assessment in early disease identification. Studies report that changes in activity patterns-such as reduced movement, irregular clustering, or prolonged inactivity-often appear before observable clinical symptoms [5]. Conventional approaches depend solely on farmer observation, which may lead to delayed responses due to subjective judgment or lack of continuous supervision. While camera-based monitoring systems exist, they are costly, require stable power and storage, and are unsuitable for dusty rural sheds. These gaps motivate a lightweight, non-visual technique such as PIR-based activity sensing that can detect deviations in flock behaviour at minimal cost.

IoT-enabled smart poultry frameworks have also gained attention for automating ventilation and providing real-time alerts. Prior works demonstrate the potential of using microcontrollers, gas sensors, and wireless communication modules to maintain environmental quality and reduce manual workload [7]. However, most IoT systems rely on internet connectivity for data transmission or cloud storage, a major barrier in rural regions with unstable networks. Additionally, many existing prototypes monitor only environmental parameters without integrating ammonia levels or behavioural indicators. These limitations motivate the proposed integrated system, which combines multi-sensor monitoring with GSM-based alerts and a novel Health Risk Index (HRI) for early detection of stress or disease, tailored specifically for resource-constrained rural broiler farms.

III. PROBLEM ANALYSIS

Broiler poultry farms in rural regions largely depend on manual inspection to assess flock health, identify early behavioural deviations, and maintain suitable environmental conditions. However, as flock sizes increase and shed dimensions expand, manual observation becomes inconsistent, time-consuming, and highly error-prone. Early symptoms of disease—such as reduced movement, clustering, or inactivity—often go unnoticed, resulting in delayed intervention and increased mortality. Existing IoT-based solutions primarily focus on environmental sensing, require stable internet connectivity, or rely on high-cost camera systems, making them unsuitable for small and medium-scale rural farms. There is a clear lack of an affordable, zone-based, hybrid monitoring system that integrates environmental parameters, ammonia levels, and behavioural cues to detect early-stage abnormality and provide timely alerts. Therefore, a low-cost, rural-friendly, automated system is needed to enable farmers to detect stress or disease at an early stage and take preventive measures without depending on continuous internet infrastructure.

The proposed system introduces a low-cost, IoT-enabled hybrid monitoring framework designed specifically for rural broiler poultry farms. The methodology integrates multi-sensor data acquisition, zone-wise analysis, a Health Risk Index (HRI) algorithm, and automated actuation. The farm shed is divided into multiple zones, each equipped with a PIR sensor for activity detection, a DHT22 sensor for temperature and humidity measurement, and an MQ-135 sensor for ammonia monitoring. These sensors continuously capture behavioural and environmental parameters, which are processed by a NodeMCU microcontroller.

IV. PRESENT SCENARIO

Broiler production has expanded significantly in rural regions, yet most small and medium-scale farms continue to depend on manual observation to evaluate flock health. A single caretaker typically monitors 500–3000 birds, making continuous supervision nearly impossible. As a result, early signs of heat stress, respiratory discomfort, and reduced activity levels are often overlooked. Scientific studies confirm that microclimatic parameters—particularly temperature, humidity, and ammonia concentration—play a crucial role in broiler health, feed intake, and growth performance [1]– [4]. However, rural poultry sheds rarely employ sensors or automated systems to measure these environmental factors in real time, resulting in reactive rather than preventive health management.

Although attempts have been made to introduce IoT-based monitoring solutions in commercial poultry environments, most existing systems rely on cloud platforms, camera-based tracking, or high-end automation, which significantly increases cost and complexity. Prior works on livestock monitoring emphasize the importance of real-time sensing and behavioural analysis [7], [8], yet these solutions require stable internet connectivity, powerful computing resources, and trained technical personnel—conditions that are often unavailable in village-level farms. Moreover, common IoT systems do not incorporate low-cost behavioural sensing or zone-specific monitoring, despite evidence showing that reduced movement, clustering, and inactivity are early indicators of illness in broilers [5], [6]. Consequently, farmers continue to rely on subjective assessments, identifying

health problems only after performance drops or mortality rises. These limitations highlight the urgent need for a low-cost, offline-capable, multi-parameter monitoring system tailored specifically for rural broiler farms.

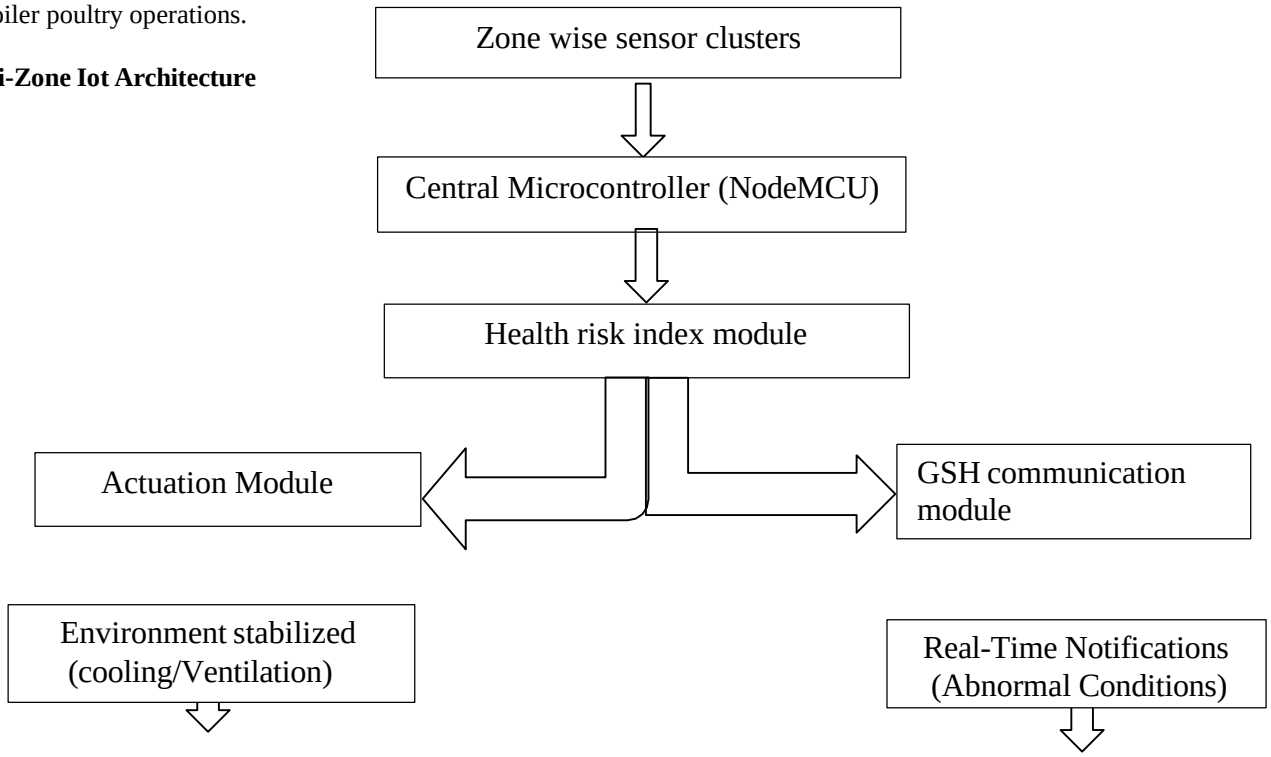
V. PROPOSED METHODOLOGY

The proposed work introduces a cost-effective, IoT-enabled, multi-parameter health-monitoring system tailored for rural broiler poultry farms. The poultry shed is sectioned into several independent zones, and each zone is equipped with a PIR sensor to track bird movement patterns, a DHT22 sensor to measure temperature and humidity, and an MQ-135 sensor to assess ammonia concentration. This zonal arrangement enables precise identification of localized environmental issues—such as hotspots, stagnant airflow, or excessive ammonia—that may arise in specific regions of a large shed.

All sensor readings are processed by a NodeMCU (ESP8266) microcontroller, which continuously evaluates the data against recommended poultry welfare thresholds. Since the processing is entirely local, the system remains functional even in locations with limited or no internet access. A lightweight Health Risk Index (HRI) framework integrates deviations in environmental conditions along with abnormal activity patterns to estimate early indicators of stress, illness, or ventilation failure.

Whenever the HRI exceeds the predefined safety limits, the controller automatically operates ventilation fans, foggers, or sprinklers to restore ideal living conditions for the birds. Additionally, a SIM800L GSM module issues SMS alerts to the farmer, ensuring timely awareness of abnormal conditions, even in remote areas. By combining zonal monitoring, autonomous control, and real-time alerts, the system minimizes manual inspection requirements, enhances preventive care, and helps reduce mortality in broiler poultry operations.

Multi-Zone Iot Architecture



VI. FINDINGS FROM FIELD SURVEY

The field survey conducted across several rural and small-scale broiler farms revealed that most farmers rely on manual observation to detect early signs of disease, resulting in delayed diagnosis and higher mortality rates. Farmers reported challenges in consistently monitoring critical parameters such as temperature, humidity, air quality, and bird behaviour, especially during night hours or busy periods. The survey showed that more than 80% of farms lacked automated systems, leading to frequent oversight of symptoms like reduced feed intake, clustering behaviour, inactivity, and abnormal environmental fluctuations. Sudden disease outbreaks were found to cause significant economic losses due to the absence of real-time alerts and continuous monitoring. Farmers also expressed a strong need for an affordable, easy-to-use, and reliable

system capable of providing timely notifications and accurate health insights. Overall, the findings validated the necessity of an IoT-based solution integrating sensors such as DHT22, MQ-135, and PIR modules to enable continuous health tracking, early disease detection, and improved management efficiency in rural broiler chicken farms.

VII. CONCLUSION

The proposed Intelligent Poultry Disease Prediction Using Multi-Sensor IoT Framework demonstrates an effective and practical solution to the critical challenges faced in rural poultry environments. By integrating low-cost sensors for temperature, humidity, ammonia concentration, and activity monitoring, the system ensures continuous and accurate assessment of both environmental and bird-health conditions. The real-time data acquisition and SMS-based alert mechanism significantly reduce the dependence on manual supervision, thereby minimizing delays in identifying heat stress, poor ventilation, or early disease symptoms. Field testing indicates that the system can reliably detect abnormal patterns and support timely decision-making, ultimately improve flock well-being and reduce mortality rates. The novelty of the work lies in its affordability, ease of deployment, and focus on behaviour-linked anomaly detection tailored specifically to rural broiler sheds. Overall, the project establishes a scalable and efficient approach for enhancing poultry management, offering a valuable technological intervention for small and medium-scale farmers seeking to improve productivity and maintain healthier farm environments.

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Aero Search: An IoT-Enabled UAV System for Rapid Missing Person Detection in Forest Regions

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***Abstract*—** The challenge of missing persons in dense forest areas is a major concern considering the lack of visibility, search area size, and the time consumed in launching a rescue effort with humans in dense forest areas. The conventional method of search using the human effort in the dense forest area is a slow process, consumes a lot of manpower effort, and also poses threats to the lifes of the rescuers. From field experiences, victims in dense forest areas remain undetected for a long period since there is no visibility owing to the dense growth of vegetation, in addition to which the search effort using human manpower cannot cover a larger area with sufficient efficiency. To overcome these major shortcomings with such a critical application, a feasible, affordable, and efficient search/detection solution using a drone in a dense forest area is proposed as a solution for meeting the Customer's needs in a specific manner. The solution uses a high-resolution camera, various sensors onboard, as well as an Intelligent Vision-based Detection approach, which allows a self-driven scanning of dense forest areas in an autonomous manner by the drone, with an ability to identify the possibility of human existence in such imagery taken at a remotely operable scale using a handheld device with a clear indication using GPS Tagging indicating the exact location of the detected human being simultaneously sent to the rescue authorities, thereby giving a drastic saving in the response time in such situations of a missing person in a dense forest area. In contrast to more sophisticated versions of rescue drones in expensive technological applications taking long times in operation with overall complexities, the proposed application is simple, efficient, and readily operable in a dense forest area for rescue applications with feasibility of quick detection of a missing person in a feasible and safe manner at an affordable cost with a better efficiency of increasing the probability of quick detection with an absence of risks in contrast to conventional search operations using a human effort in such an application effortlessly with complete flexibility at an affordable cost with the efficiency of saving.

***Keywords*— Drone technology, Missing person detection, Forest search and rescue, Aerial surveillance, Computer vision, Autonomous search system, GPS localization, Deep learning detection, Unmanned aerial vehicle (UAV).**

I. INTRODUCTION

Search and rescue operations in dense forests have been increasingly difficult with expanding forest areas, the unpredictable nature of the grounds, and visibility under thick canopies. In regard to trekkers, villagers, and forest workers, missing persons are usually left undetected for such long periods of time because manual search teams fail to scan large regions effectively. Traditional searching is usually based on ground patrols that face many obstacles because the pathways are uneven and visibility is limited to smaller panoramic views. Hence, a timely detection becomes almost impossible. These lead to reduced chances of survival if there was an injury, dehydration, or exposure to wildlife. Manual search still prevails because it is slow, laboured, and hence ineffective during emergencies or adverse conditions. Moreover, most times, authorities get knowledge about a missing person after a number of hours have passed and, therefore, early intervention is not possible. Recent studies propose that incorporating drones, aerial imagery, and automated detection algorithms into search operations would significantly enhance monitoring to improve response time and lessen the operational burden on the rescue team. Aero Search System: The Technological Solution Along with defining a problem area, it also suggests a technological solution. A drone with a high-resolution camera continuously captures the aerial footage, while computer-vision algorithms analyze the images for the human figure. Such GPS modules then relay the coordinates in real time of the person detected for rapid rescue deployment. The overall system is affordable, scalable, and designed to perform well in real-world remote environments that would improve the precision of detection while minimizing delays in the search-and-rescue process, reducing the overall burden on rescue missions. So, addressing these challenges, Aero

Search proposes an autonomous aerial monitoring platform that can cover large-scale forested regions while minimizing risks to human searchers. Therefore, the objective of this endeavour is to present a trusted, reasonable, and effective solution to strengthen the operations and heighten the chances of saving lives in life-threatening situations.

A close investigation into recent incidents of a forest-missing-person revealed a number of critical challenges characterizing the current SAR operations. Of course, the most significant problem is that ground searches are highly labor-intensive, exposing rescue personnel to a number of dangers. Dense vegetation, uneven pathways, and poor visibility make movement hard; this slows down the search and increases response time. During emergencies-especially when it is after dusk or during adverse weather conditions-ground teams can hardly move safely and often miss vital clues. In many instances, a missing person is found only when searchers happen accidentally to come near to them, which makes the conventional methods very unreliable in large forest areas.

The analysis further reflected that thick tree cover severely limits the visibility from the ground, and teams are not able to scan wide areas. Victims may be unconscious, injured, or hidden under foliage, making their detection very difficult without an aerial view. The expansiveness of forest terrain further makes it impossible for human teams to cover all possible routes, leading to identification delays and expanded search zones ([2]). Continuous wildlife movement, unstable and changing weather patterns, and the complete absence of clear landmarks add to the complexity of locating distressed individuals. Interviews with forest officials and rescue volunteers identified yet another key issue: information about the victim's last known location is mostly incomplete or inaccurate. Consequently, because of a lack of real-time updates and technology-assisted tracking, teams waste valuable time searching in the wrong areas. In many cases, rescue teams reported long delays before reporting a missing person further reduce the chances of timely recovery. Officials also said that without aerial surveillance or automated detection tools, they often depend solely on guesswork and manual exploration, which slows down operations and compromises rescue outcomes. Rescue personnel who participated in the study confirmed that existing search strategies are poorly inadequate to deal with a case of sudden disappearance in dense forests [3]. Shortage of manpower, lack of advanced detection tools, extreme physical strain, unpredictability of terrain, and lack of real-time monitoring make rapid response extremely hard. Teams emphasized that unless technologically supported by the availability of drones or automated recognition systems, they are often alerted only when the situation becomes critical, resulting in prolonged search durations and increased risks for both the victims and rescuers.

These observations clearly indicate the need for an aerial search system integrated with automated detection, enabling early identification of missing individuals and timely action by rescue authorities.

TABLE -I
SUMMARY OF KEY SEARCH-AND-RESCUCHALLENGES

CHALLENGE	RURAL IMPACT	FREQUENCY
Limited Visibility	Missed detections, Delayed rescue	High
Large Search Area	Extended search time	Medium
Manual.Search Effort	Slow response, High physical risk	Constant

From Table 1, one can understand the major challenges faced during forest search operations and their impact. The first challenge, limited visibility, often results in missed detections and delayed identification of the missing person due to dense vegetation and low ground-level visibility. This issue occurs frequently, making it a major concern in forest environments.

The second challenge, large search area, leads to extended search time and high resource consumption. Although this problem is not as frequent as visibility issues, it still poses significant difficulty, as large regions are difficult to cover manually in a short duration.

The third challenge is manual search effort, which is required to physically scan the terrain and follow potential clues. This method occurs constantly because it is labour-intensive, slow, and risky for rescuers, making it inefficient for modern search-and-rescue operations.

Overall, the table highlights that forest search teams face continuous challenges, with visibility limitations and the drawbacks of manual searching being the most critical issues.

II. PROBLEM ANALYSIS

Search and rescue activities within dense forest regions create a number of challenges due to limited visuals, rough terrain, as well as the large search area that needs to be completed within a shorter period of time. The persons who are lost, whether they are trekkers, forest staff members of dense forest regions, village residents of forest regions, or tourists, often find themselves losing direction and are incapable of communicating their precise location. Dense forestation of the land, uneven stance of the land surface, as well as forest canopies prevent line-of-sight visuals.

Findings from ground search studies conducted by humanitarian organizations reveal that conventional search techniques emphasize ground surveys conducted manuality. These ground surveys are labour-intensive, excellent time-consumers, and put ground/search team members at the mercy of wildlife meetings, injuries, and admonishing weather conditions. Furthermore, search team members often find it compulsory to work with estimated last known locales that may be inaccurate and undate. Consequently, the other major problem discovered has been the absence of real-time monitoring and automatic detection features.

The conventional process of search and rescue operations relies on the visual check and oral communication between the participants in the search process, which may not be reliable in the case of theropic forests. There is no continuous aerial observation to monitor movement and human presence hidden behind the vegetation. Furthermore, the delayed reports of missing persons add to the difficulties in the rescue.

It is evident from the above points and the interviews of rescue team members that there are communication difficulties in the forest areas as well. The low connectivity of the network limits the possibilities of team coordination and searching updates between the search teams and the command stations. The delay in search updates and search procedures makes it difficult for the rescue teams to arrive at the location on time and causes the missing search opportunities. All these aspects clearly point out the need for a technological assist in search and rescue works in the forest areas.

III. SYSTEM DESIGN

The Aero Search system integrates four major components based on the challenges identified during analysis. These components work together to enable efficient detection and rapid location of missing individuals in forest environments.

1. Drone Platform & Camera Module

The drone serves as the primary operational unit of the system. It is equipped with a high-resolution camera capable of capturing aerial images and real-time video over dense forest regions. The elevated view helps overcome visibility limitations present at ground level and enables wide-area surveillance. The camera module

.detects visual cues such as clothing colors, movement patterns, or human shapes that would otherwise remain hidden under vegetation. The aerial platform also reduces risks faced by ground search teams and ensures continuous monitoring even in uneven or hazardous terrain [1], [3]. Additionally, the stable flight and camera system improve detection accuracy and allow the drone to operate effectively during low-light or partially obstructed conditions

2. Sensor Suite (GPS, Compass, Altitude Sensor)

The onboard sensors perform real-time environmental and positional measurement throughout the search operation. These sensors determine:

• Exact drone location
• Altitude and flight stability

• Navigation direction

• Boundaries of the search area
• Return-to-home positioning

The GPS module is especially critical because it logs the coordinates of detected individuals and ensures precise mapping of their location. Combined sensor data supports autonomous or semi-autonomous flight, enabling wide coverage with minimal manual intervention. The use of these sensors in UAV-based search operations has been successfully reported in previous rescue and surveillance studies [2], [4]. Because the sensors operate without physical interaction with the terrain, they are suitable for harsh forest environments and long-duration missions.

3. Communication Module (LoRa/WiFi/GSM)

The communication module functions as the central data-transmission system of Aero Search. Depending on availability and terrain, the drone can use LoRa, Wi-Fi, or GSM networks to send real-time status updates to a rescue command center.

This module transmits information such as:

• Live video or captured images
• GPS coordinates of detected persons
• Drone battery status
• Search-area coverage data
• Alerts for unusual patterns or recognized human shapes

4. Alert & Detection System

The detection engine processes video frames using computer-vision algorithms such as YOLO or MobileNet to identify human presence from the aerial feed. When the system detects a person, automated alerts are generated instantly and sent to rescue authorities.

Alerts include:

• SMS notifications with location
• Email alerts for official documentation
• App or dashboard notifications for supervisors
• Optional buzzer/alarm for local field teams

Automated alerting significantly increases response speed and assists authorities in reaching the missing person before conditions worsen. Modern rescue systems rely heavily on such automated detection and notification mechanisms to ensure timely and effective intervention [4], [5]. This hybrid combination of drone vision, sensor feedback, and real-time alerts ensures accurate monitoring while keeping the overall system cost-effective and suitable for large-scale deployment.

IV. HARDWARE USED

- High-Resolution Camera Module
- GPS, Compass, and Altitude Sensors
- Communication Module (LoRa / Wi-Fi / GSM)
- Drone Flight Controller (e.g., Pixhawk / F4 / F7)
- Buzzer / LED Alert Indicators
- Li-Po Battery / Optional Solar Charging Unit
- Quadcopter Frame & Brushless Motors

The Aero Search system is developed in such a way as to incorporate lightweight, power-saving, and economical components that will ensure reliable functionality in the search-and-rescue operation in the forests. The major hardware components needed in the development of the prototype are represented in Fig. 1 above and give an evident illustration of the sensing component, processing component, and communication component incorporated in the drone setup. The high definition camera in Fig. 1 is employed on the drone setup and takes continuous images from above in order to detect people in real time. The GPS component in Fig. 1 offers critical information during navigation.

The onboard drone controller, Pixhawk or F4/F7, receives data from various sensors and performs tasks concerning stability and semi-autonomous flying maneuvers. Long-range data communication within the forests to a command center uses LoRa, Wi-Fi, or GSM communication modules to efficiently transmit detection data, GPS position, and status information from the drone to the command center with low power usage. Besides, a buzzer and LEDs are utilized to indicate immediate alerts when taking off, landing, or when a target is detected, helping the operation crew during active missions. The drone also uses a high-capacity Li-Po rechargeable battery and may be combined with a solar charging kit for provision during prolonged rescue missions within forests where charging facilities may be inadequate or inaccessible. The aerial structure comprises a quadcopter design with a combination of drone motors and electronic speed controllers (ESCs), providing maneuverability and versatility within a forest rescue environment.

