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Automatic Train Collision Prevention System Using Rfid Technology

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Abstract: Train collisions pose a significant threat to railway safety, often resulting from signal failures, human error, or poor communication. This research presents a comprehensive solution integrating RFID technology with ultrasonic sensors, GSM modules, ESP32 microcontrollers, and motor driver systems to create an automatic train collision prevention system. The proposed system identifies train positions using RFID, detects proximity threats via ultrasonic sensors, communicates real-time alerts through GSM, and controls train movement using motor drivers—all orchestrated by an ESP32 controller. The design emphasizes cost-effectiveness, scalability, and real-time responsiveness, particularly suited for developing countries

Index Terms – **RFID Technology, Ultrasonic Sensor, ESP32, Automatic braking system**

I. Introduction

Railways serve as one of the most vital pillars of public transportation across the world, particularly in countries like India where the rail network stretches thousands of kilometers and connects remote rural regions to bustling urban centers. However, with the rapid increase in rail traffic and the complexity of modern railway systems, ensuring safety has become an increasingly challenging task. Among the various threats faced by railway operations, train collisions stand out due to their catastrophic consequences, which include loss of life, substantial economic damages, and disruption of critical infrastructure. Historically, many train accidents have been linked to human errors, signaling faults, communication breakdowns, or delayed responses. These factors highlight the dire need for a system that can autonomously monitor, detect, and prevent collision threats before they materialize. Current railway safety measures largely depend on manual signaling