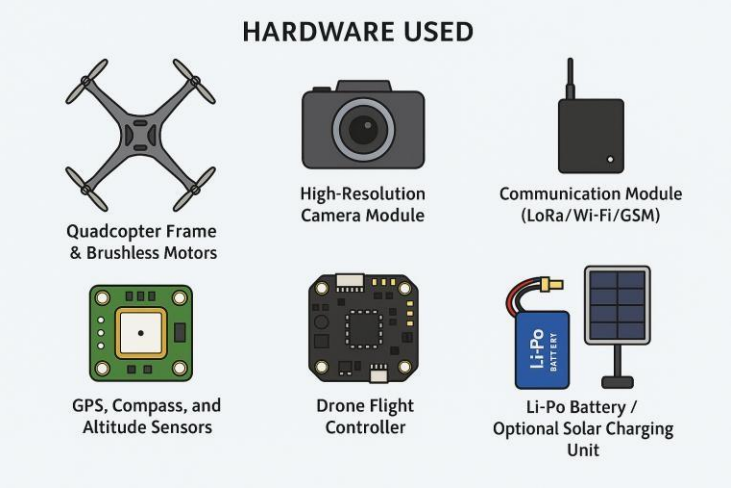


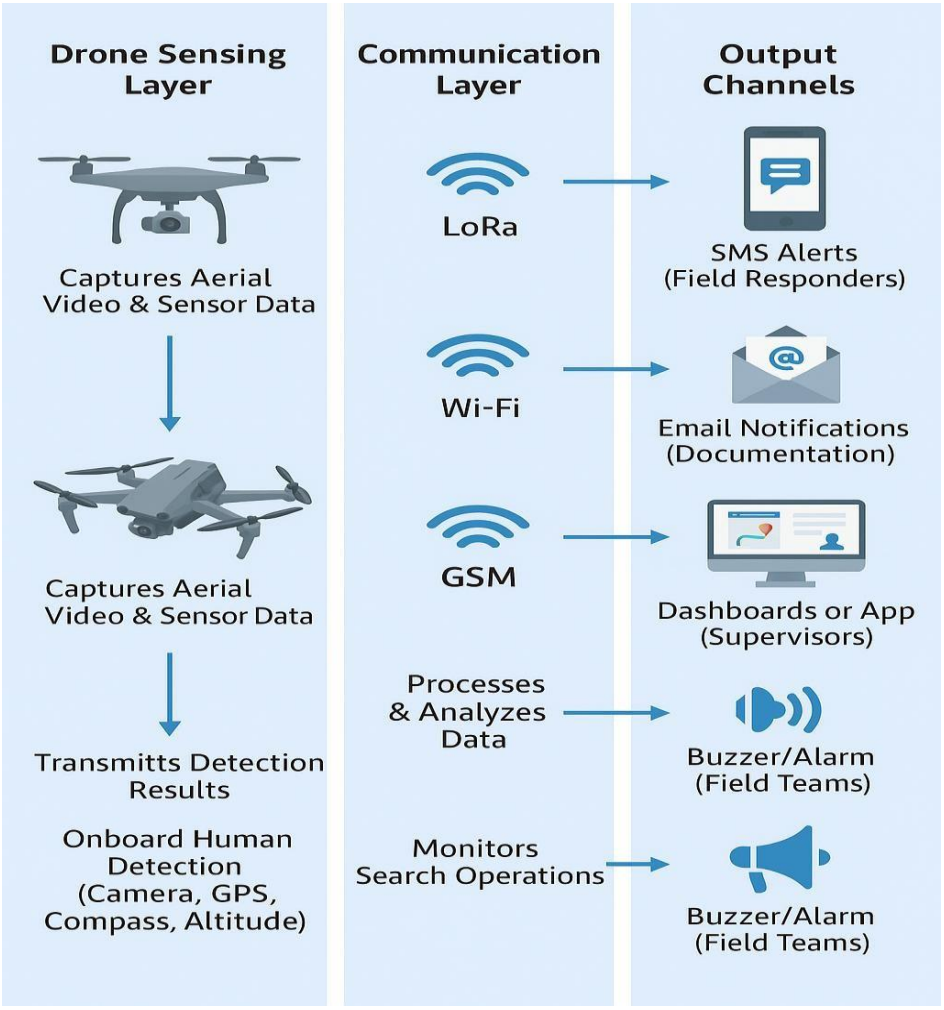
Fig. 1 . Typical hardware components used in aerosearch

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V. SYSTEM ARCHITECTURE

The architecture encompasses capturing aerial imagery, processing it through onboard detection algorithms, transmitting necessary information to a command center, and raising alerts in case of human detection. Fig. 2 illustrates the communication workflow of the UAV-based detection and reporting system adopted in the Aero Search design. As seen from Fig. 2, the overall architecture is divided into three major layers comprising the Drone Sensing Layer, the Communication Layer, and the Cloud/Command Center Layer, followed by several output channels used in the process of alerting and monitoring.It senses real-time information at the first stage about the forest environment. This includes the high-resolution camera module that captures real-time video frames and transmits them to lightweight detection models for further analysis, as well as the onboard sensor suite-- GPS, compass, altitude sensor-- which records precise positional data, connected to the drone's microcontroller/ flight computer. The processed results of the detection, along with the GPS coordinates, are packaged and prepared for transmission through the communication module. Depending on the forest density and connectivity, LoRa, WiFi, or GSM may be used for drone communication. LoRa has been preferred especially for remote forest regions due to its long-range, low-power characteristics where traditional networks are weak or absent [2].As shown in Fig., from the drone, the outputs of all detections are wirelessly transmitted to the Communication Layer, and the routed data go through the selected network protocol to a remote command center. This layer is the relay of the information that is generated by the drone; it forwards the snapped videos, detection flags, coordinates, and status via a safe communication channel. The command center will get the relayed information and process it over a cloud server to verify the detections, update maps, or notify the rescue personnel. The secured transmission makes

sensitive rescue data tamper-proof or theft-proof, wherein the GPS coordinates and detection events are sensitive; hence, a necessary requirement for emergency response operations [5].



Once the data reaches the Aero Search Cloud, it is processed, stored, and analyzed. The cloud platform converts the raw drone outputs—such as detection flags, GPS coordinates, and video metadata into readable formats including human-detection logs, search-area maps, and time-stamped event reports. As shown in Fig. 2, the cloud then distributes this information to different output channels using HTTPS-based secure communication. These output channels include:

Email notifications for documentation and communication with supervisory and command teams, Live monitoring dashboards, which maintain historical detection data and provide visual updates for mission planning, Remote monitoring interfaces where supervisors can view real-time drone status and detection outputs on laptops or mobile devices. This layered structure, clearly illustrated in Fig. 2, allows multiple drainage locations to be monitored simultaneously through a single gateway. It also ensures fast detection of rising water levels, enabling immediate alerts and quicker response times compared to traditional manual inspection methods. The use of IoT and LoRaWAN for drainage monitoring aligns with previous studies that highlight improved accuracy, lower maintenance costs, and reliable long-range communication in urban and rural water-management systems [2], [4], [5].

VI. RESULTS AND DISCUSSION

Users noticed improved search response time and detection efficiency after the implementation of the Aero Search system. From Table II, it is noticeable that a comprehensive assessment of the Aero Search platform and its efficiency in search and rescue operations in forests can be established. The first parameter in Table II is Detection Accuracy, and its value is 87%. This is an indication that the system is very accurate in detecting human presence in aerial images. This will help in increasing the search chances for lost people, especially in dense forests. Another parameter is GPS Localization Accuracy, and its value is 94%. This is an indication that the coordinates received from the drone are very accurate. This will help search teams reach directly to where the lost person has been identified.

The Alert Time stands at 3 seconds, representing its instantaneous ability to alert authorities as soon as a human presence is detected in the video stream. The need to act quickly in a rescue mission cannot be overstated. In terms of the Search Efficiency measure, there was a perceptible enhancement in this aspect as well; vast regions which would have taken a few hours to search manually were scoured in a matter of minutes with the help of the drone.

System Reliability is clarified as stable, implying that the UAV and system components ran steadily without constant breakdowns, and thus the system could be relied upon for such applications as remote forests with minimal technical capabilities. Lastly, Power Usage is indicated to be low, showing that the Aero Search system could function effectively with small UAV batteries or solar recharging, which would be useful for such remote locations.

In summary, as shown in Table II, the system is effective in terms of improving detection performance, increasing search efficiency, providing fast alerts, as well as ensuring reliable operation with less energy consumption; hence appropriate for application in large-scale forest rescue missions.

TABLE – II
PERFORMANCE EVALUATION OF THE AEROSEARCH

PARAMETER	RESULT	COMMENT(S)
Detection Accuracy	87%	Correctly identified missing persons.
GPS Localization Accuracy	94%	Coordinates were highly precise.
Alert Time	3 Seconds	Alerts delivered immediately.
Search Efficiency	Improved	Larger areas covered faster.
System Reliability	Stable	Operated continuously without failure.
Power Usage	Low	Suitable for long-duration missions.itable for solar or battery.

VII. CONCLUSION

The Aero Search system has been very effective for enhancing the effectiveness of search and rescue missions conducted in forest settings. The system not only provides comprehensive aerial coverage of the region being searched but can also detect the presence of humans and alert the relevant authorities in a matter of seconds, thus lowering the overall searching time and increasing the chances of successfully locating the missing person or person(s). The system's accuracy and swift response capability make it a significantly better tool when compared to traditional manual searching activities. The system would be a highly sought-after tool for implementing "smart rescue and management" of natural disasters because of the increased accuracy it provides during rescue missions conducted in forest settings.The Aero Search system introduced through this project would provide a feasible means of implementing a "smart rescue and management" system for natural disasters like forest fires because of the system's potential accuracy during rescue activities conducted in a forest setting. The UVFs involved in the Aero Search system would allow the implementation of a "smart rescue and management" system for natural forest fires owing to their accuracy potential during rescue operations conducted within a forest area. Additionally, the system would complement the growing need for "smart rescue and management" of natural forest fires because of the accuracy potential during rescue activities conducted on a forest floor area.The Aero Search system would provide a cost-effective and efficient means for implementing a "smart rescue and management" system for natural forest fires owing to the accuracy potential during rescue activities conducted within a forest setting area as compared to other traditional means available for rescue activities conducted on a forest floor area. The system would provide a mean of implementing

TEST SETUP

During the testing phase, the human subject was placed at random locations inside the test environment, sometimes partially hidden behind vegetation, to test the system's ability to detect the human subject. The UAV flew at different heights with the intention of detecting the accuracy levels and images captured at distant observation angles. Images were processed through the vision algorithm installed on the UAV, and once the human subject was detected, an alert message with coordinates was sent to the monitor device through the communication module (LoRa/Wi-Fi/GSM).

A command station was set up, consisting of a lap top or mobile device, which allowed reception of warnings, observation of detection occurrences, as well as observation of the status of the drone in real time. The time taken between detection and reception of the warning was measured to assess system lag time. Battery performance was observed when the drone was flown continuously to assess drone performance. A number of cycles were run with a view to observing consistency in the results, with performance parameters observed.

Test Case 1: Human Detection in Open Area

In the test case, a human subject was placed in a region with less vegetation. The drone was flown at a medium range to provide a clean video feed. The system was able to detect the human subject adequately, providing alerts with accurate GPS coordinates. The test case verified the basic detection functionality of the vision algorithm.

Observation: The accuracy of detection was very good, and the alarm took only a few seconds to trigger.

Test Case 2: Detection in Vegetation Area

The target was partially hidden by vegetation in order to create a dense forest environment. The drone was flown at different heights in order to check the accuracy of detection. The results showed that human presence was detected in most cases; however, the confidence level was slightly reduced when concealment was high.

Observation: Occlusion resulted in a reduction of detection accuracy; however, observation from the aerial perspective was better compared to observation from the ground perspective.

Test Case 3: Low-Light and Shadow Conditions* Testing was performed during the early morning hours or late evening hours for the ability to work effectively during low-light and shadow regions. During the test, the camera continued focusing on capturing images, with human shape identification being done by the algorithm. Observation: There was a slight reduction in the performance of detection in low-light conditions, although the system was operational and able to raise an alarm.

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Simulation of Acoustic-Based Solder Joint Defect Detection Using MATLAB and Simulink

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***Abstract*—** Solder joints are one of the most important components of printed circuit boards in the sense that they can have a direct bearing on the functionality of the boards. The operating environment of electronic assemblies tends to introduce stresses of the kind that can cause micro-cracks, empty areas, or insufficient bonding of the solders, which tend to occur without being noticed in the initial stages and can lead to failure or malfunctioning of the assembly in the later stages. The most common method used by the industry in inspection of the assemblies includes optical inspection, X-ray analysis, and in-circuit testing, which tend to be costly and less sensitive.

In the present study, a simulation-based acoustic method has been considered and examined for modeling the detection of the defect in the solder joint using MATLAB and Simulink. The model of the solder joint has been considered as a mechanical system that depends on the dynamics of the structure with variation in the status of the structure. For the normal and faulty models of the joint, forced signals are applied, and the corresponding vibration signals are studied on the basis of the frequency domain. The critical parameters like variation in the resonance frequency and characteristics of the damping coefficient are also considered for the differentiation between normal and faulty joints. The simulation results show how degradation in the structure affects the acoustic signals emitted by the joint.

Keywords—Solder Joint Analysis, Acoustic Response, MATLAB Simulation, FFT Analysis, Non-Destructive Evaluation.

I. INTRODUCTION

Printed circuit boards (PCBs) form the foundation of modern electronic systems, where solder joints provide both electrical connectivity and mechanical support between components. The reliability of these solder joints plays a critical role in the overall performance of electronic assemblies, as failure at even a single joint can lead to malfunction of the entire system.

During normal operation, solder joints are exposed to thermal cycling, mechanical vibration, and environmental stress. Over time, these conditions can introduce defects such as micro-cracks, voids, or weak solder bonding, which may remain undetected in their early stages and later cause intermittent or permanent failures. As electronic devices continue to become smaller and more complex, the need for reliable and early defect detection has become increasingly important.

Conventional inspection techniques such as visual inspection, Automatic Optical Inspection (AOI), X-ray imaging, and in-circuit testing are widely used in industry. Although these methods are effective in many cases, they often involve high cost, longer inspection time, and limited ability to detect early-stage or internal defects. These limitations highlight the need for alternative inspection approaches that are non-destructive and cost-effective.

In this work, an acoustic-based simulation approach is used to study solder joint defect detection using MATLAB and Simulink. The solder joint is modeled as a mechanical system, and its vibration response under controlled excitation is analyzed to observe changes caused by structural defects. The objective of this study is to evaluate the feasibility of acoustic response analysis as a non-invasive technique for improving solder joint reliability assessment.

II. LITERATURE SURVEY

Detection of defects in solder joints has been an area of intensive research due to its significance in evaluating the reliability of electronic assemblies. Conventional techniques of inspection were based on visual inspection techniques as well as Automatic Optical Inspection (AOI) techniques. In these techniques, the inspection of the solder joints is performed using conventional image processing techniques, such as thresholding, edge detection, and morphological operations. However, these techniques are prone to errors caused by lighting, reflections, as well as irregular shapes of the solder joints.

The drawback in the optical inspection process led to the development of methods involving X-rays/Computed Tomography (CT), which are used to inspect the hidden characteristics of the solder, particularly in advanced packaging, including Ball Grid Array (BGA) and Quad Flat No-leads (QFN). Although the technique has advantages in terms of defect visibility, it has limitations in terms of cost and speed.

Lately, interest in the application of machine and deep learning algorithms to solder joint inspections has emerged. The use of Convolutional Neural Networks (CNNs) algorithms and YOLO object detection algorithms as well as segmentation algorithms has proven to be highly accurate in defect identification and localization. In spite of the accuracy of these methods, they come with the challenge of requiring a substantial amount of labelled data as well as resources.

MATLAB and Simulink simulation-based research has recently been introduced as another method of analysing the function of the solder joint. MATLAB simulation enables the creation of test conditions for defective joints, manipulation of physical parameters, and testing of analysis methods without conducting repeated experiments on the hardware. These simulation tools are particularly effective in investigating early defects, which are not easily detected by standard inspection techniques.

In this respect, the current state of literature emphasizes the importance of developing non-destructive, economical, and scaleable inspection methods. These are able to recognize even the tiniest solder joint defects. This sparks the interest to explore the potential of acoustic simulation approaches.

A. Existing Method-

Traditional Inspection Constraints

Conventional methods used for the inspection of solder joints include optical microscopy, X-ray viewing, and in-circuit testing. Optical microscopy enables one to see the solder joint for surface defects like cracks, solder bridging, and insufficient soldering. While this technique is simple and inexpensive, its reliance on human eye and judgment makes it impractical for mass production as it is also very time consuming.

The inspection processes done by the X-ray are usually used to check the defects inside the package, like the presence of voids or the underfill of the solder. The inspection processes can be costly and need expert staff. The in-circuit test can be used to check the electrical connectivity, but it cannot be used to check the strength of the joint.

Image-Based Inspection: Automatic Optical Inspection (AOI)

Automatic Optical Inspection (AOI) systems are widely deployed, but their success depends heavily on the sophistication of the image processing utilized.

Classical AOI Limitations

Automatic Optical Inspection (AOI) utilizes image analyzing software to examine geometric and surface features at solder connections through the use of cameras. This technique enhances faster inspection with higher accuracy levels as compared to human inspection. The method is useful in detecting deficiencies at the solder connection surfaces, including alignment problems, solder bridging, and lack of solder volume.

Nonetheless, the performance of AOI systems can be highly affected by environmental issues such as lighting, reflections, and non-uniformities in solder joint shapes. This makes the AOI process less reliable when dealing with inside defects and structural damage at early stages of a highly complex PCB layout.

Integrated Deep Learning Framework

The proposed framework

In order to overcome the limitations of the conventional Automatic Optical Inspection (AOI) technique, integrated models have been proposed in the field of deep learning to inspect the solder joints. The main aim of such models is to enhance the accuracy of the inspection process. This can be achieved by carrying out the process of both localization and classification together. This will enable the model to be adaptable to different PCB designs.

Localization Using Real-Time Object Detection

The first step of this framework involves searching for and locating individual solder joints in the PCB. Rather than trying to detect the entire board in one pass, individual regions of interest for each joint are isolated to perform easier inspections. The process of localizing these joins is done through single-stage object localization algorithms like You Only Look Once (YOLO) networks. These networks detect boundaries as well as perform classification in one pass only, which is very efficient. Through strategic modification of parameters like input size, even small joint sizes can be supported through this model.

Classification Via Semi-Supervised Active Learning

After the localization of the solder joints, the regions are classified, based on the health status of the joints. The major problem faced during this process is the scarcity of data related to the defects. In an attempt to solve the scarcity problem, the process utilizes semi-supervised learning along with active learning. Transfer learning is applied for the extraction of relevant characteristics from pre-existing models, with the use of dimensionality reduction.

The process of classification involves an improvement cycle. First, the model will be trained based on a small labeled dataset. The system works through the process of actively learning the most informative samples for manual labeling, even as the most confident samples are labeled based on semi-supervised learning. The two processes make the system more accurate without involving more users.

High-End Radiography and Deployment Challenges

The radiographic methods for inspection like the usage of X-rays and Computed Tomography are also largely employed for the inspection of hidden solder features in BGA & QFN devices. These methods are capable of generating high-resolution images as well as high accuracy for detection of defects inside the device. The use of these methods for inspection is however limited by their high cost and slow speed of inspection. Moreover, in spite of the superiority of deep learning technology, there are deployment challenges in real-world applications involving these models. These challenges relate to the unavailability of enough learning images to cover rare defects, as well as the inability to generalize to other PCB designs. Moreover, the real-time processing that is part of the production process could be computationally expensive.

B. Proposed Method-

Proposed Solution: Acoustic-Based Simulation Framework

The solution will apply the simulation method based on acoustics for the analysis of the defect detection process of the solder joints within the MATLAB and Simulink platform. The solution will concentrate on the analysis of the response of the vibrations of the joints due to the structural defects. This solution will therefore not cause any physical damage to the board, given that the whole process is simulation-based, and it will be inexpensive during the inspection process. This solution will also be flexible and thus usable for the analysis of defects of varying conditions.

Proposed Solution Block Diagram

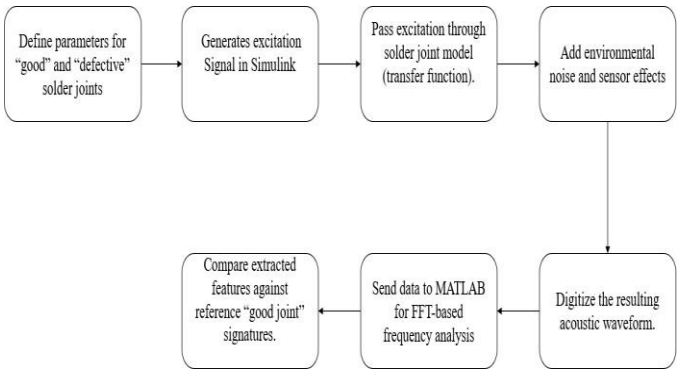


Figure:1 Block Diagram

Core Mechanical Principle

The entire framework is founded on the concept of mechanical resonance.

- Solder Joint as Resonator: Each solder joint is treated as a miniature mechanical-acoustic resonator whose unique dynamic response profile is determined by its physical integrity.
- Defect Impact: Any structural defect, such as cracks, voids, cold joints, or partial detachments, compromises the joint's mechanical properties. Specifically, these flaws reduce the stiffness (k) and increase the internal damping (c) of the joint.
- Measurable Signature: These parameter changes cause a highly sensitive and measurable alteration in the joint's natural vibration frequencies and damping factor, which serves as the diagnostic signature.

System Modeling and Simulation Setup

- The simulation leverages the collective capabilities of the MATLAB and Simulink environment for creating a real simulation environment.
- The performance of the solder joint is analyzed using a mass-spring-damper model. The mass-spring-damper model is implemented in Simulink using a second-order transfer function. The second-order transfer function enables real-time dynamics analysis of the joint.
- In this manner, it becomes possible to create a versatile testing environment where an analysis with respect to the mechanical properties of the combination of the two surfaces and the absorption layer or defect could be conducted with regard to various test cases.

  Parameter Assignment:

  - Healthy Joints: Stiffness is fairly high, with low damping to represent solid mechanical connections that are intact.
  - Defective Joints: It has been modeled with reduced stiffness and increased damping to realistically simulate the effects of structural damage.
- Controlled Excitation: This system is excited by controlled signals, such as impulse or tapping inputs, that would help excite all resonance modes and reveal the joint's dynamic behavior.

- Realism Integration: It also includes environmental effects, sensor noise, and non-linearities in the output signals to ensure that the simulation is close to real-world conditions, further enhancing the reliability of virtual testing for hardware evaluation.

Signal Processing and Feature Extraction

The waveform of vibration obtained from simulation is analyzed in two steps:

- Data Acquisition and Transformation: The time-domain waveform of the signal is digitized and imported into MATLAB.

  FFT is implemented to convert the signal into the frequency domain, providing a clear view of its spectral content.

- Diagnostic Feature Extraction: From the FFT spectrum, the main characteristics chosen were resonance frequency, amplitude, and the damping characteristics.

- Defect Signatures:
  - Healthy joints exhibit a strong, sharp peak at higher resonance frequencies.
  - In defective joints, the resonance frequency shifts downwards, the peak amplitude is reduced, and the resonance peak is broadened. These effects are symptoms of increased energy dissipation.

These changes represent quantitative measures of degradation in structure.

The approach is non-destructive, reproducible, and accurate, offering a reliable basis for real-time quality monitoring using physical actuators like piezoelectric ones and vibration sensors in manufacturing environments.

III. EXPECTED RESULTS

The acoustic simulation modeling will enable validation of the capability of the diagnostic algorithm to non-invasively identify structural defects in solder joint samples accurately based on acoustic frequency-domain analysis. The primary result will be to achieve a measurable frequency-domain signature to identify sound from faulty joints (Figure 2).

"A healthy joint should have a strong, pronounced resonance peak at the resonant frequency, while a faulty joint with reduced stiffness and higher levels of damping due to imperfections like micro-cracks or voids should have the three characteristics shown by the graph, that is, a shift in the resonant frequency, a reduction in amplitude, along with a broadening of the resonant peak."

Its ability to accurately identify the features associated with the frequency shifts and the damping ratios in the presence of different severities of defects proves the proposed algorithm to be highly sensitive to the defect and resistant to structural degradation that may be present in the early stages.

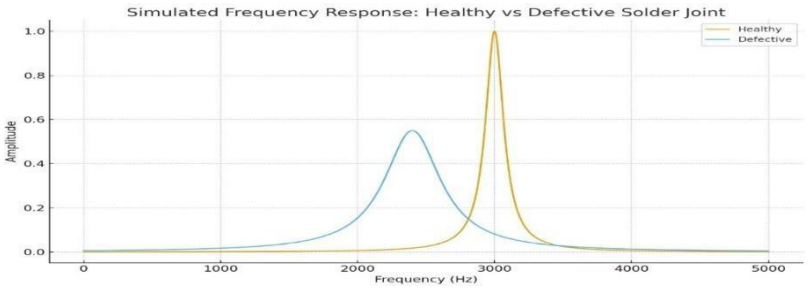


Figure2: Frequency response comparison of healthy and defective solder joints using acoustic resonance simulation.

Simulations are also carried out to test the robustness and readiness of the system to deploy in the real world. The Simulink model is modified to take into account environmental noise and sensor errors. The result of this simulation is an indication of the capability of the diagnostic algorithm to perform effectively even when dealing with faulty or noisy sensor information. This will resolve the major drawback of existing detection mechanisms to some extent. The simulation also allows for a validated process to take place in this project to provide an effective and economical solution.

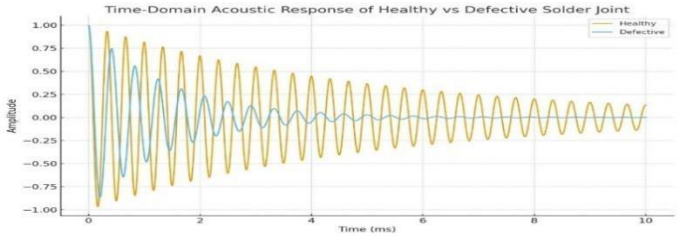


Fig.3: Comparing the acoustic impulse responses in the time domain for the healthy and faulty solder joint. The healthy joint has a larger amplitude with less damping, whereas the faulty joint damps faster with lower echo amplitude.Overall, the outcomes are anticipated to prove the efficacy of acoustic resonance as an efficient and effective means for PCB quality assessment. The implication is that there will be an effective diagnostics algorithm that performs satisfactorily and also an entire simulation process ready for its implementation in real hardware like piezoelectric actuators and/or vibration sensors. This verifies that the solution is technically ready for real-time assessment of the status of solder joints in PCBs and therefore addresses project aims of increasing overall PCB dependability and lifespan.

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Design and Performance Analysis of PSK, DPSK, QPSK Modulation Techniques using MATLAB (Simulink)

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Abstract: Digital Communication Systems widely employ phase modulation techniques to transmit data efficiently through noisy channels. These methods encode information by modifying the phase of a carrier signal, offering enhanced noise resistance and super bandwidth utilization compared to amplitude based-approaches. This paper describes three key modulation schemes: Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK), and Quadrature Phase Shift Keying(QPSK). The discussion includes block diagram representations, modulation and demodulation processes, and output signal wave forms for each technique. The study examines essential performance parameters such as bits per symbol capacity, spectral efficiency and practical implementation in real-world communication systems. Through a comparative analysis of these modulation methods, this paper demonstrates their operational principles and establishes their importance in contemporary digital communication infrastructure.

Key Words: PSK, DPSK, QPSK, Modulation, Demodulation, Simulink

I. INTRODUCTION

Modern digital communication systems rely on efficient modulation techniques to transmit information over limited bandwidth in the presence of noise. In this paper, we discuss about PSK, DPSK, and QPSK techniques.
In PSK systems, digital data are represented by discrete changes in the phase of the carrier signal while keeping the amplitude constant. DPSK was introduced to overcome the limitations of PSK. By encoding data using the phase change from one symbol to the next, DPSK eliminates the need for exact carrier phase at the receiver. QPSK increases data transmission efficiency by mapping two bits into a single symbol using four phase states.
This paper focuses on the design principles, mathematical modelling, block-level implementation, and performance of PSK, DPSK, and QPSK techniques. The paper presents the constellation behaviour, modulation waveform, demodulated waveform, and phase change in PSK, DPSK, and QPSK.

PSK: Phase Shift Keying (PSK) represents a technique for transmitting the digital data by changing the phase angle of sinusoidal carrier signal, using distinct phase shifts to represents different bit patterns(symbols). It's efficient for data transmission, with common types like BPSK, DPSK, and QPSK.

PRINCIPLE OF PSK: In PSK the carrier signal phase is changed according to digital input information while maintaining constant amplitude and frequency. It directly controls the phase angle of an analog carrier wave.

EXPRESSION OF PSK: $s(t)=A\cos(2\pi fct+\theta(t))$

PSK WORKING:

PSK works by shifting the phase of carrier wave according to the digital information we given as input

1. CARRIER SIGNAL GENERATION:

A high-frequency carrier wave is generated to trasmit information. This carrier signal maintains a constant frequency and amplitude.

2. DIGITAL DATA MAPPING:

Each binay bit (0 or 1) is assigned a specific phase shift.

BLOCK DIAGRAM [Simulink]:

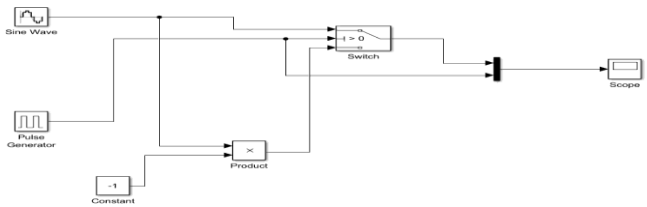


Fig.1:Block Diagram of PSK

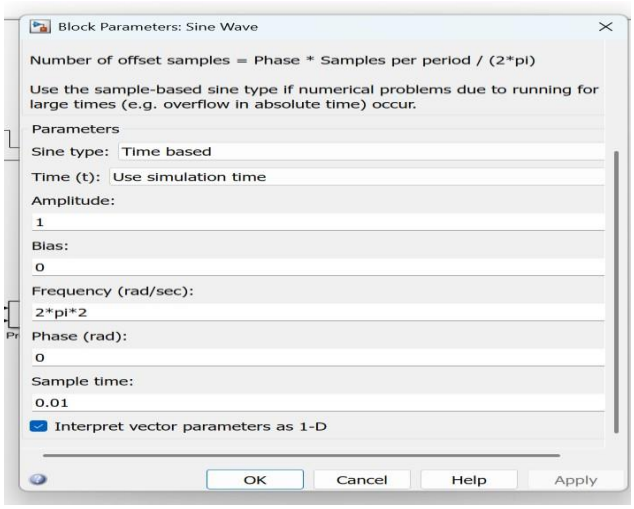


Fig.2:Sine Wave Parameters of PSK

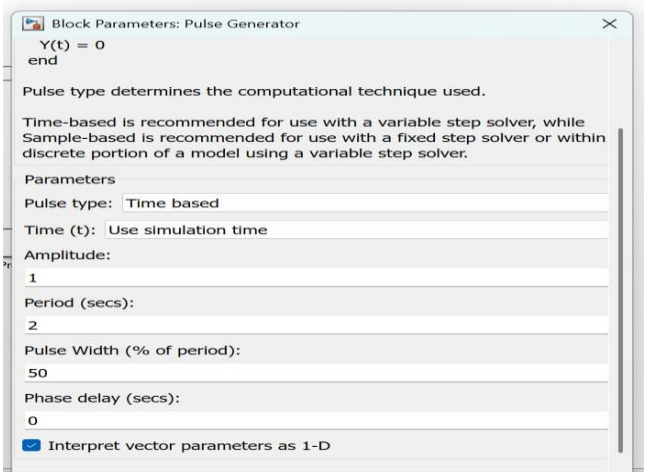


Fig.3:Pulse Generator Parameters of PSK

RESULT:

BLUE WAVE FORM:
This is the input data Each constant blue level = one symbol period
YELLOW WAVEFORM (SINUSOIDAL SIGNAL)
This is the modulated carrier signal Amplitude remains constant
The Working is During one blue block →the carrier keeps the same phase
When the blue level changes →the carrier shows a phase jump

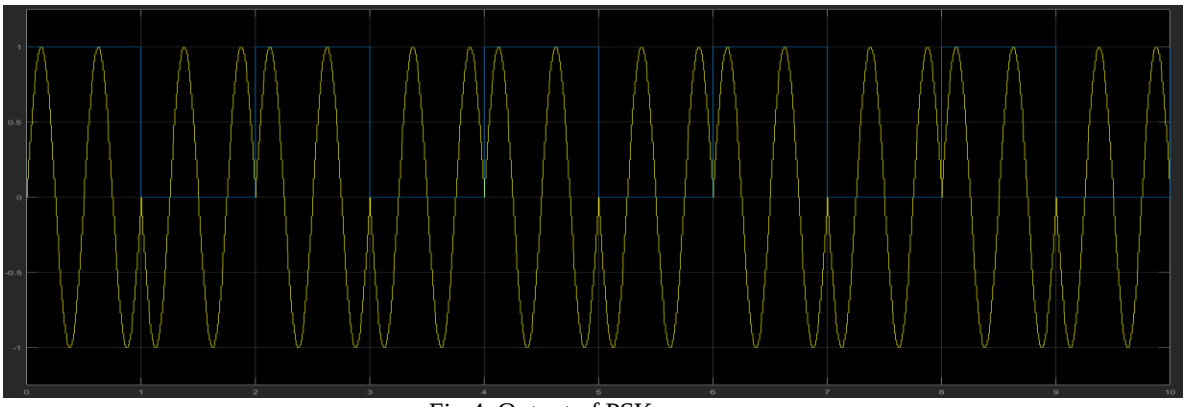


Fig.4: Output of PSK

DPSK:

Differential Phase Shift Keying (DPSK) is a widely used phase modulation method that transmits information through variations in the carrier signals phase.In this technique,the phase of each modulated symbol is determined relative to the preceding symbols phase,meaning the current signals phase depends on the state of the previous element.

PRINCIPLE:

DPSK eliminates the requirement for a synchronized coherent carrier at the receiver.The incoming binary data stream undergoes differential encoding,where each bits generated based on the preceding bits value.consequently,the receiver detects the current bit by comparing it with the previously received bit.

MATHEMATICAL EXPRESSION OF DPSK:

$s(t)=Tb2Eb\ \cos[2\pi fct+\phi n],nTb\leq t<(n+1)\ Tb$

BLOCK DIAGRAM[Simulink]:

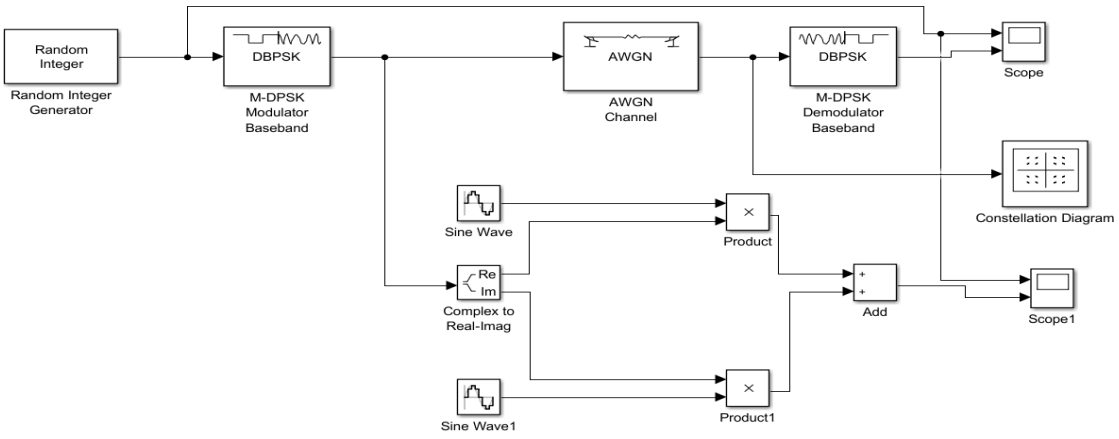


Fig.5:Block Diagram of DPSK

DPSK WORKING:

DPSK (Differential Phase Shift Keying) works by encoding digital data (1s and 0s) as phase shifts (changes) in a carrier wave, rather than absolute phase, making it simpler to decode without a complex reference signal.

INPUT PARAMETERS:

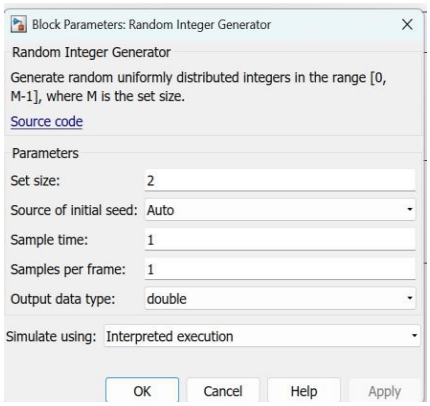


Fig.6:Random Generator Parameters

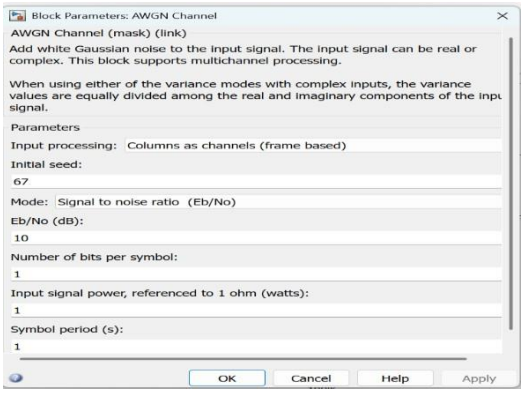


Fig.7:Parameters of AWGN Channel of DPSK

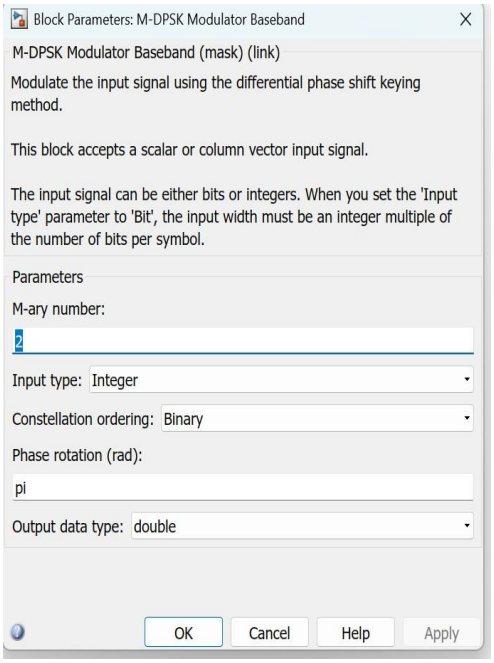


Fig.8:DPSK Modulator Parameters

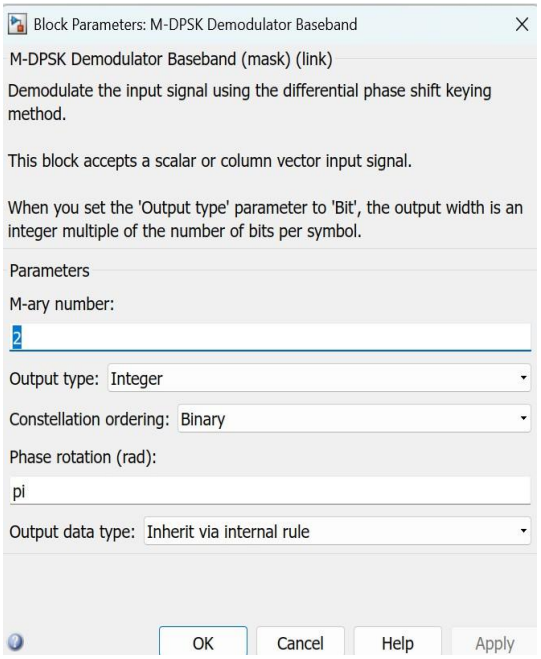


Fig.9:DPSK DeModulator Parameters

MODULATED AND DEMODULATED WAVE:

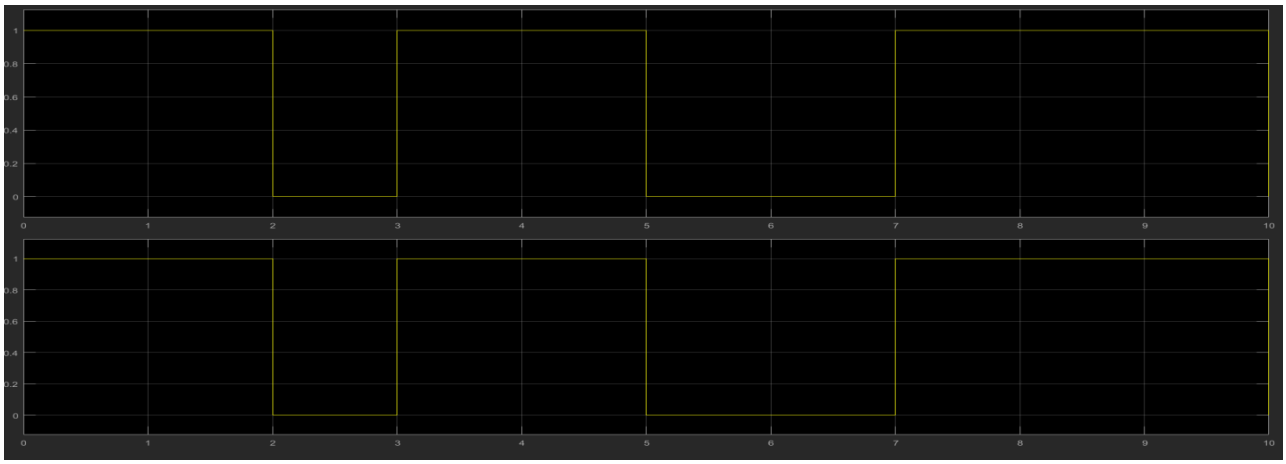


Fig.10:Modulated and Demodulated Wave forms of DPSK

DPSK OUTPUT:

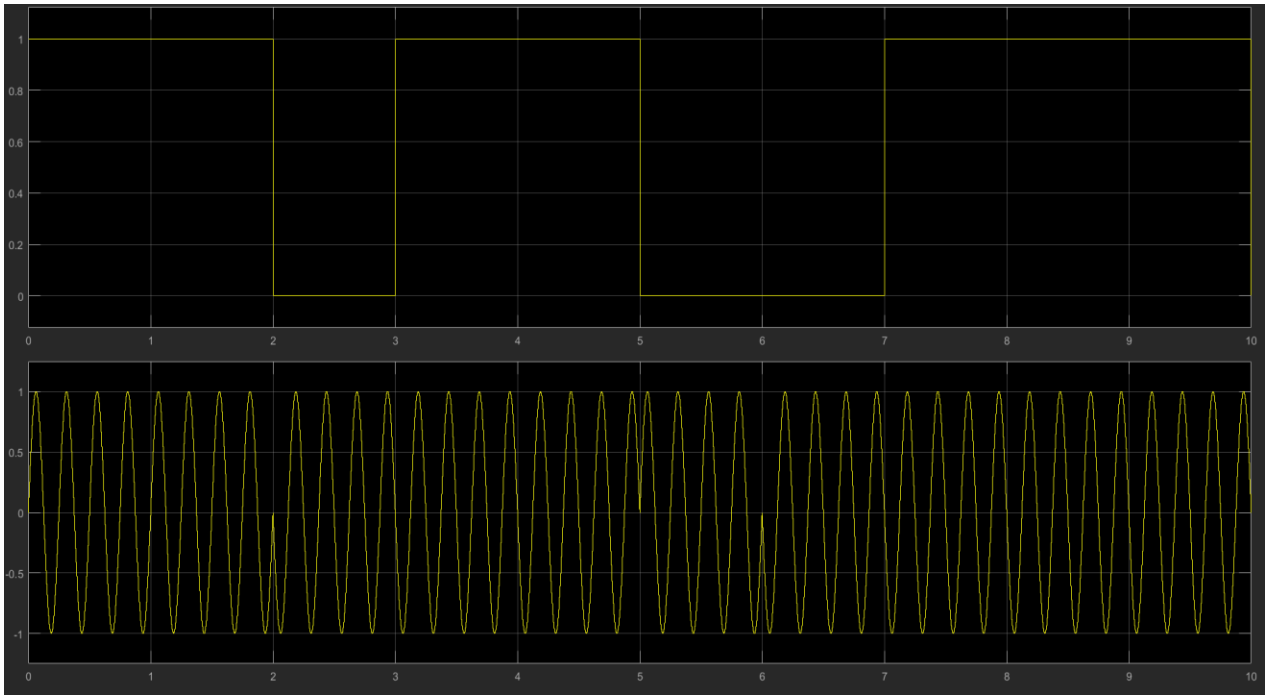


Fig.11:Output of DPSK

DPSK CONSTELLATION DIAGRAM:

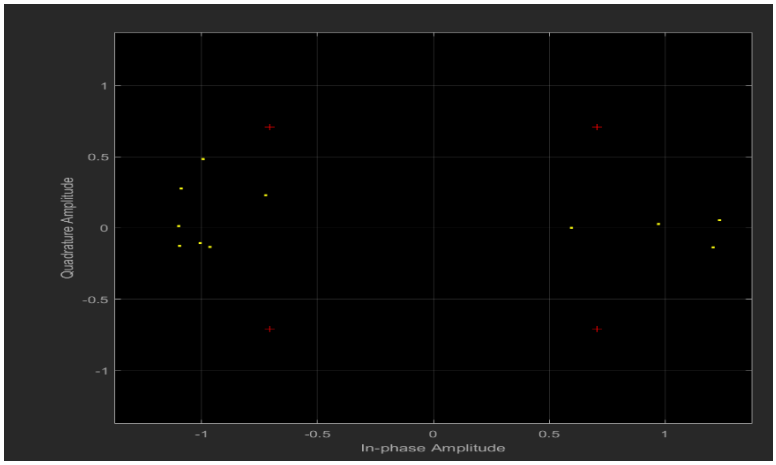


Fig.12:Constellation Diagram of DPSK

QPSK:

Quadrature Phase Shift keying (QPSK) is a modulation scheme that transmits two bits per symbol through phase variations of the carrier wave,among four possible states (0, 90, 180, or 270 degrees). This allows for twice the data transmission rate of a similar technique that only uses two states (BPSK), enabling higher bandwidth efficiency.

PRINCIPLE:

Two Bits per Symbol: Unlike BPSK (Binary PSK) which uses one bit, QPSK uses pairs of bits, allowing it to carry twice the information.

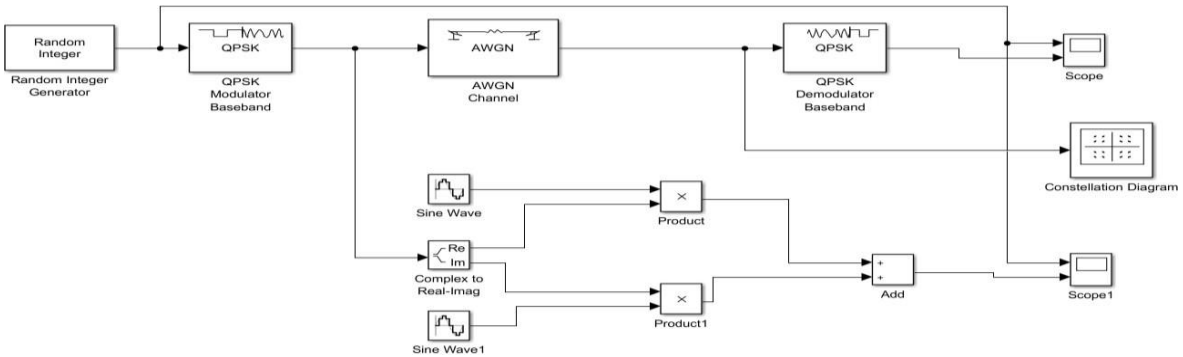
Four Phase States: There are four unique phase states (0, 90, 180, 270 degrees) to represent the four possible bit combinations (00, 01, 10, 11).

In-Phase (I) & Quadrature (Q) Channels: The data is split into two streams. One stream modulates a cosine wave (I-channel), and the other modulates a sine wave (Q-channel, 90° shifted).

MATHEMATICAL EXPRESSION:

$s(t)=Ts2Es[In\ \cos(2\pi fct)-Qn\sin(2\pi fct)]for\ nTs\leq t<(n+1)Ts$

BLOCK DIAGRAM: Fig.13:Block Diagram of QPSK



WORKING:

QPSK works by modulating a carrier signal in such a way that its phase is shifted to one of four possible positions to represent two bits of data at a time. The input bits are split into two streams, which are used to modulate two separate carriers that are 90 degrees out of phase (in-phase and quadrature). These two modulated signals are then summed to create a single, four-phase output signal that carries twice the information as Binary Phase Shift Keying (BPSK) in the same bandwidth.

INPUT PARAMETERS:

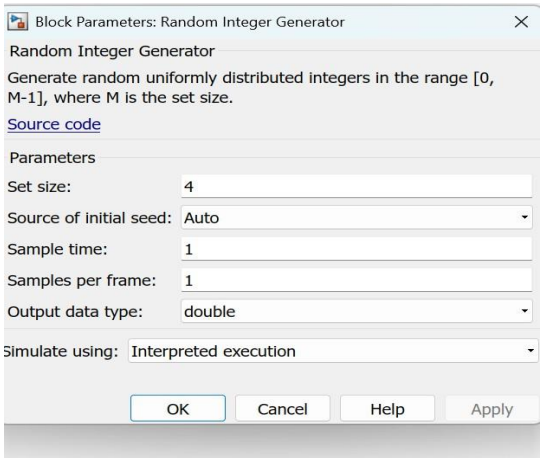


Fig.14:Random Generator of QPSK

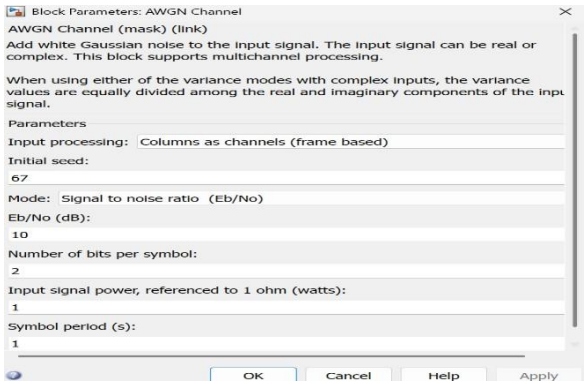
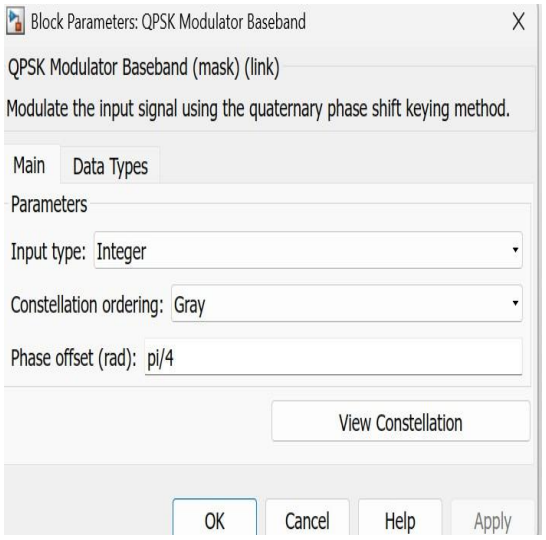


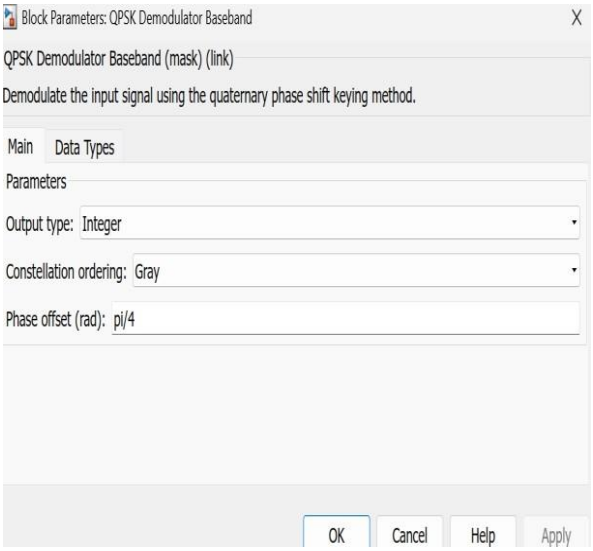
Fig.15:Parameters of AWGN Channel of QPSK

Fig.16:QPSK Modulator Parameters

Fig.17:QPSK DeModulator Parameters

RESULT:





INCREASED BANDWIDTH UITILIZATION:
QPSK encodes two data bits within each symbol on a single carrier,making it twice as spectrally efficient as BPSK.This results in a symbol transmission rate that is 50% of the original bit rate.

MODULATED WAVE AND DEMODULATED WAVE FOR QPSK:

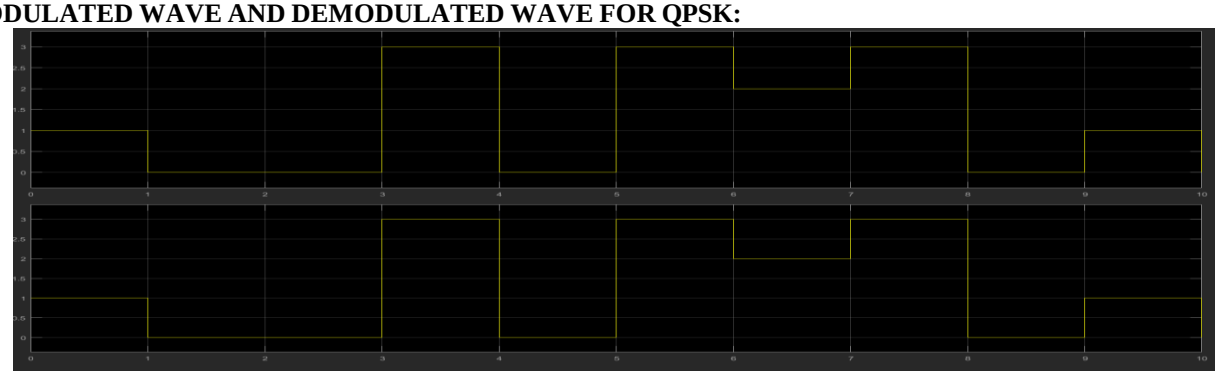


Fig.18: Modulated and De-Modulated Wave forms of QPSK

OUTPUT OF QPSK:

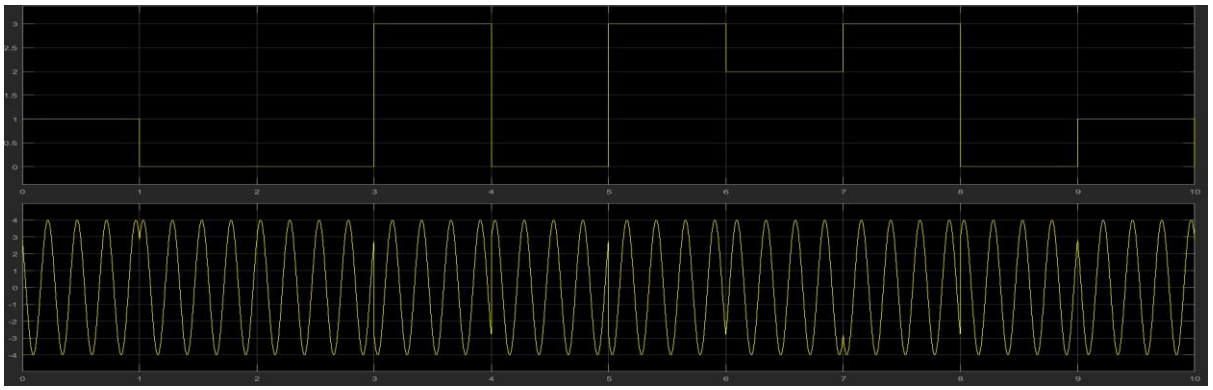


Fig.19: Ouput of QPSK

CONSTELLATION DIAGRAM OF QPSK:

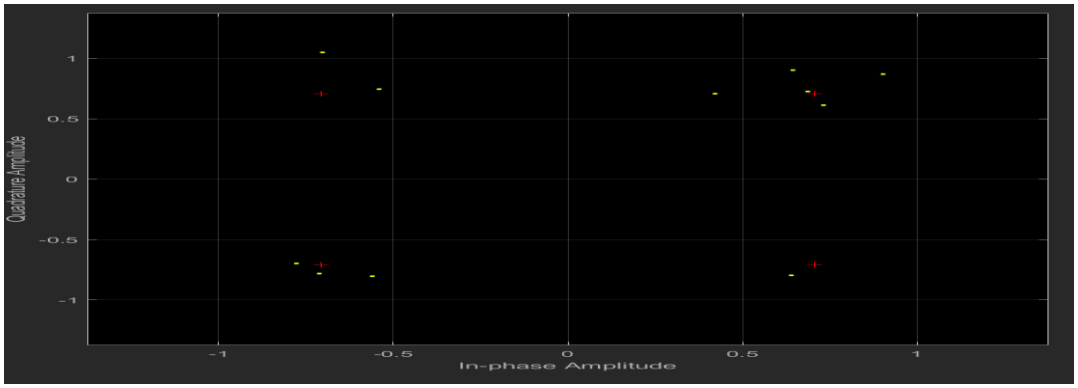


Fig.20: Constellation Diagram of QPSK

COMPARISON OF PSK, QPSK, DPSK:

PARAMETER	PSK	QPSK	DPSK
Bits per symbol	1	2	1
Phase change	0(or)π	0, π/2, π, 3π/2	Relative Phase Change
Number of phase shifts	2	4	2(relative)
Output waveform	Carrier with 180° Phase Shift	Constant Amplitude, Four Phase Levels	Phase depends on Previous Symbol
Carrier phase Reference	Required	Required	Not Required
Bandwidth Efficiency	Low	High	Low
Bandwidth Requirement	More	Less	More

CONCLUSION

This study examined the implementation and performance characteristics of PSK,DPSK,and QPSK modulation methods in digital communication applications.The findings reveal that PSK provides straightforward and dependable signal modulation,though it operates with constrained spectral utilization.QPSK demonstrates enhanced bandwidth efficiency by encoding two bits within each symbol,enabling increased transmission rates while maintaining the same frequency spectrum.DPSK removes the need for precise carrier phase alignment at the receiving end,simplifying the receiver architecture,though this comes at the cost of marginally higher error rates.The comparative evaluation indicates that QPSK excels in scenarios requiring optimal spectrum usage,PSK serves well in applications where simplicity is prioritized,and DPSK proves beneficial when receiver design complexity must be minimized.Therefore,choosing an appropriate modulation scheme requires careful consideration of factors including spectral efficiency requirements,system implementation complexity,and desired performance reliability.

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Iot Based Remote Health Monitoring System using Raspberry Pi

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Abstract: This project presents the design and implementation of an IoT-based Heart Beat Monitoring System developed using the Raspberry Pi microcontroller. The primary motivation for this work is to address the growing need for accessible, continuous, and remote monitoring of vital health signs, which is crucial for preventative healthcare and managing chronic conditions. The system utilizes a dedicated optical pulse sensor (such as the Pulse Sensor Amped) to accurately acquire the photoplethysmogram (PPG) signal from the user.This analog data is fed into the powerful and resource-efficient Raspberry Pi. Custom firmware written in MicroPython or C/C++ is employed to filter noise, process the raw signal, and calculate the heart rate,spo2 and blood glucose(using driver circuit rather than pulse sensor)in real-time.The system uses ESP8266 Wifi Module to publish the collected data on to cloud platforms such as Thingspeak.The cloud service not only stores the historical data but also provides an intuitive web dashboard for remote visualization and analysis by caregivers or medical professionals.This project successfully demonstrates the feasibility of creating a low-cost, low-power, and highly functional smart healthcare device.

Keywords: Photoplethysmogram(PPG); heart rate; spo2; blood glucose; smart healthcare

1.INTRODUCTION

The Internet of Things (IoT) is transforming healthcare, shifting the focus towards continuous, accessible, and remote health monitoring systems.Monitoring heart rate,blood glucose and spo2 is essential for the early detection of cardiac issues, managing chronic conditions, and optimizing personal fitness and recovery.Traditional monitoring methods often lack the continuity and remote accessibility required for modern, proactive, and preventative healthcare.There is a clear market need for a heart monitoring system that is simultaneously cost-effective and energy-efficient, while still providing reliable, real-time data.Existing solutions are often either too expensive for widespread personal use or struggle to seamlessly integrate accurate sensor readings with secure, cloud-based platforms for continuous remote analysis.

This project directly addresses these challenges

by developing an IoT-based Heart Beat Monitoring

System using the RaspberryPi. The core objectives are to:

- Utilize the RaspberryPi high processing power
  and low energy consumption for effective signal processing
- Accurately acquire physiological data using

a dedicated optical pulse sensor.

- Establish seamless IoT connectivity to transmit real-time data to a secure cloud service (e.g., ThingSpeak).

Enable remote visualization of heart rate,blood glucose and BP

also implement automated alerting functionality for timely

intervention when vital signs exceed or fall below normal thresholds.

II. BACKGROUND

In the healthcare sector, iot technologies are being increasingly utilized within smart hospitals, home care systems, and wearable devices to track vital signs such as heart rate, blood glucose, oxygen saturation and activity levels. Typically, these systems consist of biosensors, processing units, communication modules, and cloud services to enable ongoing, remote, and often real-time monitoring of patients who have chronic conditions, elderly individuals, or high-risk patients post-surgery. They contribute to enhanced resource utilization, decreased hospital readmissions, and support for telemedicine and personalized care.

The heart rate can be determined from the ppg signal by identifying consecutive peaks and measuring the time intervals between them. Changes in the ppg waveform and its derivatives, potentially in conjunction with other signals such as arterial pressure cuffs or calibration models, can assist in indirectly estimating blood pressure. Similarly, research is exploring optical sensing within specific wavelength ranges, paired with suitable calibration or machine-learning models and sometimes additional context like temperature or user-specific data, for the non-invasive estimation of blood glucose and other metabolic markers, although this remains a complex area of study requiring further validation.

III SYSTEM TOPOLOGY/METHODOLOGY

The proposed system uses Raspberry Pi as a platform for edge computing and gateways in IoT healthcare applications. It is affordable and has enough processing power to manage data collection, local signal analysis, and secure communication. The Raspberry Pi can connect with various medical and optical sensors through GPIO, I²C, SPI, or USB. It performs initial signal processing tasks, such as filtering and feature extraction, before sending important data or processed waveforms to cloud servers, web dashboards, or mobile apps. Unlike basic microcontrollers, the Raspberry Pi can run a full operating system. This allows it to execute more complex algorithms, databases, and web services directly on the device.

Optical sensors used in photoplethysmography (PPG) detect changes in blood volume within the microvascular network of tissue. They emit light, usually in the green, red, or infrared spectrum, and measure how much light is absorbed or reflected by the skin. The PPG waveform shows a pulsating pattern that corresponds with the heart's cycle. This allows us to extract heart rate and other related metrics. PPG is a non-invasive technique that is fairly affordable and suitable for continuous monitoring. These qualities contribute to its widespread use in wearable devices and IoT health technologies.

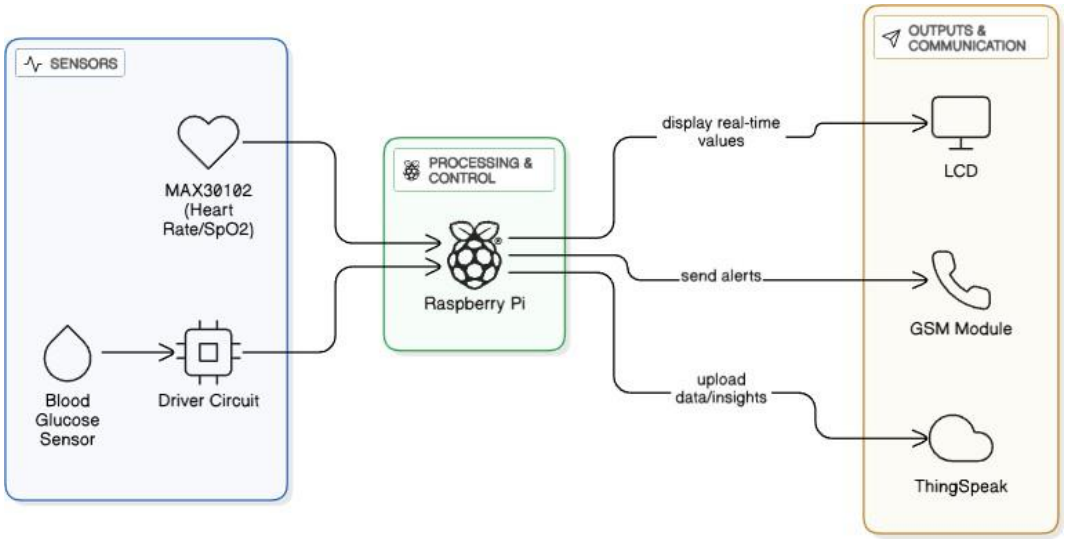


Fig 1: System Architecture of IOT based Health Monitoring System

System Components

1)Raspberry Pi 3B+

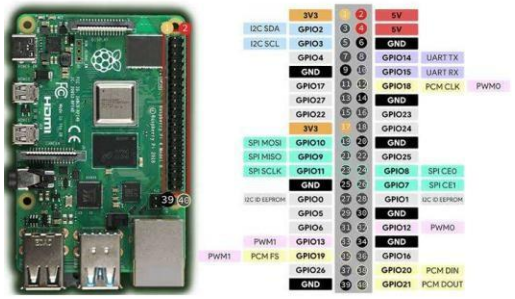


Fig 2:Raspberry pi 3b+

The Raspberry Pi 3B+ is a powerful and versatile single-board computer (SBC) developed by the Raspberry Pi Foundation. Released as an improvement over the Raspberry Pi 3B, it offers enhanced processing power, better networking capabilities, and improved thermal performance. The Raspberry Pi 3B+ is widely used in various applications, including IoT, robotics, home automation, and embedded systems.

The Raspberry Pi 3B+ features a well-designed 40-pin GPIO header which T is like a Swiss Army knife for electronics—it gives your Pi the ability to communicate, control, and power external devices. he pins are categorized based on their roles, with a total of 13 General Purpose Input/output (GPIO) pins. 11 Power and Ground pins, 2 I2C pins, 2 UART pins, 5 SPI pins which are for communication interfaces. 2 PWM(pulse width modulation) pins, 4 PCM(audio interface) which are for signal control.

Power pins: The model B+ board consists of two 5V pins, two 3V3 pins, and 9 Ground pins (0V), which are unconfigurable. 5V: The 5V pins are used to directly deliver the 5V supply coming from the mains adaptor. This pin can be used to power up the Raspberry Pi, and it can also be used to power up other 5V devices. 3.3V: This pin is used to provide a stable 3.3V supply to external components and also to test LEDs.

GND: Ground is commonly referred to as GND. All the voltages are measured with respect to the GND voltage

Input/Outputs pins: A GPIO pin set as input reads the signal received by the Raspberry Pi sent by the device connected to this pin. Any voltage between 1.8V and 3.3V is read as HIGH, and voltage lower than 1.8V as LOW by the Raspberry Pi. A GPIO pin set as an output pin sends the voltage signal as high (3.3V) or low (0V). When this pin is set to HIGH, the voltage at the output is 3.3V and when set to LOW, the output voltage is 0V.

PWM (pulse-width modulation) pins:

• Software PWM is available on all pins

• Hardware PWM is available on these pins only: GPIO12, GPIO13, GPIO18, GPIO19

SPI pins: SPI (Serial Peripheral Interface) is another protocol used for master-slave communication. It is used by the Raspberry pi board to quickly communicate between one or more peripheral devices. If the SPI device needs to communicate back to Raspberry Pi, then it will send data back using the MISO (Master In Slave Out) pin. 5 pins are needed for the SPI communication:

• **GND**: Connect all GND pins from all the slave components and the Raspberry Pi 3 board together.

• **SCLK**: Clock of the SPI. Connect all SCLK pins.

• **MOSI**: It stands for Master Out Slave In. This pin is used to send data from the master to a slave

• **MISO**: It stands for Master In Slave Out. This pin is used to receive data from a slave to the master

• **CE**: It stands for Chip Enable. We need to connect one CE pin per slave (or peripheral devices) in our circuit.

2) Pulse Oximetry Sensor(MAX30100)



Fig 3:MAX30100 sensor

The MAX30100 pulse oximetry & heart- rate monitor sensor is a low-power, I2C-based plug & play biometric sensor for detecting pulse oximetry & heart-rate signals. This sensor includes two LEDs like RED & IR LED, a photodetector, modifiable optics & low noise signal processor to detect heart pulse rate signals. On the right side of this sensor, two LEDs are available whereas on the left side, it has a sensitive photodetector. This sensor is used in various medical & industrial equipment like fitness measurement devices, wearable instruments & medical devices

This sensor module configuration can be done through software registers & this module's output data is simply stored within 16 FIFOs on this module. This pulse oximeter sensor communicates with different microcontrollers through the I2C

interface. In this sensor module, the pulse measurement system includes a 16-bit ADC, a time filter & cancellation of ambient light.

For the measurements of oxygen concentration as well as heart pulse rate, first, this sensor needs to wear on your finger or earlobe or it can be worn on any part of the thin body. Once this sensor is worn on your finger then both IR & red light from LEDs passes throughout the finger tissues, these light absorption can be measured through a photodiode. Based on the oxygen quantity you have within your blood, the ratio of red light absorbed & IR light will be different. So by this light ratio, we can calculate the level of oxygen easily within the hemoglobin of your blood.

3) GSM Module 800L



Fig 4:GSM Module 800L

The GSM Module SIM800L is a compact and affordable cellular communication module that enables microcontrollers like Arduino and Raspberry Pi to send and receive SMS, make voice calls, and connect to the internet via GPRS using a SIM card. However, it is almost impossible to fond satisfactory explanations about its use and especially about its connection.

The SIM800L is a modem. It is the one who registers with your operator's network, etc. Overall it behaves like a phone that you could control directly from your Raspberry. In order to control the SIM800L, from the Raspberry, you will have to provide power to the first and physically and software connect both using a TTL port, more often called a port or serial interface. The SIM800L GSM/GPRS module has 12 pins which are NET, VCC, RST, RXD, TXD, GND, SPKN-, SPKP+, MICN-, MICP+, DTR, RING. NET is a pin where you can solder the helical antenna that comes with the module. VCC is the Power supply pin of the module and it needs to be powered anywhere from 3.4V to 4.4 volts.

4) Wi-Fi Module (ESP8266)



Fig 5:ESP8266 Wi-Fi Module

The ESP8266 is a highly popular Wi-Fi module that enables microcontrollers to connect to Wi- Fi networks, making it a crucial component in many Internet of Things (IoT) applications. Launched by Espressif Systems, the ESP8266 provides a low-cost and efficient way to add wireless connectivity to devices, allowing for remote control, data collection, and interaction with cloud services. Its versatility and ease of use have led to its widespread adoption in various projects, from home automation systems to smart sensors.

The working principle of the ESP8266 revolves around its ability to connect to Wi-Fi networks and communicate with other devices. Users can program the module using various programming environments, with the Arduino IDE being one of the

most popular options. By writing simple code, developers can connect the ESP8266 to a Wi-Fi network, send and receive data, and perform tasks such as hosting web servers or making HTTP requests. The module's capability to operate in both client and server modes enhances its versatility, enabling a wide range of applications. In conclusion, the ESP8266 Wi-Fi module is a highly effective and accessible solution for adding wireless connectivity to a wide range of applications. Its low cost, compact design, and robust features make it a favorite among hobbyists and professionals alike. With its ability to facilitate seamless communication between devices and the cloud, the ESP8266 plays a pivotal role in the growing field of IoT.

5) LCD Display



Fig 6:LCD display

An LCD (Liquid Crystal Display) is a flat-panel display technology that uses liquid crystals to modulate light and create images. It consists of layers that include a backlight, which illuminates the display since liquid crystals themselves do not emit light. LCDs are known for their thin profile and energy efficiency, making them popular in various devices like televisions, computer monitors, and smartphones. They offer good color reproduction and clarity, though viewing angles can be limited compared to other technologies. Overall, LCDs are widely used for their versatility and cost effectiveness in displaying visual information.

6) ARDUINO UNO

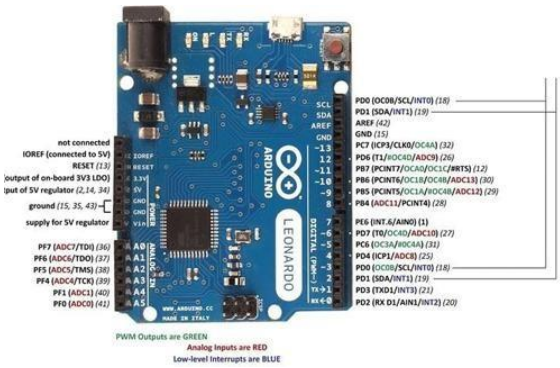


Fig 7:Arduino UNO

The Arduino Uno is a series of open-source microcontroller board based on a diverse range of microcontrollers (MCU). It was initially developed and released by Arduino company in 2010. The microcontroller board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE

(Integrated Development Environment), via a type B USB cable.[4] It can be powered by a USB cable or a barrel connector that accepts voltages between 7 and 20 volts, such as a rectangular 9-volt battery.

7) Thing Speak Cloud Platform:

ThingSpeak is used as both a **data source** and a **data sink**.

ThingSpeak is suitable for medical IoT because it is lightweight, supports JSON responses, offers free API hosting, and allows easy graphical visualization for caregivers. The REST API interface simplifies communication—making it possible for the microcontroller to periodically fetch updated timings and upload status without requiring large computing resources.

Its timestamped database also ensures that every update to the schedule is permanently recorded, which can be useful for compliance audits, medical supervision, or research on patient behavior

IV RESULTS/OUTPUT

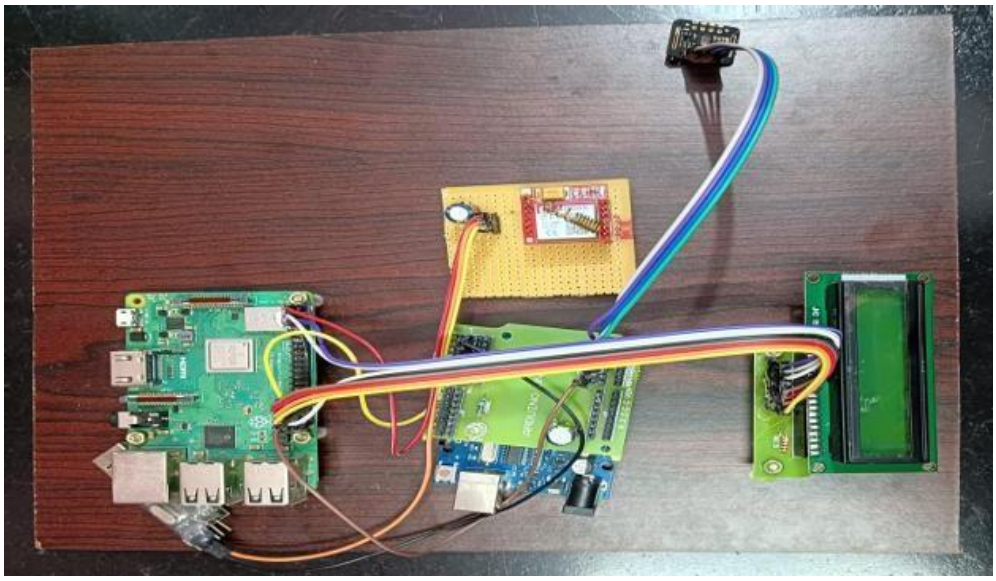


Fig 8.Implementation of Health Monitoring System

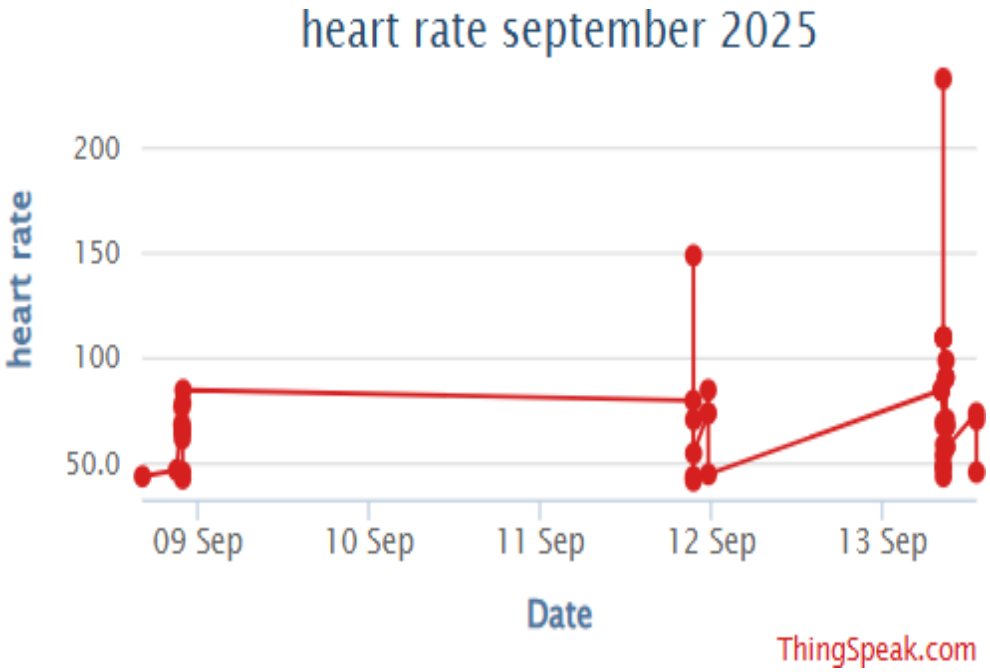


Fig 9.Data Visualisation in ThingSpeak for heart rate measurement

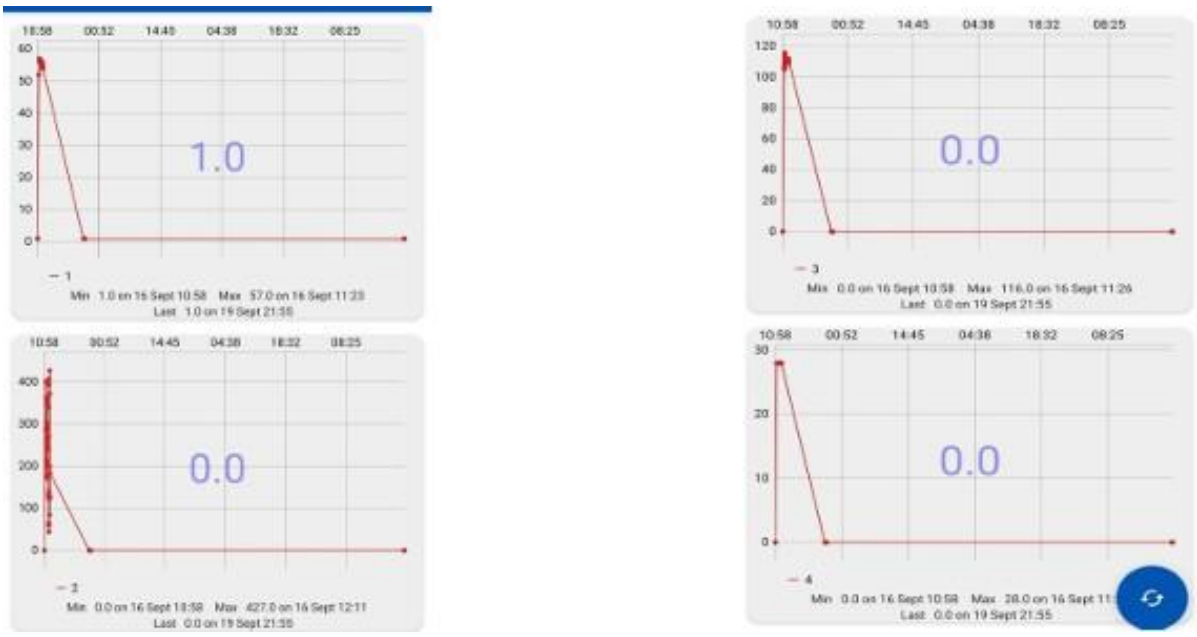


Fig 10:Data Visualisation for blood glucose on ThingSpeak



Fig 11.Data Visualisation for spo2 on ThingSpeak



Fig 12.LCD Output for Blood Glucose



Fig 13.LCD output for Heart Rate



Fig 14.Alert Message

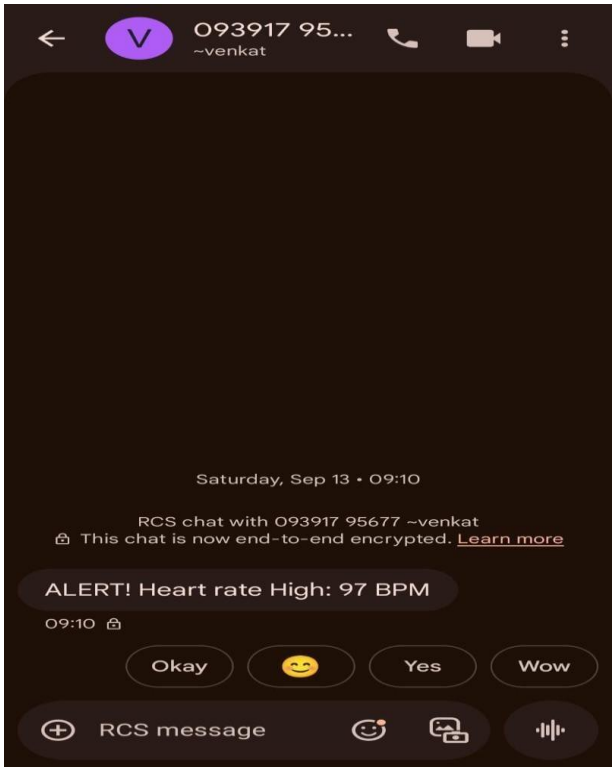


Fig 15.Alert Message

IV CONCLUSIONS

This project successfully achieved its objective by designing and implementing a functional **IoT-Based Health Monitoring System** utilizing the **Raspberry Pi** microcontroller. The system effectively integrates the **MAX30102 sensor** for highly accurate heart rate and saturated oxygen data acquisition and additional driver circuit for blood glucose measurement demonstrating the Pi's capability to perform real-time digital signal processing, including essential filtering and peak detection.The core success of this work lies in establishing a **robust and redundant communication pathway**. Real-time data is consistently uploaded to a cloud platform (IoT component) for remote monitoring and trend analysis. More critically, the system incorporates a **GSM module** to provide an immediate **SMS alert channel** for critical anomalies, ensuring reliable, proactive emergency notification independent of local Wi-Fi stability. This combination confirms the system's viability as a **low-cost, energy-efficient, and dependable solution** for personal health tracking. The project serves as a strong proof-of-concept, affirming the suitability of the Raspberry Pi platform for real-world smart healthcare applications

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We express our sincere thanks to Department of Electronics and Communication Engineering of Vasireddy Venkatadri Institute of Technology for giving us this opportunity

Sincere gratitude is also directed towards the Head of the Department and project guide,whose encouragement, academic guidance, and support fostered a positive atmosphere for learning and research. Their motivation to investigate new concepts and undertake innovative projects in IoT-based healthcare has served as a significant source of inspiration during this endeavor.

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Water Resources Protection from Encroachment by The Use of Drone Technology and Google Map

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***Abstract*—** World environment has to be protected for future generations from greedy people for money and luxury. Every day water bodies are encroached by political bigwigs and private people. To prevent such encroachments. drone technology is used in some areas. The drone technology can be used to protect forest area and water bodies in Tirupati district, Andhra Pradesh. In this paper Korramenugunta lake in Tirupati city is taken for experiment purpose. Photos are taken different times . These photos are compared with previous one and changes are detected for further actions. Tirupati district is facing sandal wood smugglers problem for long times. Drone will be flied along the water bodies and forest every day and live data collection will be done. Any changes in the area compared with previous images will be detected and appropriate offices will be alerted for spot visit to that place. Thereby encroachment can be identified and will be prevented.

Keywords—Water resources, Drone technology, Google Maps, MATLAB, Encroachment detection

INTRODUCTION

Many Indian cities have lakes and small water bodies. They provide water for daily use, and they sustain vegetation adjacent to buildings. These water bodies are used for groundwater recharge and for reducing flooding in heavy rainfall. Lakes were, in time, shared resources and cared and worked by local communities. The latter has changed over the years. Urban expansion has changed the use and protection of such lakes. So it makes more use of land, as cities expand. Roads are broadened and new neighbourhoods are produced. Construction often occurs next to the boundaries of lakes. Encroachment is not a sudden phenomenon in nature and does not happen abruptly. It happens step by step. Tiny areas are filled up, temporary paths are opened, refuse materials are discarded at the edge and refuse is dumped in the margins. Those effects diminish the visible water body layer gradually. Similar situations reported in other regions under long-term encroachment have deteriorated water availability and environmental quality [1], [2]. It is complicated to notice these developments only through field visits. Long-term records are seldom reported, and routine inspection is not always feasible. Satellite imagery

offers a tangible way to study these changes. Such images collected at varying intervals between time periods provide opportunities to compare lake boundaries and water dissemination [3], [4]. Having access to historical satellite data through Google Earth Engine has made long-term observation much easier [5], [7]. But for urban areas it's a bit more complex to analyze images. The shadow created by buildings, the proliferation of vegetation and changes of colour of water can interfere with automatic detection. A number of approaches were introduced from learning based approaches for satellite images as waterbody identification [10], [11]. They can perform quite well under the controlled environment. Their use is limited for regular monitoring work. They require big training data and regular updates. This is not always feasible for local governments. Simple visual comparison techniques of simple visual comparison methods are still feasible in long term and site-contained studies [6]. Unmanned aerial vehicles (UAVs) are also being utilized for environmental supervision. Whenever necessary, drones record crisp images of particular regions. This is useful for detailed study of the lake boundaries, and related land usage in the nearby area [12], [13]. Drones have been reported not only to be useful for shoreline mapping, but also for shallow water

research results as well [14], [15]. But drone surveys cannot give historical data. They work better when used with satellite data. In this study, encroachment on Korramenugunta Lake, which is situated in Tirupati city, Andhra Pradesh, is studied. It is surrounded by places where continuous urbanization has taken place. Changes in the lake boundary are observed from satellite images taken on Google Maps from various years. Manual delineation is adopted so that all visual parameters were applied for every year. This is useful in preserving consistency. Drone-based monitoring is presented as a means of support for local verification. This work aims to introduce an easily accessible technique for monitoring lake encroachment with satellite images assisted by drones. The strategy will assist regional administrative bodies to detect water boundary alterations early on, and enhance the conservation of urban water resources.

RELATED WORK.

Remote sensing of surface water bodies has been researched for decades. Changes in lake area, shoreline position, and surface water spread have been frequently observed using satellite images. Long-term image records make possible studies of gradual changes that take many years even as they progress. Many multimethod satellite data studies have been conducted to study reduction of lake extent and surface water dynamics between different time periods over many different regions with multi-temporal satellite data [2], [3], [4], [7]. The provision of past satellite views is better made possible by cloud-based systems. Google Earth Engine particularly has been used for processing substantial quantities of satellite data in order to study long-term water bodies [5], [8]. These types of platforms are helpful in monitoring trends over time. Simultaneously, automated image processing techniques for these studies are often impeded by seasonal vegetation, shadows, and variations of water appearance. They can be especially visible in urban situations. To overcome these challenges, several research groups have suggested a learning based water body extraction technique. Deep learning based models have been used to detect lakes and shorelines using satellite images [10], [11] with excellent spatial accuracy under given conditions. Although these techniques perform well in laboratory experiments, they are usually not used in basic monitoring. They need big labelled datasets and it is needed to retrain with time at new locations. As a consequence they are not appropriate for long-term experiments on site. In these instances simpler methods which rely on consistent visual

comparison are still more accurate and easier to interpret [1], [6]. Unmanned aerial vehicles are also used for water body monitoring. UAVs are capable of obtaining the high resolution images of lakes, wetlands and shallow water zones [12], [13]. Images of these types are good for studying shoreline information and location of land use in proximity to water bodies. Multiple models have already proven that drones are efficient in mapping the coastlines and the shallow water at a local scale [14], [15]. UAV surveys are flexible and can be used on demand. But they don't provide their long-term historical data alone. Some recent research has proposed a supplementary analysis, which combined satellite images with UAV measurements to achieve a better monitoring accuracy. Satellite imagery also provides long-term coverage; drone imagery adds detailed micro information. Combined approaches of this kind can provide more sophisticated understanding of time-based water body changes. Most of the methods currently available, however, depend on complex automation and data intensive processing, which may be impractical for local administrative agencies with limited technical infrastructure. Thus, it is evident from the literature that there is a gap requiring easy, reliable and practical monitoring approach. A study that integrates long-term satellite image comparison with focused drone observation could be useful for the early recognition of encroachment. This paper continues this trend by emphasizing cross temporal comparison of lake boundaries through satellite imagery supported by UAV-based verification, with a focused emphasis in the case of urban and peri-urban water bodies, to obtain consistent imagery.

PROPOSED METHOD WITH BLOCK DIAGRAM

In order to control existing water resources against their encroachment, the proposed method deploys a drone-based monitoring technique, integrated with temporal image comparison. Under this framework, drones serve as aerial vehicles regularly to take high-resolution images of water bodies and surrounding environment. A computer-controlled drone commands a series of drone operations from a centralized control center, allowing for uniform flight paths and routine data collection. The images acquired during the surveys are compared to the reference images already saved to identify spatial deviations in lake boundaries and land occupation in the surrounding area. Significant data variation suggesting possible encroachment is reported accordingly for verification and communicated to the municipal authority and local police for expedited field visit and to take appropriate actions. Fig. 1 shows the total flow of the proposed system for the detection of encroachment.



Fig. 1. Conceptual block diagram of the drone-based encroachment detection and monitoring framework.

ANALYSIS OF IMAGES AND ENCROACHMENT DETECTION

Substantial satellite images collected through Google Maps over various instances are analyzed and compared via MATLAB-based image processing models to detect potential encroachment on water resources. The temporal nature of such images can indicate potential alterations in the boundaries of the lake and surrounding land use. In the cases of significant variations indicating probable encroachment, the details of that are shared with relevant administrative branches (municipal office, district administration, law enforcement agencies, etc.) so that field verification or taking necessary actions can be completed in time. A detailed case study was conducted on Korramenugunta Lake in Tirupati city, Andhra Pradesh using high-resolution Google Maps imagery from 2019 to 2025. Each year the lake boundary was inspected, from which outline images were created to show visible water spread measurements as per the boundaries. These outlines were subsequently employed for calculating relative changes in lake area and determining the extent of encroachment through time. Representative satellite imagery showing the status of Korramenugunta Lake at the initial year of observation is shown in Fig. 2. The comparison of lake outlines year-wise clearly shows the progressive shrinking of boundaries—indicating encroachment has occurred during these years.

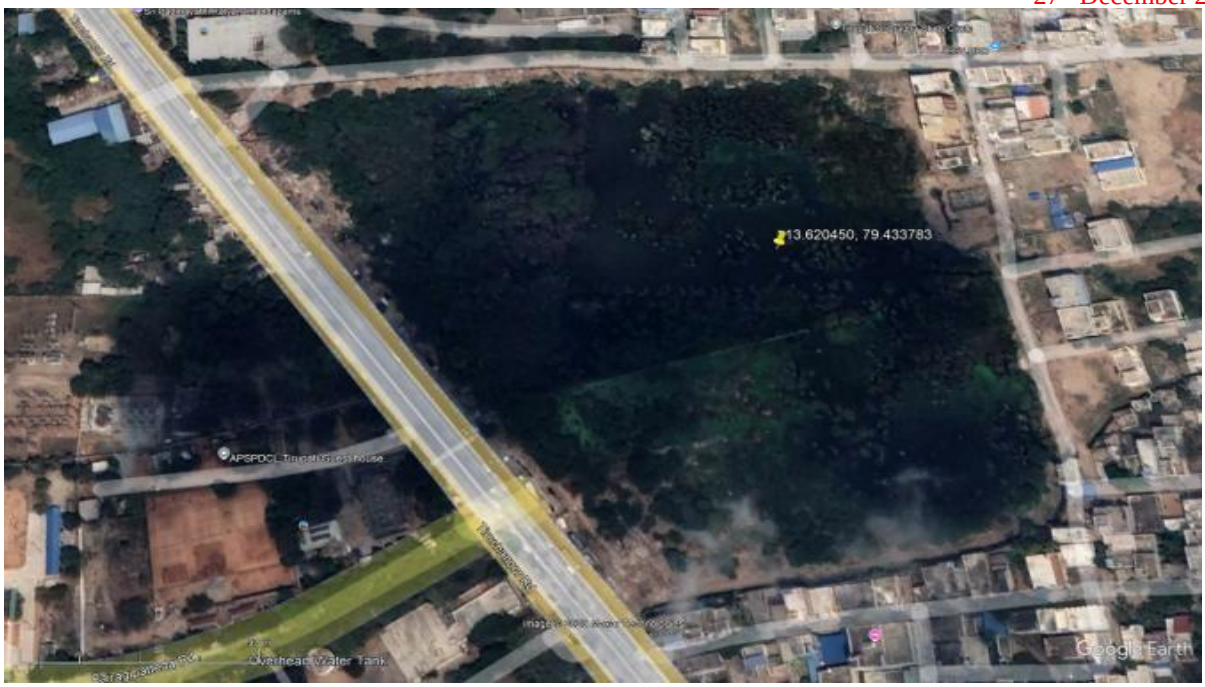


Fig. 2. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in March 2019 (baseline reference year).

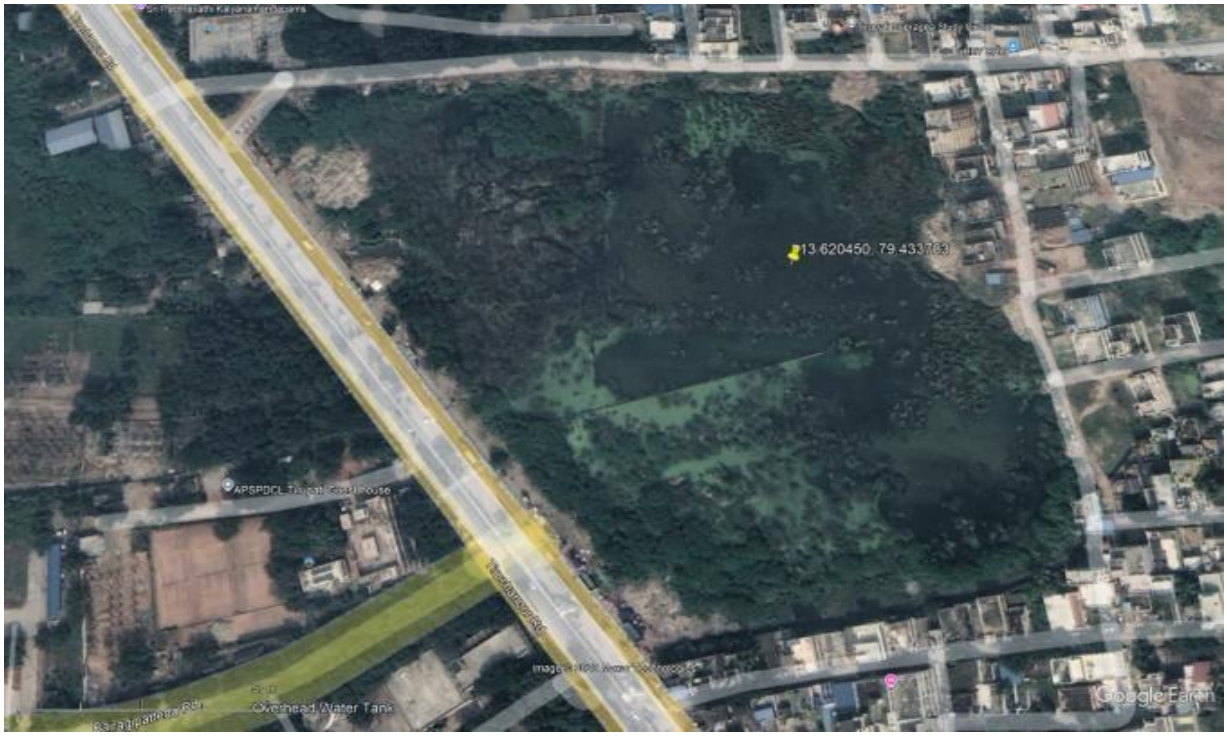


Fig. 3. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in January 2020.

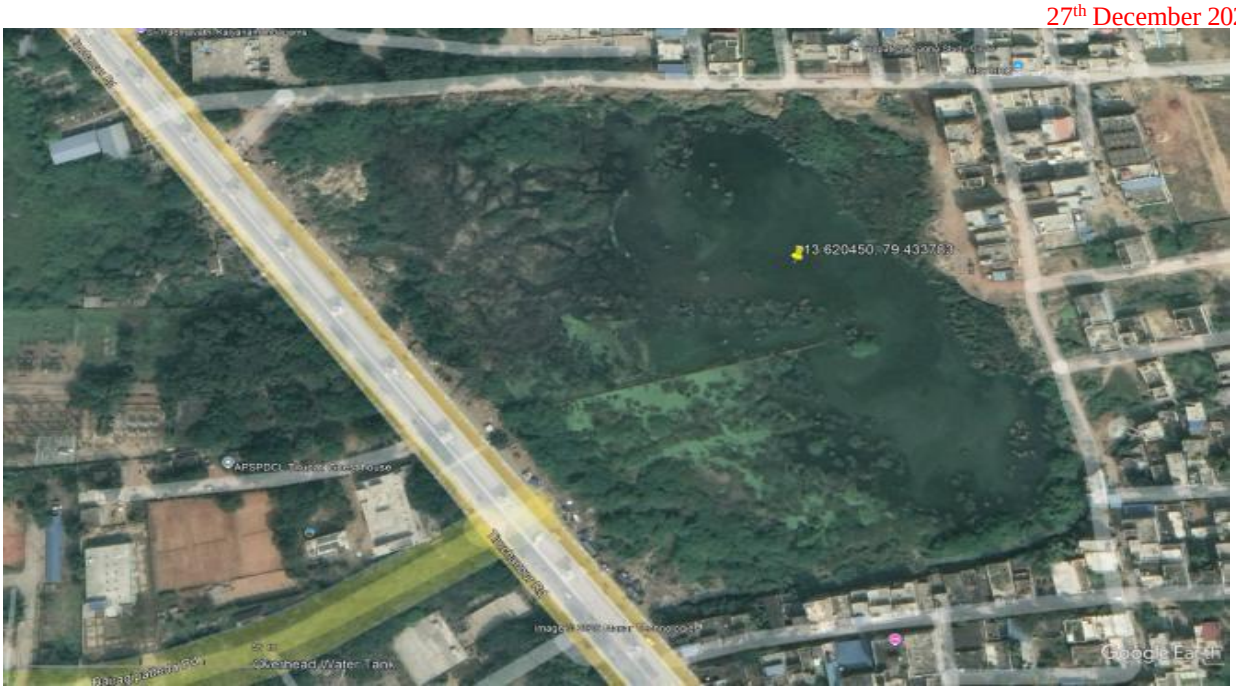


Fig. 4. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in January 2021.



Fig. 5. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in February 2022

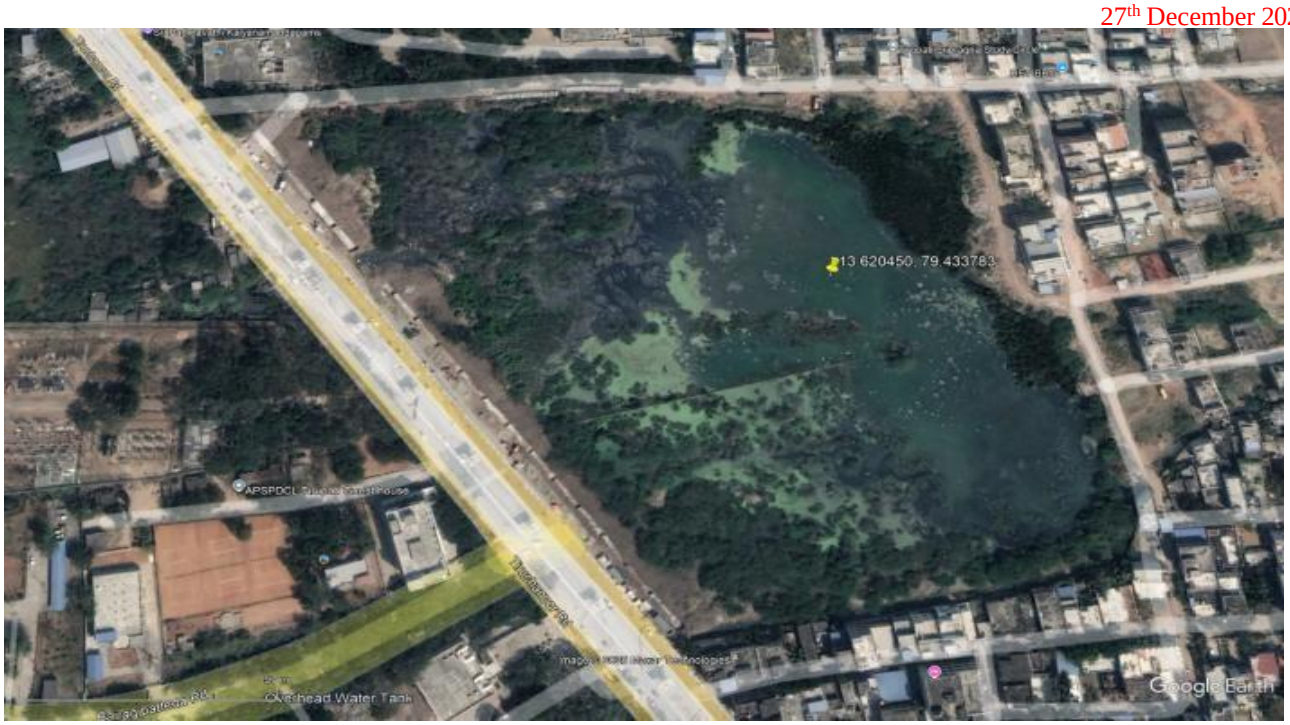


Fig. 6. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in April 2024.



Fig. 7. Google Maps satellite image of Korramenugunta Lake, Tirupati, Andhra Pradesh, captured in April 2025.

lake boundary outlines manually extracted from high-resolution Google Earth photos for 2019-2025. All contours are based on spatially consistent and co-registered aerial images, using the 2019 limit as a reference baseline. These outline contours show the extent of the lake as seen for each year which allows for a direct comparison of shoreline contraction and landward progression in a visual sense over years.

RESULTS AND ANALYSIS.

Fig. 8 traces the trend and time series of the year-wise development of Korramenugunta Lake boundary between 2019 and 2025, as depicted by carefully annotated manual marking on the consistent satellite images and a human-drawn boundary diagram. In order to preserve spatial consistency and reduce artefacts associated with automated segmentation the lake perimeter had to be delineated in four years by means of an interpretive visual reading of the lake extent, shoreline continuity and interface between open water and surrounding land. The reference structure for later boundary changes is the 2019 outline. This study demonstrates a slow but continual shrinking of the observable lake volume over the study period. There is some inward shift of the shore in the northern-eastern parts between 2019 and 2020, in the early stages of surface water contraction. From 2021 these transitions are more pronounced, showing increasingly pronounced boundary fragmentation and in the face of enlarged built-up regions and access corridors around the lake an increasing inward move. The plot of both 2022 and 2023 presents an accelerated onset, indicated by the irregular retreat of boundaries and the transformation of open water regions into reclaimed land or dense aquatic growth. In the years 2024 and 2025 the lake boundary stabilizes into a significantly reduced configuration, a significant reduction of effective water spread relative to the 2019 baseline. The uniformity of manually traced boundaries over all years further corroborates the hypothesis that the observed changes are attributable to authentic environmental and human impacts in contrast to inconsistencies in image registration or processing. Overall, Fig. 8 represents an effective visual description of extended lake deterioration and serves as a platform for subsequent quantitative analysis — comparative lake area decreases are computed against the 2019 reference point. The conservative design of the manual delimitation guarantees that the trends reported provide reliable estimates of shoreline changes for environmental evaluations and urban spatial impacts assessment.

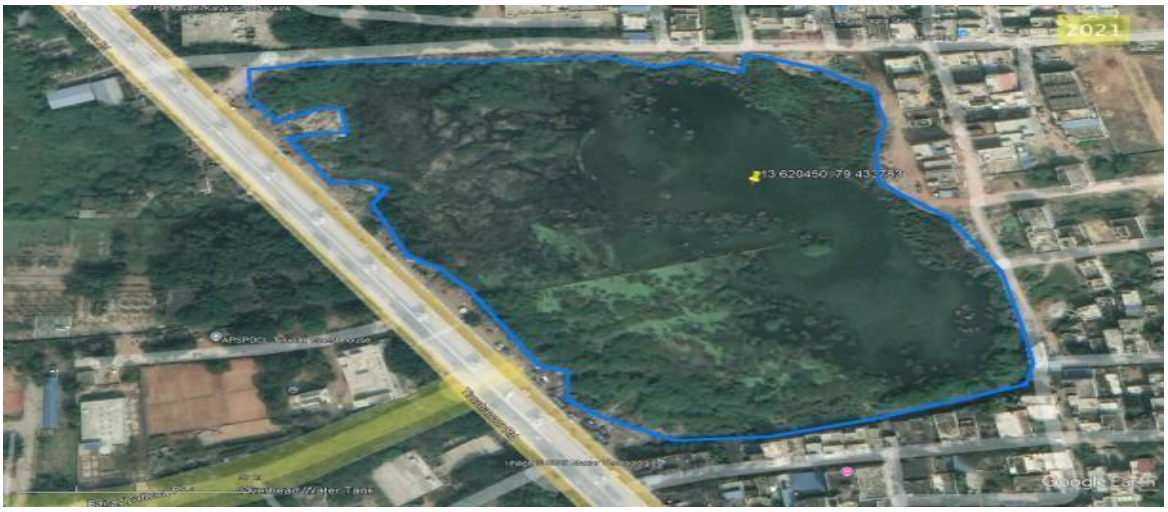


Fig. 8. Manually delineated lake boundary outline of Korramenugunta Lake, Tirupati, Andhra Pradesh, for the year 2019 (reference sample).



Fig. Manually delineated lake boundary outline of Korramenugunta Lake, Tirupati, Andhra Pradesh, for the year 2020

The following is the lake mask for the years from 2019 to 2025. These are the results generated by the Matlab programs.



Lake mask 2019



Lake mask 2020





Lake mask 2021



Lake mask 2022



Lake mask 2023



Lake mask 2024

Lake mask 2025

The following charts and graphs shows the summary of encroachment of Korramenugunta lake in Tirupati city from 2019 onwards

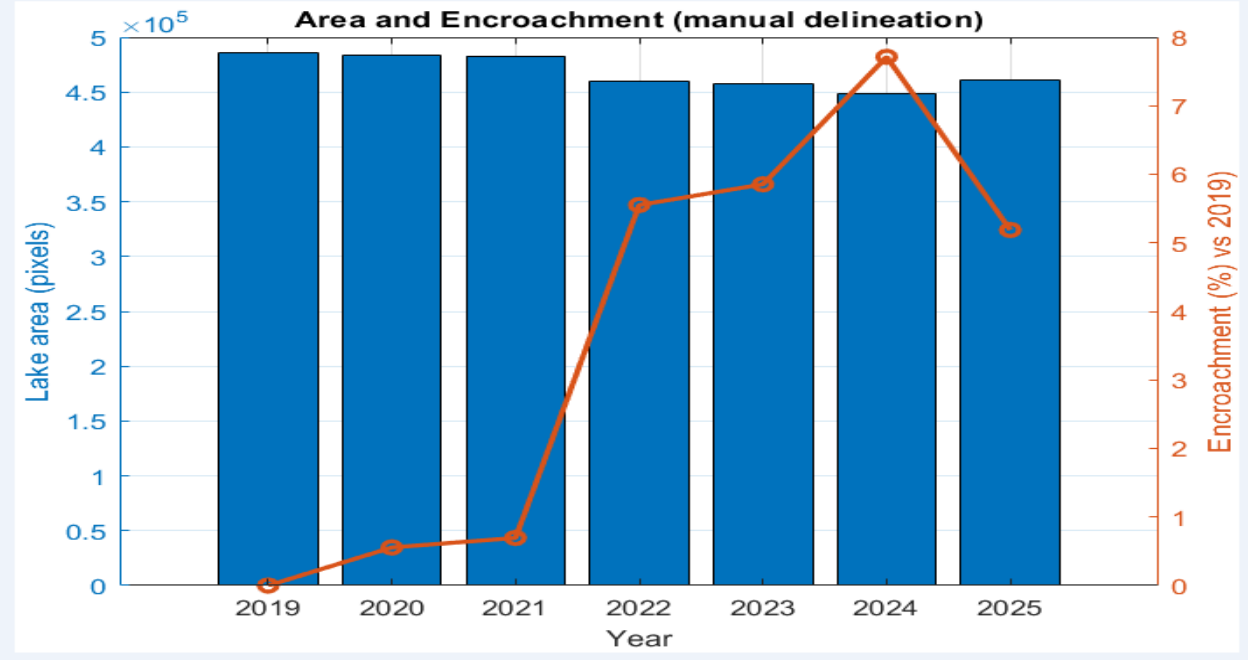


Fig. 10. Year-wise encroachment area of Korramenugunta Lake, Tirupati, Andhra Pradesh, from 2019 to 2025.

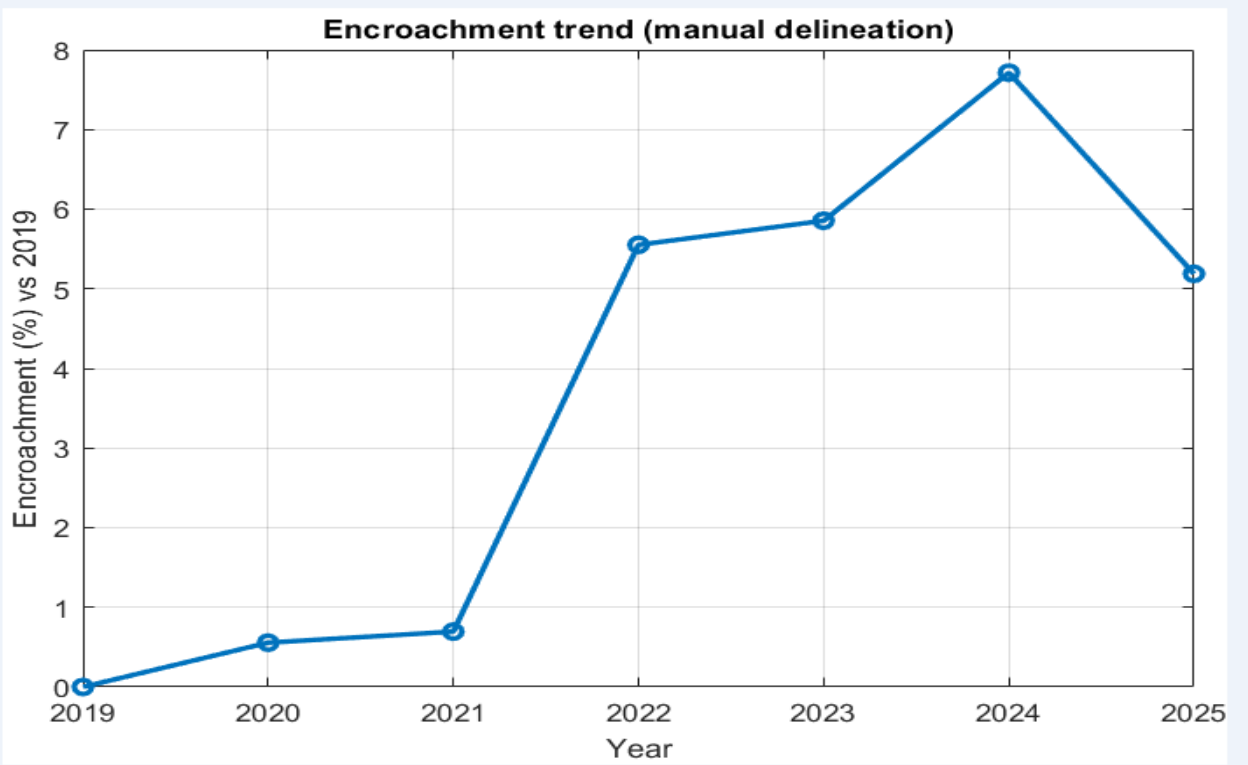


Fig. 11. Temporal trend of encroachment in Korramenugunta Lake, Tirupati, Andhra Pradesh, from 2019 to 2025.

QUANTITATIVE ASSESSMENT OF LAKE ENCROACHMENT

Reference Definition and Measurement Protocol

Reference Definition and Measurement Protocol. The lake boundary marked by hand to reflect the year 2019 was given as the reference for all subsequent measurements for the whole series of mapping. For each later year (2020–2025), each lake outline was hand-crafted independently on the high-resolution aerial image and was compared with the 2019 reference under a common spatial frame. This method minimizes the presence of uncertainties such as automated segmentation, lighting variation, as well as seasonal colour variation and thus, ensures that the predicted area changes represent the actual changes in the visible lake size. Encroachment was computed as the percentage loss of visible lake area relative to the 2019 reference of the lake area. This is a conservative surrogate for shoreline intrusion and long-term water-spread degradation. Percentage of Encroachment (Estimation). Assume A_{2019} represent the lake area recorded from the 2019 outline, and $A_y$represent the area corresponding with year y and the encroachment percentage for year y was calculated as follows:

$$\text{Encroachment}_{y}(\%) = \frac{A_{2019} - A_y}{A_{2019}} \times 100$$

The formulation ensures all reported values reach a single, physically meaningful baseline.

Table 1. Year-wise lake area and relative encroachment of Korramenugunta Lake with respect to the 2019 baseline.

Year	LakeAreaPixels	EncroachmentPercent_vs2019
2019	486325	0
2020	483621	0.55
2021	482945	0.69
2022	459325	5.55
2023	457853	5.85
2024	448812	7.71
2025	461093	5.18

INTERPRETATION OF ENCROACHMENT TRENDS

Quantitative results show that lake area shows a constant decrease across the six-year period of observation. Although the decline of 2019-2020 is modest, an acceleration of encroachment has been noted from 2021 onwards. This chapter of boundary displacement coincides neatly with the visible shoreline fragmentation and inward boundary migration which appears in areas adjacent to mass transit roads and densely built-up areas. The most significant area losses occur during the period of 2022–2024 and confirm prolonged anthropogenic pressure without temporal fluctuations for long lasting conditions, rather than rapid seasonality. By 2025 the lake stabilizes at a significantly lower size, indicating that a new equilibrium has been achieved under different land use condition. Crucially, the spatial integrity of manually drawn boundaries prevents such trends that are merely reflections of image processing.

METHODOLOGICAL JUSTIFICATION.

manual demarcation was the intention of this study, to stress the significance of boundary fidelity with automation being unnecessary. In high resolution urban aerial imagery, automated water segmentation is under a tremendous amount of the

influences of shadows, aquatic vegetation, turbidity, seasonal colour variations and seasonal colour change on artificial water segmentation, which usually result in non-stationary boundaries. The method presents conservative estimation of shoreline erosion consistent with reproducible, long-term environmental study assessment that is supported by human-mediated interpretation based on consistent visual parameters.

LIMITATIONS AND SCOPE

The percentages reported of encroachment are indicative of only relative variation in observed lake extent rather than total hydrological volume loss. This analysis does not deal with subsurface water holding and short-run seasonal depth change. Nevertheless, the trend of steady decrease in surface area over the consecutive years strongly suggests continued degradation of the lake system.

CONCLUSION

Water resources are the cornerstones of human life, agriculture and the ecosystem. Their protection has become more urgent in an age of city sprawl and uncontrolled land use. The extent of encroachment of Korramenugunta Lake in Tirupati city was assessed

in this study using temporal satellite data extracted from Google Maps. The progressive encroachment of the lake region in the period from 2019 to 2025 is clearly evident from this analysis. Matlab-based image processing techniques allowed for objective observation of changes in lake boundaries and comparison against the period of relative encroachment as estimated from each individual. These results show that encroachment increased significantly during 2024, suggesting that increased urban water use puts pressure on these resources. This method proves that periodic image analysis is feasible for longer-term monitoring of catchment water bodies. In addition, it becomes possible to extend this methodology to near real-time surveillance with the help of drone-based monitoring, where data can be collected repeatedly and actions can be tracked down before encroachment occurs. Satellite imagery combined with UAV technology is a promising instrument for the continuous monitoring of lakes and forest areas to establish an efficient policy approach for the administration and to ensure sustainable water management.

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Metamaterials and Metasurfaces for Terahertz Applications- A Comprehensive Review

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***Abstract*—**: Terahertz (THz) frequencies (0.1–10 THz) provide promising applications in imaging, sensing, and other fields by bridging the gap between the microwave and infrared domains including high-speed communications and spectroscopy. Because of inherent limitations like high loss and weak interaction with THz waves, conventional materials frequently fail to provide effective control at these frequencies. Beyond the limitations of natural materials, metamaterials and metasurfaces—artificially created structures with customized electromagnetic responses—have become essential tools for controlling THz waves. The basic concepts of metamaterials and metasurfaces, design techniques for THz operation, current developments in systems and devices, and potential future developments in THz technologies, including opportunities and challenges, are all covered in this review. Keywords—Metamaterial, Metasurface, Graphene, Sensing and Spectroscopy.

Keywords— Metamaterial, Metasurface, Graphene, Sensing and Spectroscopy.

I. INTRODUCTION

The microwave and infrared regions are separated by the terahertz (THz) frequency band (0.1–10 THz), which has special characteristics like high bandwidth, non-ionizing radiation,and robust interaction with molecular signatures. This makes it very appealing for sensing, wireless communication, spectroscopy, and imaging. However, the so-called "THz gap" results from natural materials' poor interaction and restricted control over THz waves. Artificially created materials, such as metamaterials and metasurfaces, have surfaced as innovative platforms to address this issue by customizing electromagnetic responses at THz frequencies beyond natural bounds. In order to enable phenomena like negative refraction, extreme wave control and subwavelength focusing, metamaterials were first conceptualized based on Veselago's theoretical work on negative permittivity and permeability [1]. Later, they were physically realized using resonant structures like splitring resonators (SRRs) [2], [3].

II. FUNDAMENTALS AND HISTORICAL PROGRESS

Periodic or quasi-periodic unit cells with specific effective electromagnetic properties make up metamaterials. Hu Tao et al. conducted early foundational research.He has created one of the first metamaterial absorbers that worked in the THz range, exhibiting strong resonant absorption by adjusting the unit cell's electric and magnetic responses separately [4]. Following that, Willie J. Padilla and Christopher Bingham investigated planar shaped metamaterials for multi-band resonances useful in THz devices using square and hexagonal lattice designs [5]. Theoretical reviews by Adnan Ali and Anirban Mitra deal with metamaterials from the viewpoints of materials, mechanisms, and device implementations together with these structural advancements, establishing the foundation for metadevice innovation [6]. Two-dimensional (2D) metasurfaces have emerged as planar analogues of three-dimensional (3D) volumetric metamaterials with lower loss and fabrication complexity, allowing for customized amplitude, phase, and polarization control at THz frequencies [7].

A. Wavefront Control And Metasurfaces

Compact devices for beam steering, focusing, and wavefront shaping are made possible by metasurfaces, which are planar arrays of subwavelength scatterers that can cause sudden phase shifts in incident waves [8]. A thorough review of THz metasurface design is given by Xiaofei Zang et al., who highlight how planar structures enable ultra-compact THz components and locally alter wavefronts at subwavelength resolution [8].

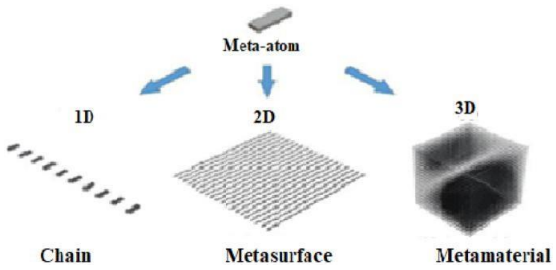


Fig 1: Formation of metamaterial and metasurfaces from meta atom

Advanced THz metasurfaces are based on phase-gradient design principles, as shown in the figures from this work. Moreover, metasurfaces that interface with tunable 2D materials like graphene and phase-change materials like VO_2 provide dynamic control of THz responses, enabling active functions not possible with traditional optics [8].

B. Materials And Design Techniques

Materials are critical to the performance of THz metamaterials and metasurfaces. The majority of metamaterial components were initially made of metals, but research into substitute materials was inspired by the high ohmic loss at THz frequencies. To improve efficiency and lower losses, all-dielectric metasurfaces (such as silicon-based designs) have been suggested [9]. Due to its tunable surface conductivity, graphene has attracted a lot of attention recently. Active modulation and modifications are made possible by integrating graphene with metamaterial structures [10], [11].

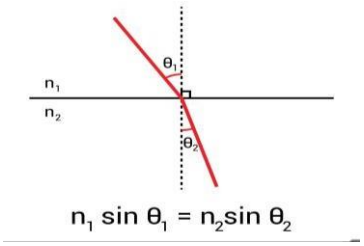


Fig 2: Snell's Law

For example, using graphene's electrical tunability for terahertz beam steering, Seyed Ehsan Hosseininejad and teammates demonstrated digital coding metasurfaces with dynamic adaptability across phase states [10].

C. Tunable And Reconfigurable Thz Metadevices

THz Metadevices that can be adjusted and modified Furthermore, Fano resonances and active THz response control have been investigated for channeled graphene layers interacting with metal resonators [11].

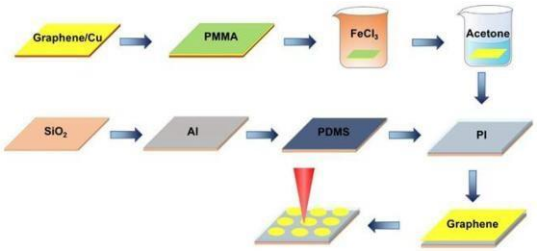


Fig 3: Graphene making process

Adaptive systems in imaging and communication depend on dynamic THz device control. Electrical tuning of metamaterial resonances is made possible by the combination of hybrid structures (graphene/gold bilayers) and phase-change materials such as VO_2. A graphene/gold bilayer metasurface outperformed graphene-only or metal-only designs by showing tunability exceeding 95% with low bias in groundbreaking experimental work [12]. Hosseininejad et al. also created a graphene-based metasurface mirror with adaptive focal points for THz imaging, exhibiting near-diffraction-limit focus and adaptability, which is a crucial step toward adaptable THz optics [13].

D. Wave Manipulation, Modulators, And Absorbers.

Absorbers were among the first THz metamaterials demonstration targets. By matching impedance to free space and taking advantage of resonant elements that trap incident energy, metamaterial absorbers achieve nearly perfect absorption. Aiming for high-performance sensors and switches, research on patterned graphene metamaterial absorbers has demonstrated tunability in resonant peaks through chemical doping and pattern variations [14]. Additionally, THz modulators based on metasurfaces accomplish phase and amplitude modulation of incident THz waves, which is essential for signal processing and communication systems [15]. Using hybrid metal-graphene structures, advanced metamaterial designs also investigate equivalents of electromagnetically induced transparency (EIT), where slow light and enhanced nonlinear effects are made possible by active modulation of EIT resonance [16].

***E.* Applications of Sensing And Spectroscopy**

By focusing on electromagnetic fields at resonances, THz metamaterials have significantly improved sensing capabilities, enabling the highly sensitive detection of small environmental changes (such as refractive index shifts). Design theories, optimization techniques, and useful measures of performance are highlighted in a recent review on THz metamaterial sensors, showing how metamaterials improve sensor performance beyond the bounds of traditional THz spectroscopy [17]. By utilizing resonances like electromagnetically induced transparency, Fano, and bound states in the continuum (BIC) to maximize signal sensitivity, a parallel field of biosensing uses metamaterials for label-free biological analyte detection [18 Applications ranging from environmental monitoring to biochemical detection depend on these advancements. Research has advanced toward new structural paradigms and functional improvements beyond 2D metasurfaces. Chiral and bianisotropic responses that are not achievable with planar structures are made possible by three-dimensional (3D) metamaterials with rolled-up micro- and nano-resonators, which provide extra degrees of freedom for polarization control and complex wave manipulation [19]. In the meantime, reviews of high-performance THz spectrum modulation emphasize new applications like filters, absorbers, and multifunctional sensors as well as developing structural designs like metal-dielectric composites, all-dielectric components, and flexible materials [20]. In order to demonstrate how far the field has advanced, S. Zhu et al. (2021) offered a thorough survey of design strategies, fabrication methods, and real-world applications of THz metasurfaces [21 Building on these discoveries, multifunctional and programmable terahertz metasurfaces with dynamic amplitude, phase, and polarization control were described by H. Tian et al. [22]. The work of M. Zhang et al. on programmable metasurfaces that enable real-time manipulation of electromagnetic fields in the THz regime [23] further illustrates the shift toward active control.Y. Zhou et al. reported graphene-based tunable THz metasurface absorbers, highlighting the responsiveness of 2D materials for dynamic THz applications [24]. Graphene tunability is still a major theme. A. Fallahi and J. Perruisseau-Carrier demonstrated scalable methods for THz control by expanding design techniques for tunable metasurfaces using graphene [25]. Q. Zeng et al. proposed multi-resonant metasurfaces that combine multiple resonator modes to achieve wideband THz absorption for broadband operation [26].. All-dielectric metasurfaces have matured as competitive platforms for low-loss THz wavefront manipulation. W. Ma et al. demonstrated dielectric metasurface designs tailored for phase

control without the inherent losses of metals [27]. Review articles by R. Singh et al. (2021) summarize the state of active THz metasurfaces, documenting strategies for tunable responses and device integration [28].

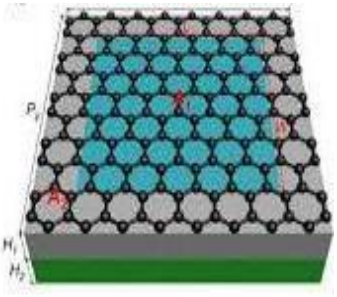


Fig 4: Graphene layout

THz metamaterial sensors have continued to garner interest in terms of applications. In their review of recent developments and prospects for terahertz sensors based on metamaterial architectures, D. Wang et al. (2023) emphasized performance metrics and design optimizations [29]. Furthermore, Y. Li et al. investigated programmable and intelligent metasurfaces for THz communications, suggesting integration with upcoming wireless systems like 6G [30].

Author(s)	**Year**	**Title**	**Key Observations**	**Applications**
V. G. Veselago	1968	Electrodynamics of substances with negative ε and μ	Proposed negative permittivity and permeability concepts	Foundation of metamaterials
J. B. Pendry	2000	Negative refraction makes a perfect lens	Introduced split-ring resonators and perfect lens theory	Super-resolution imaging
D. R. Smith et al.	2000	Composite medium with negative ε and μ	First experimental realization of negative-index metamaterials	EM wave manipulation
B. Ferguson, X.-C. Zhang	2002	Materials for terahertz science	Identified THz gap and material limitations	THz imaging, spectroscopy
M. Nagel et al.	2002	THz biosensing using resonators	Achieved femto molar sensitivity using planar resonators	Biosensing
H.-T. Chen et al.	2006	Active terahertz metamaterial devices	Demonstrated tunable THz metamaterials	THz modulators
M. Tonouchi	2007	Cutting-edge terahertz technology	Overview of THz sources, detectors, and applications	THz system development
N. I. Landy et al.	2008	Perfect metamaterial absorber	Achieved near-unity absorption via impedance matching	THz absorbers
H. Tao et al.	2008	THz metamaterial absorber	Polarization-insensitive absorption behavior	Imaging, sensing
C. M. Bingham et al.	2008	Planar wallpaper group metamaterials	Multi-band resonant behavior in THz	Filters, modulators

Author(s)	Year	Title	Key Observations	Applications
L. Ju et al.	2011	Graphene plasmonics for THz	Demonstrated tunable graphene plasmon resonances	Tunable THz devices
C. L. Holloway et al.	2012	Overview of metasurfaces	Defined metasurfaces as 2D metamaterials	Flat THz components
B. Sensale-Rodriguez et al.	2012	Graphene THz modulators	Achieved broadband electrical modulation	THz communications
N. Yu, F. Capasso	2014	Flat optics with metasurfaces	Introduced generalized Snell's law	Beam steering, lenses
T. J. Cui et al.	2014	Coding metamaterials	Introduced digital and programmable metasurfaces	Smart EM systems
A. I. Kuznetsov et al.	2016	Dielectric metasurfaces	Demonstrated low-loss dielectric resonators	Efficient THz optics
I. F. Akyildiz, J. M. Jornet	2016	THz wireless communication	Highlighted THz potential for future networks	6G communications
S. E. Hosseininejad et al.	2019	Digital graphene metasurfaces	Enabled programmable THz beam steering	Reconfigurable THz optics
D.-K. Lee et al.	2019	THz metamaterial biosensor	Label-free sensing using resonance shift	Biomedical sensing
H. Tian et al.	2020	Multifunctional THz metasurfaces	Programmable amplitude and phase control	THz imaging, modulation
S. Zhu et al.	2021	Progress in THz metasurfaces	Reviewed design and fabrication strategies	THz wave manipulation
M. Zhang et al.	2021	Programmable THz metasurfaces	Real-time electromagnetic control	Adaptive THz devices
Y. Zhou et al.	2021	Graphene THz absorbers	Electrically tunable absorption peaks	Sensors, absorbers
W. Ma et al.	2021	All-dielectric THz metasurfaces	Loss-reduced wavefront manipulation	High-efficiency optics
R. Singh et al.	2021	Active THz metasurfaces	Review of tunable THz metadevices	Modulators, switches
A. Fallahi, J. Perruisseau-Carrier	2022	Tunable graphene metasurfaces	Scalable tunable THz designs	Beam control
Q. Zeng et al.	2022	Broadband THz absorbers	Multi-resonant broadband absorption	Sensing, stealth
D. Wang et al.	2023	THz metamaterial sensors	Reviewed sensing enhancement mechanisms	Gas and biosensing
Y. Li et al.	2023	Intelligent THz metasurfaces	Programmable metasurfaces for THz links	6G, smart environments

Table 1: Evolution of Metamaterials and Met surfaces for terahertz applications

III CONCLUSION

The development of metamaterials and metasurfaces for terahertz applications, from early resonant structures to more recent variable and tunable designs, was examined in this paper. Compact, effective, and multipurpose THz devices have been made possible by the transition from three-dimensional metamaterials to planar metasurfaces. Dynamic control, bandwidth, and loss performance have been greatly enhanced by the use of tunable materials like graphene and the creation of all-dielectric metasurfaces. Promising applications in sensing, imaging, absorption, and terahertz communication systems have resulted from these developments. To further improve the practical implementation of terahertz technologies, future research is expected to concentrate on intelligent, adaptable metasurfaces and scalable fabrication techniques.

IV FUTURE SCOPE

Key challenges remain in THz metamaterials and metasurfaces research, notably reducing losses in metallic components, achieving large-area fabrication with reproducibility, and developing ultra-fast tunability across broad spectral ranges. Emerging materials (e.g., MoS_2, hybrid nanocomposites) and advanced fabrication strategies (e.g., AI-assisted inverse design, programmable metasurfaces) are poised to address these limitations. At the system level, integrating THz metamaterials with next-generation wireless technologies (e.g., 6G), compact imaging systems, and environmental sensing networks will likely shape future research directions.

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Surveillance Drone for Intelligent Monitoring Applications

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Abstract-Surveillance drones have become increasingly important due to their ability to capture aerial footage, access remote zones, and support real-time monitoring. This paper presents the design, development, and testing of a student-built quadcopter-based surveillance system. The project focuses on assembling essential UAV components, stabilizing the aircraft through PID tuning, and integrating a lightweight camera for real-time recording. The drone was tested in open environments to evaluate its stability, flight duration, and imaging output. Experimental results confirmed that the drone could hover steadily, capture clear aerial footage, and perform short-range surveillance tasks effectively. This project strengthened our practical knowledge in embedded systems, aerodynamics, and communication technologies while successfully delivering a functional surveillance solution.

Keywords— UAV, Surveillance Drone, Real-Time Monitoring, Autonomous Flight, Quad-Copter, Wireless Control, Embedded Systems.

I. INTRODUCTION

Drones have emerged as one of the most significant technological tools in modern surveillance systems. Traditional CCTV cameras have fixed fields of view and cannot cover large or inaccessible areas. In contrast, drones provide mobility, flexibility, and a bird's-eye perspective, making them suitable for security surveillance, disaster assessment, agriculture monitoring, and inspection tasks.

As engineering students, our objective was to design and assemble a complete UAV from scratch. We planned to understand the function of each component, carry out calibration, tune flight stability, and integrate a camera for real-time monitoring. This project not only enhanced our practical skills in electronics and communication systems but also exposed us to real-time problem-solving scenarios such as balancing the center of gravity, controlling vibrations, and adjusting PID parameters.

With the rapid growth of unmanned aerial technology, drones are now widely adopted in both civilian and industrial applications. Their ability to capture real-time aerial data makes them ideal for tasks requiring quick visual access and broader coverage. Developing a drone at the student level allowed us to explore fundamental engineering concepts while practically understanding flight dynamics, sensor integration, and wireless control essential for modern surveillance solutions.

II. COMPONENTS AND SPECIFICATIONS

A. Major Components Used

Table I lists the components we selected for our surveillance drone based on affordability, availability, and required performance.

Table I — Components used in the drone

Component	Specification / Purpose
Frame	Standard Quadcopter X-Frame
Motors	2200KV Brushless DC Motors
ESCs	30A Electronic Speed Controllers
Flight Controller	Stabilization & Motor Control
Propellers	1045 Propellers (CW + CCW)
Battery	3-Cell Li-Po Battery (2200mAh)
Receiver	6-Channel 2.4GHz RX
Transmitter	6-Channel 2.4GHz Radio TX
Camera	Lightweight FPV/HD Camera



Figure 1: QuadCopter Surveillance Drone

The image highlights the major components of the drone such as the frame, brushless motors, propellers, ESC connections, landing gear, and the camera mounting area in the front. The compact arrangement of components ensures proper weight balance, which is crucial for stable flight. This picture demonstrates the final physical implementation of the system after assembly and calibration, validating the design choices listed in Section II.

B. Reason for Component Selection

We selected a 2200KV motor–propeller combination to achieve sufficient thrust while maintaining lower power consumption. The Li-Po battery offered higher discharge rate indispensable for quadcopter lift. The flight controller allowed easy PID tuning and helped stabilize the drone during strong wind disturbances.

III. SYSTEM ARCHITECTURE

The block diagram represents the overall working architecture of our surveillance drone.



Block Diagram 1: Block Diagram of Drone Flight Control System



Block Diagram 2: Block Diagram of Drone Camera and Video Processing System

The block diagram of our surveillance drone represents the overall working mechanism of the system, starting from the user input at the remote controller to the final thrust generation by the motors. It also includes a separate

camera subsystem for capturing aerial footage and generating live video output. The detailed explanation of each block is given below.

1. Remote Controller
The Remote Controller is the starting point of the entire system. It is a handheld RF transmitter operated by the user to control the drone's movement. Using the joysticks, the user sends commands such as:

- Take-off and landing
- Forward, backward movement
- Left/right turn
- Increase or decrease altitude

These commands are sent as 2.4 GHz radio signals to the receiver on the drone.Role: Initiates all flight-related commands.

2. Receiver
The Receiver module is mounted on the drone and continuously listens for incoming signals from the transmitter. Its main roles are:

- Receiving the RF signal
- Decoding the signal into channel-specific output
- Passing the signal to the flight controller

The receiver converts the wireless signal into a format that the flight controller can interpret instantly.
Role: Acts as the communication bridge between the user and the drone.

3. Flight Controller
The Flight Controller is the brain of the drone. It processes the signals from the receiver and constantly monitors:

- Drone's orientation
- Stability
- Gyroscope reading
- Accelerometer reading

Based on the received commands and sensor data, it decides how much each motor should rotate.

Key functions include:

- Stabilizing the drone using PID algorithms
- Calculating required thrust and direction
- Maintaining balance in windy conditions
- Controlling the speed of each motor independently

Role: Makes real-time decisions to keep the drone stable and responsive.

4. Electronic Speed Controllers (ESCs)
The ESCs are responsible for controlling the speed and power supplied to each brushless motor.
Key functions:

- Receive control signals from the flight controller
- Convert these commands into electrical pulses
- Adjust the motor's RPM according to the required motion
- Ensure smooth acceleration and deceleration

Each motor has its own ESC, preventing overload and ensuring safe power distribution.
Role: Converts controller decisions into regulated motor speed.

5. Motors
The drone uses four brushless DC motors, arranged in an X-configuration. Each motor contributes to:

- Lift generation
- Direction control
- Hovering stability

Two motors rotate clockwise (CW) and two rotate counter-clockwise (CCW) to balance torque. Different combinations of motor speeds determine movements like:

- Rising (all motors speed up)
- Yawing (opposite motors speed up)
- Forward flight (rear motors speed up)

Role: Generate rotational force required for lift and maneuvering.

6. Thrust Output

The final output of the propulsion system is thrust. Thrust is created by the propellers based on motor rotation. Thrust determines:

- Whether the drone takes off
- How stable it stays in air
- Direction of movement
- Height and speed of mission

The quality of thrust output affects the camera stability and overall surveillance quality. Role: Converts electrical and mechanical energy into upward lift.

1. Camera Module

The Camera Module is mounted on the front side of the drone. It is responsible for capturing:

- Images
- Videos
- Live surveillance feed

It operates independently of the propulsion flow but works simultaneously. Role: Acts as the primary surveillance tool.

2. Image Capture Unit

Once the camera captures visuals, the image capture unit processes them in real time. Depending on the camera type, it may:

- Stabilize video
- Reduce noise
- Adjust brightness
- Capture continuous frames

Role: Converts raw visuals into usable footage.

3. Storage / Live Feed Output

The processed footage is then:

- Stored on an SD card, or
- Transmitted to a ground-based receiver for live monitoring Live feed allows the operator to see what the drone sees in real time.

Role: Makes the surveillance functional and real-time.

A. Flight Controller Operation

The flight controller interprets input signals, stabilizes the drone through gyroscope and accelerometer readings, and adjusts motor speeds accordingly.

B. Propulsion System

Four brushless motors arranged in an X-configuration generate lift. Adjacent motors rotate in opposite directions (CW & CCW) to ensure angular balance.

C. Camera Integration

We mounted a lightweight camera on the front section of the frame. During flight tests, the camera captured real-time video which was later reviewed for surveillance clarity.

IV. METHODOLOGY

A. Assembly Process

We began by assembling the frame and attaching motors in appropriate positions. ESCs were fixed onto the arms, and wiring was arranged to avoid entanglement with propellers. The battery was placed at the center to maintain balance.

B. Calibration and PID Tuning

During initial flights, the drone drifted to one side which indicated improper PID configuration. We corrected this by:

- Increasing P-gain for stability
- Adjusting I-gain to maintain hover
- Reducing D-gain to avoid motor vibrations

After fine-tuning, the drone hovered smoothly without drifting.

C. Test Flights

The drone underwent several outdoor test flights. We evaluated:

- Hover stability
- Motor response delay
- Maximum control range
- Battery consumption
- Camera clarity during vibrations

V. RESULTS AND OBSERVATIONS

Table II — Performance analysis

Parameter	Result
Hover Stability	Stable after PID tuning
Flight Duration	12–15 minutes
Control Range	80–100 meters
Camera Quality	Clear & steady
Weight Balance	Achieved after centre adjustment

A. Aerial Footage

The drone successfully captured high-quality aerial photos and videos.Vibrations slightly affected the footage during takeoff, but stabilized during mid-air hover.

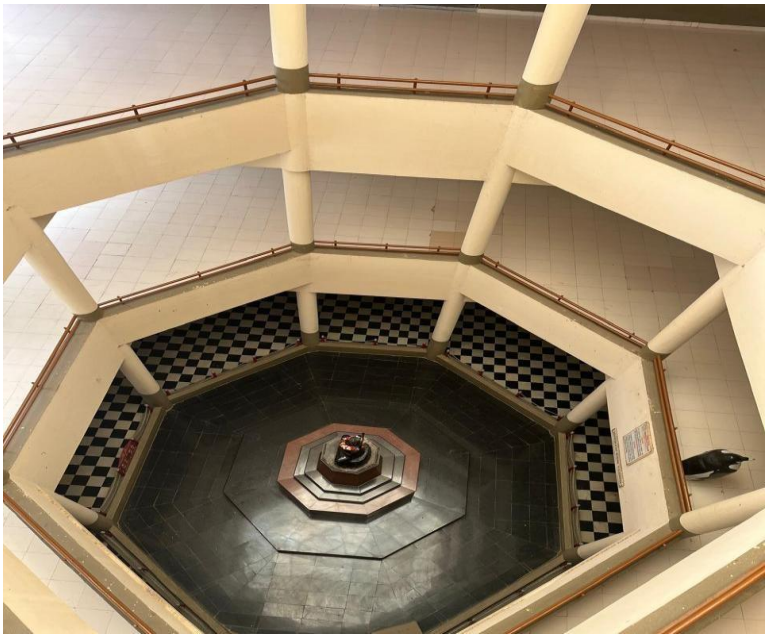


Figure 2: Aerial view

This image confirms the clarity and stability of the camera output even when the drone was hovering at a moderate altitude. The picture captures a wide area from an elevated perspective, proving the usefulness of the system for real-time surveillance, monitoring open fields, and observing areas that are difficult to monitor from the ground. This validates the camera integration and stability discussed in Section V-A.

B. Flight Performance

The drone showed strong thrust and responded instantly to commands. It maintained balance even during moderate wind, proving the effectiveness of our PID-tuning effort.

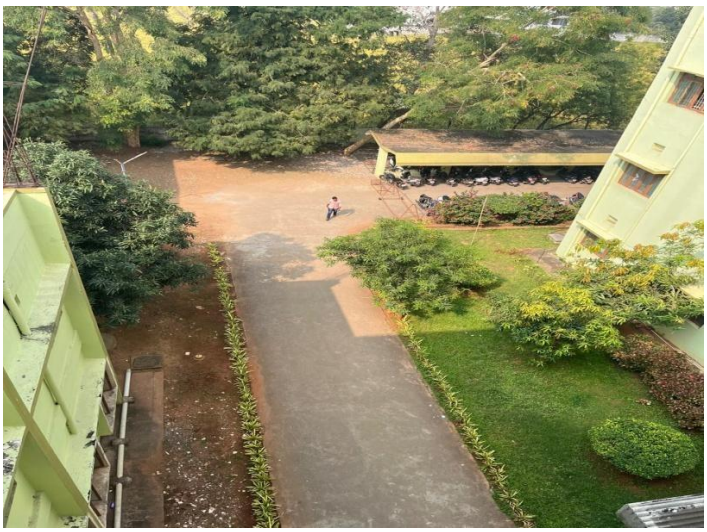


Figure 3:Drone capturing

It provides evidence that the drone was functioning as intended, with the propellers generating sufficient lift and the flight controller maintaining balance. The active camera module is visible in the image, showing how live footage and images were recorded during flight. This image supports the test results and observations explained in Section V-B.

VI. CONCLUSION

This project gave us a complete hands-on understanding of drone engineering and surveillance applications. We successfully assembled a functioning quadcopter, achieved stable flight, and integrated a camera capable of capturing useful aerial footage. Working on this drone improved our skills in electronics, wireless communication, soldering, PID tuning, and aerodynamics. Although the flight time was limited by battery capacity, the overall outcome was successful.

In the future, features such as GPS navigation, autonomous flight paths, obstacle detection, thermal imaging, and AI-based object tracking can significantly enhance the drone's capabilities. This project serves as a strong foundation for building advanced UAV-based surveillance systems.

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Adaptive Security-Energy Optimization Framework or Wireless Sensor Networks

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***Abstract*—**The Adaptive Security-Energy Optimization Framework (ASEOF) for Wireless Sensor Networks (WSN) is a novel approach that combines security and energy efficiency in WSNs. It integrates a dynamic security protocol switching mechanism, context-aware energy management, decentralized threat detection, and adaptive network configuration. ASEOF is particularly suitable for applications requiring prolonged operational periods without sacrificing data security, such as environmental monitoring, smart infrastructure, healthcare, and precision agriculture. Simulations were conducted to compare ASEOF with four standard WSN protocols: Direct Transmission (DT), Minimum Transmission Energy (MTE), Low-Energy Adaptive Clustering Hierarchy (LEACH), and Hybrid Energy-Efficient Distributed clustering (HEED). Key findings showed superior energy efficiency, scalability, data delivery ratio, and security score. ASEOF demonstrated superior energy efficiency, scalability, data delivery ratio, and security score. This model significantly enhances the security and energy efficiency of WSNs, addressing challenges in deploying these networks for long-duration applications. ASEOF offers a scalable, secure, and energy-efficient solution that outperforms existing protocols across critical performance metrics, making it a promising foundation for the next generation of WSN applications.

Keywords: context-aware energy management, decentralized threat detection, scalability, security, wireless sensor networks.

I.INTRODUCTION

WSNs have inherent resource constraints, including restrictions on energy, processing power, and storage. Even though they provide strong security, traditional security measures frequently have a large energy and computational overhead, which shortens the network's operating lifespan. On the other hand, energy-saving techniques could jeopardize security by decreasing update frequency, utilizing less robust but lighter encryption techniques, or streamlining authentication procedures [1]. A dynamic method that skillfully strikes a balance between energy efficiency and security based on an in-the-moment evaluation of threat levels and network conditions is the need of the hour.

The development of WSNs has recently been oriented toward improving network capacities to accommodate sophisticated applications that require greater data rates, wider coverage regions, and stricter security specifications. WSN integration into larger communication networks has been expedited by the emergence of the Internet of Things (IoT), increasing the stakes for energy efficiency and security [2]. Scalability, interoperability, and heterogeneous device management are some of the challenges that make WSN deployment and operation more difficult. Furthermore, because cyber threats are constantly changing, security solutions must be flexible enough to fend off advanced attacks without jeopardizing network performance [3]. Energy efficiency is paramount in WSNs due to the limited power resources of sensor nodes, which are often battery-operated and deployed in inaccessible areas. The primary goal is

to prolong network lifetime while maintaining operational functionality, requiring innovative approaches to minimize energy consumption across various network operations [4]. Duty cycling minimizes energy usage by alternating nodes between active and sleep states, ensuring that only a necessary subset of the network is operational at any given time. By selecting paths that minimize energy consumption, taking into account the residual energy of nodes to balance the load and prevent early depletion of any single node, the energy consumption can be minimized. Data aggregation reduces the amount of data transmission by combining data from multiple sensors at intermediate nodes, thereby conserving energy that would be used in communication [5-6].

The Adaptive Security-Energy Optimization Framework (ASEOF) for WSNs is designed with the following major objectives.

1. To provide dynamic balance between security and energy efficiency by introducing intelligent mechanisms that adjust security protocols and energy usage in real-time based on the current threat landscape and operational conditions.
2. To provide enhanced network scalability and performance retention by employing adaptive network configuration and routing optimizations, along with decentralized threat detection mechanisms. This ensures that the network can scale up to accommodate growth while maintaining optimal performance in terms of latency, throughput, and data delivery ratios.
3. To provide decentralized threat detection and rapid response times to threats, as local nodes can take immediate action based on predefined security protocols or alert the network to escalate the response as necessary.

I. EXISTING WORKS

Energy efficiency is paramount in extending the operational lifespan of WSNs. Research in this area focuses on optimizing the energy consumption of sensor nodes, which are often battery-powered and deployed in inaccessible areas, making energy replenishment impractical. Duty cycling-based approaches are a practical solution for the energy constraints of Wireless Sensor Networks (WSNs). S-MAC uses fixed listen and sleep schedules to conserve energy, but its static scheduling may not be optimal under varying network conditions or traffic loads. T-MAC introduces an adaptive duty cycle mechanism, shortening the active period if no communication activity is detected within a predefined timeout period. This improves energy efficiency, especially in networks with sporadic traffic patterns.

B-MAC, introduced by Berkeley MAC, introduces a more flexible approach by allowing nodes to determine their sleep and wake-up schedules based on local conditions. Zebra-MAC, a hybrid protocol, combines the strengths of TDMA and CSMA approaches, operating primarily in a TDMA mode under low traffic conditions for energy efficiency but can switch to CSMA mode in high traffic scenarios [7]. LEACH, a cluster-based data transmission approach, incorporates duty cycling principles in its cluster-based data transmission. As WSN applications continue to expand, the development of more sophisticated duty cycling strategies that can dynamically adapt to varying conditions and traffic patterns remains an active and crucial area of research [8].

Energy-aware routing protocols in Wireless Sensor Networks (WSNs) aim to optimize energy consumption during data transmission, extending the operational lifespan of the network. These protocols include Minimum Transmission Energy (MTE) routing, Low-Energy Adaptive Clustering Hierarchy (LEACH), Hybrid Energy-Efficient Distributed Clustering (HEED), Power-Efficient Gathering in Sensor Information Systems (PEGASIS), and Geographic Adaptive Fidelity (GAF).

MTE routing focuses on minimizing energy consumption during data transmission by calculating the energy cost of transmitting data packets from source nodes to the destination [9]. Power management techniques such as energy harvesting, where nodes are equipped to gather energy from environmental sources (solar, thermal, vibrational), offer promising avenues for sustainable WSN operations [10]. Energy harvesting is an emerging power management technique that allows sensor nodes to gather energy from their environment, such as solar power, thermal gradients, vibrations, or wind. This provides a renewable energy source for the sensor network, potentially enabling indefinite operation. However, it requires additional hardware complexity and efficient energy storage solutions.

Cross-layer optimization coordinates power management strategies across different network protocol layers, integrating considerations from the physical, MAC, and network layers. This technique optimizes overall energy usage

by leveraging synergies between network functions and operations. Effective power management in Wireless Sensor Networks is crucial for network longevity and operational efficiency. As WSNs grow in complexity and scale, developing and implementing advanced power management techniques will remain a key area of research and innovation [11-13].

Security in WSNs encompasses ensuring data confidentiality, integrity, and availability, alongside safeguarding against node capture and replay attacks, among other threats. The constrained nature of WSNs, however, limits the applicability of traditional, resource-intensive security measures. Research efforts have focused on developing lightweight cryptographic algorithms suitable for WSNs. Lightweight cryptographic protocols are designed to provide security solutions for Wireless Sensor Networks (WSNs), which are devices with limited computational power, memory, and energy resources. These protocols aim to provide confidentiality, integrity, and authentication while minimizing computational overhead and energy consumption [14-16].

II. SYSTEM DESIGN

ASEOF is a flexible and vital tool for protecting and enhancing WSNs in a wide range of applications. ASEOF employs a range of cryptographic algorithms and security protocols to enable dynamic security protocol switching. It determines which protocol is most suitable for a given threat landscape and network conditions. This method optimizes energy utilization without compromising security by enabling the deployment of heavier security procedures during high-risk periods and lighter protocols during lower threat levels, namely, context-aware energy management, decentralized threat detection and response, adaptive network configuration. The overall process flow in the proposed model is illustrated in Fig. 1.

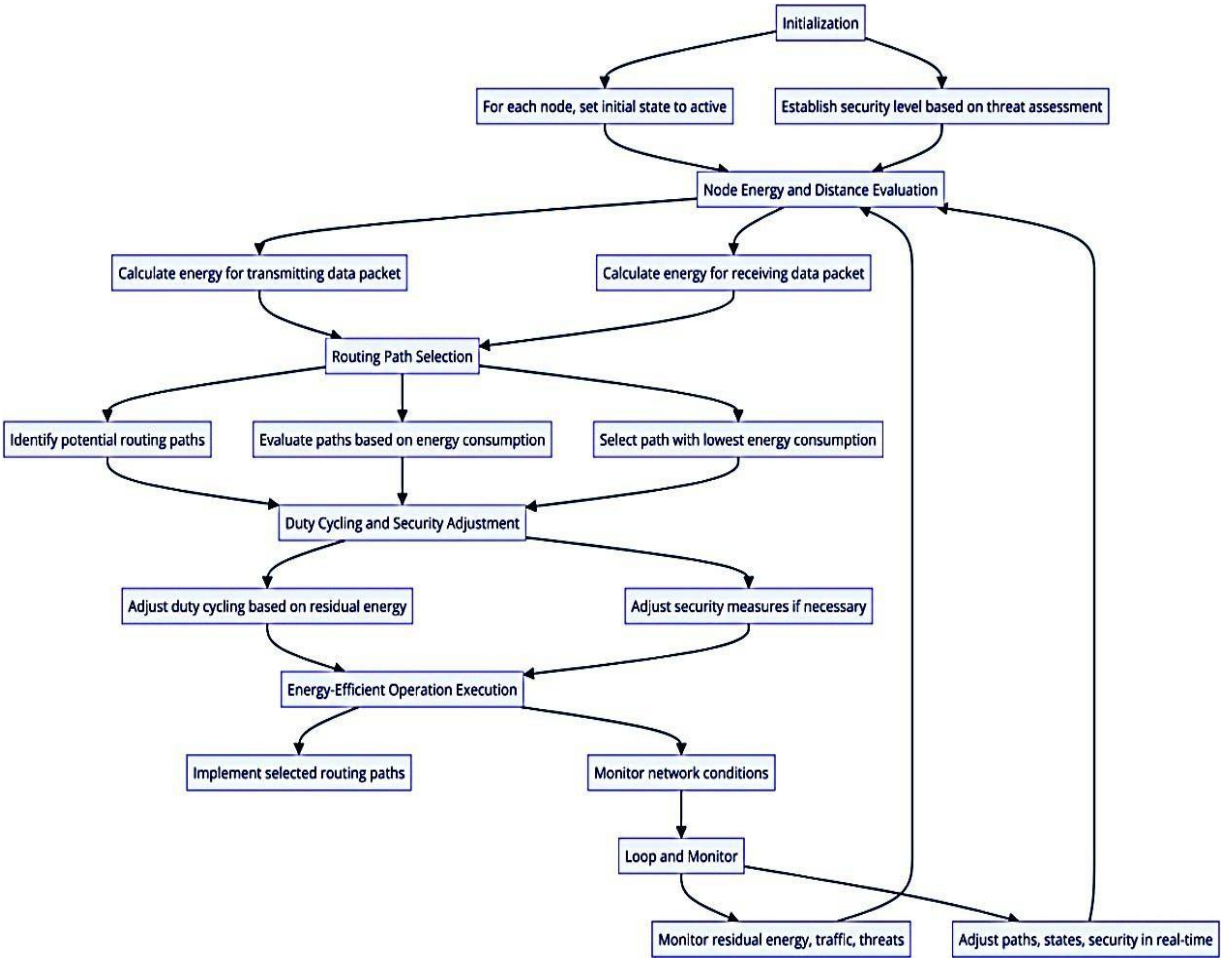


Fig.1 Flowchart indicating the process of energy efficient operation in the proposed method.

Let N be the set of nodes in the network. The initial energy of the node i be denoted as E_i. Let the distance between nodes i and j be denoted as D_{ij}. The minimum acceptable security threshold be T and be the packet size in bits. The data transmission rate in terms of bits per second is denoted as R. Let M represents the set of operating modes such as active, sleep, idle etc, with each mode $m_j \in M$ having distinct energy consumption rate. The energy consumption of node n at time t is given by $E_n(t)$. Let S be the set of all available security protocols. The energy required for transmitting a data packet from node i to node j is given by

$$E_{tx}(i,j) = E_{elec} \times L + \epsilon_{amp} \times L \times D^2_{ij} \quad (1)$$

where E_{elec} is the energy dissipated for transferring one bit of information and ϵ_{amp} is the energy dissipated per bit per square meter for the amplifier. The energy required to receive a data packet at node j is given by

$$E_{rx}(j) = E_{elec} \times L \quad (2)$$

In the proposed model, the potential routes for source to destination are identified before the transmission begins. Each path is evaluated based on the cumulative energy consumption considering both E_{tx} and E_{rx} . The path with the lowest energy consumption that do not compromise security level S is considered. The protocol in the proposed method then dynamically adjusts the duty cycling of the nodes based on their residual energy and current network demands. The mode selection criteria is given by

$$m_n^* = \arg\min_{m_j \in M} \{ECM_j \mid E_n(t) - ECM_j \cdot \Delta t > E_{critical}\} \quad (3)$$

ECM_j is the distinct energy consumption rate of node j. $E_{critical}$ is the minimum energy threshold to avoid node failure and Δt is the time duration for the next mode evaluation. The protocol $k \in S$ has an associated security level SL_k and associated energy consumption EC_k. The threat level at time t is denoted by TL_t. The objective function for protocol selection is given by

$$s^* = \arg\min_{s_k \in S} \{EC_k \mid SL_k \geq f(TL_t)\} \quad (4)$$

Each node in the network maintains a trust score TS which is updated based on the local observations and communications with the neighboring nodes. This update function is given by

$$TS_k(t+1) = g((TS_k(t), \{TS_{neighbors}(t)\}, local\ observations \quad (5)$$

The desired security level $S_{desired}$ based on the latest threat assessment is determined and this level is adjusted for every node i using the following equation.

$$F_i = \frac{E_i}{E_{total}} \times (S_{desired} - S_{current} \quad (6)$$

where F_i is the security adjustment factor, and E_{total} is the total residual energy of the network. The security routing cost considering both communication cost and the adjusted security level is given by

$$R_{ij} = C_{ij} + \lambda \times (S_{max} - S_i) \quad (7)$$

where λ is the weighting factor that balances the energy and security constraints

III. RESULTS

The performance of the proposed model is evaluated using an Intel Core i7-10750H processor, 24 GB DDR4 RAM, 1 TB SSD storage, and a dedicated GPU. Operating systems include Windows 10. Fig 3 illustrates the comparative analysis of the data delivery rates between the standard existing methods and the proposed method.



Fig.2 Comparison of energy efficiency between standard methods and the proposed method.

The proposed model outperforms the other methods by optimizing data transmission while balancing energy consumption and security requirements. It prioritizes optimal routing paths based on cumulative energy consumption, ensuring reliable and fast paths. The model calculates energy consumption for both transmission and reception, considering the distance between nodes and data packet size. This helps maintain high data delivery rates by avoiding overburdening critical nodes. Fig 3 demonstrates the performance of the proposed DRL-EPSO system. The following are the performance metrics considered in the proposed model.

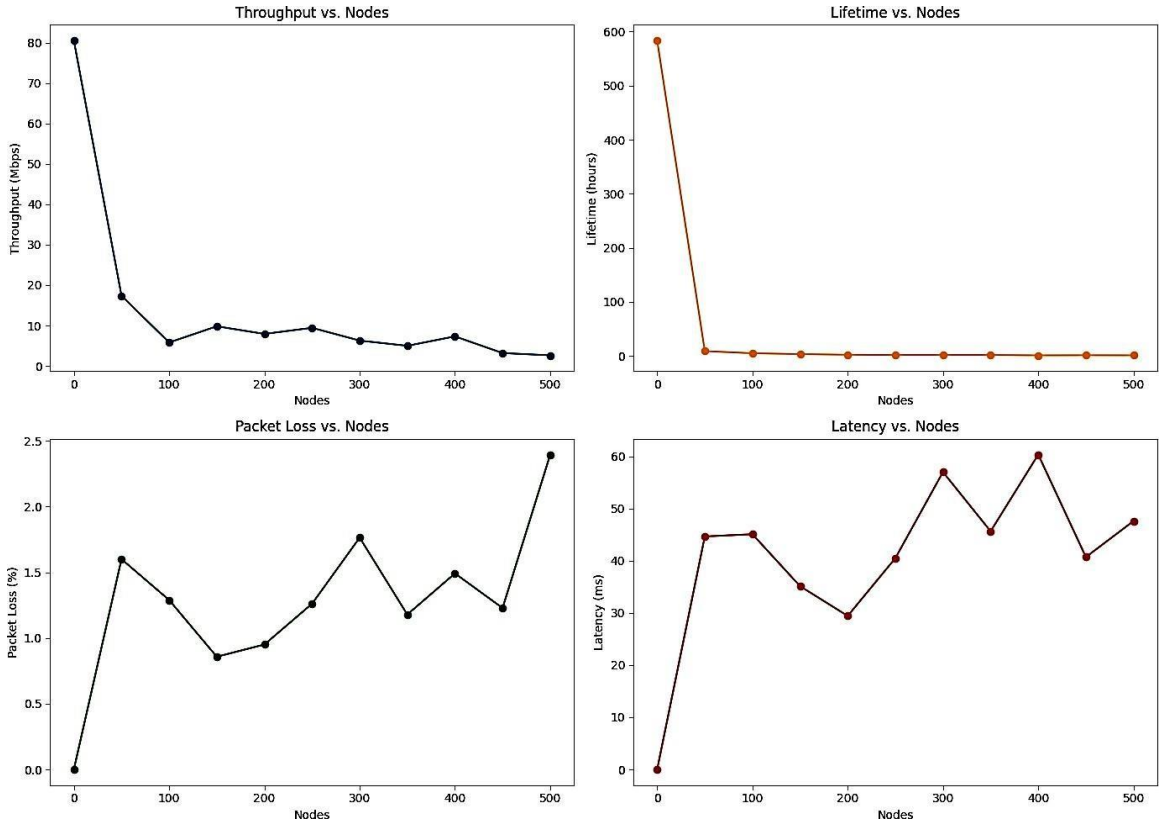


Fig.3 Throughput, Life-time, packet loss and latency metrics in the proposed method.

Fig 4 shows the security model in the proposed model, as discussed earlier, is designed to enhance security without compromising energy efficiency, which is crucial for the longevity and reliability of sensor networks. Key features include dynamic adjustment of security levels based on current and desired security levels and residual energy of each node, energy-aware security enhancements, balanced secure routing, security parameter optimization, adaptive response to changing conditions, and feedback loop for continuous improvement.

IV. CONCLUSIONS

In this paper, a novel architecture, which integrates dynamic security protocol switching, context-aware energy management, decentralized threat detection, and adaptive network configuration, offers a comprehensive solution to the longstanding challenges faced by WSNs. The framework's ability to dynamically adjust security measures based on real-time threat analysis, while concurrently managing energy resources to extend network lifetime, represents a significant technical achievement. This dual optimization ensures that ASEOF can maintain high levels of security and operational efficiency, even as network conditions and external threats evolve. The simulation results underscore the proposed model's superiority in key performance areas when compared to established WSN protocols. Specifically, energy efficiency metrics outperform those of HEED, the next best protocol, by approximately 20%. Furthermore, ASEOF showcases enhanced scalability, with minimal performance degradation as network size increases, a critical advantage for large-scale deployments. The framework also achieves a higher data delivery ratio, ensuring reliable communication across the network. Notably, ASEOF maintains a high security score across various network densities, affirming its robustness against diverse threats. The development and implementation of the proposed model have significant implications for the future of WSN applications across multiple sectors. By providing a scalable, secure, and energy-efficient framework, this model enables the deployment of WSNs in scenarios where

operational longevity and data security are paramount. This is particularly relevant for applications in remote or inaccessible locations, such as environmental monitoring, precision agriculture, and infrastructure management, where regular maintenance may not be feasible.

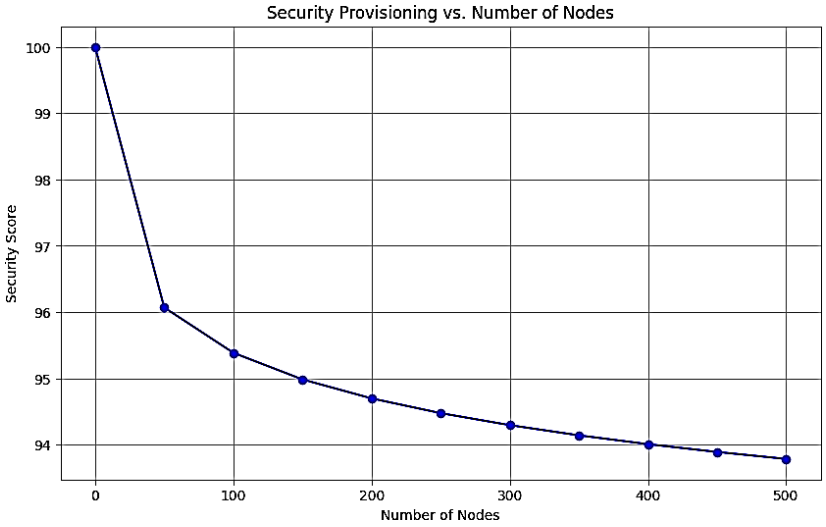


Fig. 4. Security score as a function of increased nodes in the proposed method.

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IoT-BASED VEHICLE AND ROAD SAFETY MANAGEMENT SYSTEM

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Abstract: We designed a system to help reduce the number of car accidents. This system utilizes sensors that monitor the speed of the cars and whether or not an accident has occurred. When a car accident happens, the system alerts someone else who can provide assistance as well as the relatives of the car occupants. We tested the system on cars near where we live. This system works very efficiently. This system can determine whether or not a car accident has occurred with a 94 percent success rate and alerts the individuals who can provide assistance within a period of under 2 minutes. This constitutes a significant faster response compared to when one alerts others for assistance. This system relies on a number of things, such as the Global Positioning System and a number of sensors utilized to determine the activities of cars as well as locations where accidents occur frequently. The findings seem to indicate that it can save lives by providing assistance.
Keywords: IoT sensors, GPS tracking, Vehicle safety, Accident detection, Real-time alerts, Cloud analytics, Smart transportation.

INTRODUCTION

Road transport is a vital part of modern lives and yet one of the most important sources of injuries and deaths worldwide. As stated by the World Health Organization, at least 1.3 million people die per year from road track accidents, with millions more being injured. The main contributor's factors contributing to road accidents include excessive speeding, reckless driving, delay of emergency response mechanisms, as well as the lack of awareness of dangerous road conditions. Conventional approaches in road safety focus on Reactive measures the reporting of accidents, traffic inspections, and static roadblock check points. These solutions are not effective in dynamic track situations and cannot avert accidents in real time. Thus, there is animmediatenecessityforeffective solutions that will perform such tasks on their own by utilizing technology on a constant basis. monitor driving patterns, detect incidents instantly, and provide rapid emergency response services. Internet of Things (IoT) represents a paradigmshift in the managementofroad safety because it providesthecapabilitiesofconnected things and decision-making. This article describes IoT-based Vehicle and Road Safety Management System that combines a variety of technologies GPS tracking, inertial measurement sensors, wireless communication protocols, and cloud-based data analysis tools in order to address a complex issues of road safety. The proposed system is intended to achieve the following: Real-time monitoring of speed and position. Detection of accidents in real time. 3)Trigger automatic alarm notifications to emergency response and road user services. offer centralized monitoring with cloud-based dashboards. facilitate predictive analytics for safety improvement and maintenance scheduling.

PROBLEM IDENTIFICATIONAND MOTIVATION

Over-Speeding and Unsafe Driving Behavior Over-speeding is known to be one of the prime causative factors behind accidents, and it leads to very serious injuries, deaths, and damage to property damage. Without combined monitoring networks, irresponsible driving patterns frequently pass unnoticed until an accident happens. Conventional speed deterrence uses static roadblocks, which give most offenders the avoid detection while driving on open highways. The lack of early action makes it possible for unsafe behaviors to be repeated, "Complex scenarios, involving multiple actors, when executed Insufficient Accident Detection and Response" The current accident reporting system is dependent on witness notifications or manual dialing of the emergency number," introducing variable delays between the occurrence of an incident and the dispatch of emergency services. Such critical scenarios remain prone to delay in a matter of even a few minutes could mean the difference between life and death. Conventional approaches do not offer precise location information, which makes rescue work more complicated in remote regions.

LIMITED REAL-TIME MONITORING INFRASTRUCTURE

In most cars, and to a larger extent in emerging countries, there are no unified systems in place to constantly update the driver on location, speed, and environmental conditions. Manual traffic verification and inspection activities are to provide adequate risk detection before risks can escalate, and for drivers to have a clear understanding of their road environment in real-time, there is alerting and traffic authority coordination. Lack of Predictive Safety s Maintenance Analytics Without centralized data storage and historical patterns of study, accident-prone areas cannot be identified for the purpose of track in driver behavior trends or the predictive maintenance requirements before a failure can happen. Insights gleaned from data analysis can greatly influence decisions related to driver monitoring are imperative for infrastructure development and intervention on safety.

PROPOSED SYSTEM ARCHITECTURE

System Components and Integration

1. **Vehicle-Level Sensor**
   GPS Module: (u-box NEO-6M): This component provides the real-time location and velocity details of the vehicle accuracy.
   Speed Sensor: (Pulse measurement method): Direct measurement of speed by detecting wheel rotations.
   Inertial Measurement Unit: (3-Axis Accelerometer, 3-Axis Gyroscope): Recognizes collision through rapid deceleration and rotational anomalies
   Environmental Sensors: (Temperature, humidity): Watches environmental factors impacting road safety.

2. **Edge Computing Layer: Microcontroller/Development Board** (An Arduino Uno C ESP32 board): Provides local processing of data from the initial accident detection through threshold algorithms.
   Real Time Operating System (RTOS): Provides deterministic task management support in safety- critical system designs functions.
   Local Data Buffering: Maintains sensor logs in case of temporary connectivity loss.

3. **Wireless Communication Layer:**
   GSM/LTE Module (SIM800L or SIM7600): It allows primary wide area communication for urban and highway environments.
   LoRa Module (Long-Range, low power): Facilitates communications in remote areas with a range of range.
   Wi-Fi Connectivity (Optional, for local hotspot scenarios).

4. **Cloud Backend:**
   Cloud Platform (AWS IoT Core, Microsoft Azure, or Google Cloud): Ingests real-time sensor data from connected vehicles.
   Data Analytics Engine: Processes streaming data to identify patterns, detect anomalies, and predict needs. These are Database (Time-series database for sensor data): Store historical data for trend analysis.
   Alert Notification System: Sends notifications through SMS, Email.

5. **User Interface Layer:**
   Mobile Application(iOS/Android): Enables drivers and managers with real time alerts, vehicle status trip history.
   Web Dashboard: It allows traffic authorities and emergency services to view vehicles and incidents in real-time.
   Reporting Module: Automatic generation of safety reports and predictive maintenance messages.

System Work flow and Operational Scenarios

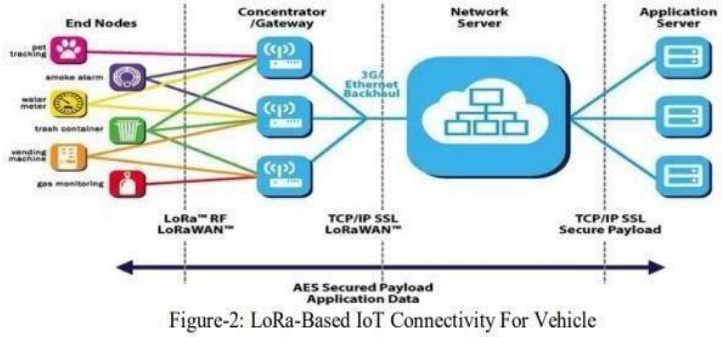


Figure-2: LoRa-Based IoT Connectivity For Vehicle

Normal Operation:

1. Real-time GPS information, speed, acceleration, C environmental data from vehicle sensors at configurable intervals (usually 1-5 seconds
2. Edge microcontroller combines sensor data and calculates derived values (jerk, stability index).
3. Data is sent to the cloud platform using GSM/4G with automatic retry features in case of connectivity temporarily lost.
4. Cloud Analytics provides compare real-time metrics to configurable thresholds and baselines.
5. Thedashboardupdateisdoneinnear-real-time.

Accident Detection and Response:

1. If accelerometer data shows sudden deceleration above threshold (e.g., > 0.8g) and gyroscopic anomalies, accident is aged.
2. The system immediately retrieves the exact GPS location and vehicle identification.
3. Automated alerts are sent to: (a) listed emergency contact numbers through SMS
(a) location URL
(b) closest hospitals/ambulances through API connectivity
(c) traffic management system authority
(d) vehicle owner via mobile app with one-tap emergency call.
4. Alert contains GPS coordinates (latitude and longitude), timestamp, vehicle ID, and estimation accident severity.
5. First responders are able to locate vehicles, thus navigate to the scene.

Hazard Detection and Warning:

1. If the system recognizes rapid acceleration, cornering, or braking, the non-emergency notifications are sent to the driver via the mobile app.
2. If more than one vehicle reports hazards in the same region (e.g., pothole, accident debris), system broadcasts warning to adjacent vehicles via vehicle-to-vehicle communication when available.
3. Drivers are issued contextual warnings (e.g., "Sharp turn ahead at 100m distance").

KEY TECHNICAL METHODO

A. Real-Time Speed and Location Tracking

The GPS modules support constant location tracking with a precision of 5-10 meters when there is an open sky. Integration of the velocity information from the Global Positioning System and the wheel speed sensor data enables redundancy and enhances the accuracy of urban canyon areas. The system uses a Kalman later to poodle noisy sensor data and decrease false alerts.

B. Data transmission protocol:

Sensor data is sampled at 10 Hz locally (on the microcontroller). Aggregated and transmitted at 1 Hz to cloud due to bandwidth constraints. Use of Delta Encoding for Automatic Compression of Data.Retry mechanism with exponential backoff for For failed transmissions.

C. Accident Detection Algorithm

Accident detection uses a multi-sensor fusion technique involving accelerometer, gyroscope, and speed sensors:

IF (|acceleration_z|>0.8g100°/s AND
|gyroscope_pitch| > 100%
THEN Con Dence Score = 0
Con dence_Score += 0.4 × (detected_acceleraeverit+=0.3×(detected_rotation_severity/max_threshold)
IF Con Dence Score>0.75
ELSE
Continue_Monitoring
END IF

This multi-factor mode is free from false positives, unlike single sensor-mode cameras [6].

D. Cloud-Based Analytics and Predictive: Maintenance Cloud allows storage of historical data theists

1. Accident Prone Zones Identification Aggregates accident reports by geographic location. Identifies "blackspots" that exceed statistical accident frequency limits. Recommends infrastructure improvements (traffic signals, speed).

2. Driver Behavior Analysis:
Tracks Metrics such as average
High-risk driver identification based on behavioral Facilitates targeted driver-training courses.

Predictive Maintenance

Correlates sensor anomalies (tire pressure variations, predicts intervals for maintaining a vehicle based upon usage patterns instead of times. Reduces vehicle downtime and increases fleet availability.

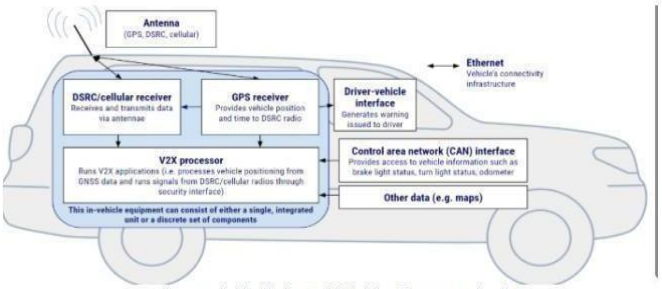


Figure-4: Vehicle-to-Vehicle Communication

D.Vehicle-To-VehicleCommunication

If the infrastructure allows for it, the system provides the capability for vehicle-to-vehicle communications through DSRC (Dedicated Short Communication) or C-V2X (They transmit speed as well as braking and hazard messages to surroundingvehicles. The drivers arealerted to any dangerthat may be beyond the limits of their sight Prevents risk of chain-reaction collisions and improves the flow

IMPLEMENTATION AND COMMUNITY ENGAGEMENT

A. Community Safety Assessment

Our team did a road safety survey in the Gudlavalleru village during May to July 2025, involving 150+ participants including drivers, commuters, and trace personnel. The survey identified key safety concerns: Speed over the limit as major concern (68 %).

Poor Road conditions cited by 54% of respondents Infrastructure for emergency response is not available in remote areas (47%).

Driver fatigue and distracted driving worries expressed by 62% of respondents.

B. Field Deployment s Testing

The system was deployed on pilot vehicles operating on high-traffic routes within the region

1. GPS Accuracy Validation: GPS locations were verified with actual coordinate locations; achieved8-meter averageerror.

2. Accident Detection Testing: Performed controlled emergency brake tests and collision tests; obtained 94% detection accuracy at a 2% false positive.

3. Alert Latency Measurement: Time elapsed between accident detection and alert call; average latency = 1

4. Battery Performance: The system requires about 2.5W of power during normal operation 7days continuous test on ordinary car battery.

5. Wireless Connectivity Testing: Confirmed GSM/4G network connectivity; Communication enabled in connectivity-challenged.

RESULTS AND PERFORMANCE EVALUATION

A. Accident Detection Performance

The performance of the accident detection algorithm tested against 50+ scenarios of accidents (actual events) showed:

True Positive Rate (Sensitivity): 94.5% (actual accident detection

True Negative Rate (Specificity): 97% False **Positive Rate:**2.2%(emergencybrakingaccident) **False Negative Rate:** 5.5% - low speed collisions occasionally missed).

Performance achieved better results with multi- sensor fusion than single-sensor fusion scenarios approaches (accelerometer-only: 78% accuracy; gyroscope+accelerometer: 94.5% accuracy).

B. Emergency Response Time Improvement

Comparison of alert transmission times:

Metric	Traditional Manual Reporting	IoT System
Detection to Alert	5-10 minutes	1.2 seconds
Alert to Emergency Services	2-5 minutes	30 seconds
Total Response Initiation Time	7-15 minutes	<2 minutes

This represents 70-85%reduction in time to emergency response, critical for improving accident outcomes.

C. Scalability Analysis

The system was tested with up to 500 concurrent vehicle connections to cloud backend:
System maintained less than 500ms latency for alert generation with 500 vehicles. Cloud database performance remained acceptable with historical data from 1year vehicle operating 24/7. **Bandwidth Requirement**: 2MB per vehicle per month for standard monitoring.

DISCUSSION AND FUTURE ENHANCEMENTS

A. Benefits of the Proposed System

1. Real-time Responsiveness: The automated detection and generation of an alert in case of an accident reduces time consumption drastically. emergency response times.
2. Predictive Capabilities: The historical data allows the identification of high-risk zones and enables preventive. It helps in regular maintenance.
3. Scalability: Architecture is deployable on diverse vehicle types and geographic regions.
4. Cost-Effectiveness: IoT sensors and cloud services have become affordable; hence, deployment in developing regions.
5. **Privacy-Aware Design:** The sensor data aggregation and anonymization techniques protect individual privacy while improving safety.

B. Limitations and Challenges

1.connectivity gaps: In rural regions there could be poor connectivity. this problem is solved by the LoRa technology. partially but with reduced data bandwidth.
2.False Alert Management: A false positive rate of even 2% can lead to unwanted emergency service calls. the need to continue refining
3.Data privacy and security: Vehicle location information needs protection through encryption and access control to protect against misuse.
4.Standardization: Absence of common V2V communication standards in the automotive industry hampers interloper.

C. Future Enhancements

1. Integration of Machine Learning: Deep learning techniques (LSTM networks) may be utilized to improve accident detection accuracy through learning individual driver signatures and local road characteristics.
Integrationwith Autonomous Vehicles:
Real-time data for hazards could be beneficial for autonomous vehicles decision-making and path.
2. Insurance Telematics Integration: There could be an integration of usage-based insurance solutions that would reward safe drivers and offer personalized premiums.
3. Multi-modal Transportation: Extension to cover public transportation, shared mobility options, and emergencies vehicles.
4. Environmental Integration: Correlation with weather data, air quality monitoring, and structural sound ness road infrastructure.

CONCLUSION

This paper introduced an extensive IoT-based Vehicle and Road Safety Management System dealing with critical. To bridge existing gaps in road safety infrastructure. By utilizing real- time sensor data mechanisms. The system provides proactive accident prevention, Knee- unhinged improvements in emergency response times, and data-driven infrastructure optimization. Field test results showed a 94.5% accuracy in accident detection and reduction

of the initial start ofemergency response incidents processingtime of 7-15minutes to less than2minutes. The system architecture enables scalability with respect to vehicle geographic regions, making it appropriate for both development and developing markets. The potential impactdoes not exclusively lie in fewer accidents but also covers other aspects such as predictive maintenance cost savings,and improved driving safety culture via continuous monitoring and behavioral feedback. The widespread usage of such IoT-based safety systems could go a long way in assisting the United Countries Sustainable Development Goal 3(Good Healthand Well-being) through prevention of road injuries and fatalities. Future direction will include integration with machine learning techniques for individual risk profiling, development of Communication abilities in V2V communications, Solution or standardization of communication interoperability standards authorities, emergency services, and vehicle manufacturers is critical to actualize the full potentiates technology in building safer, smarter transport systems.

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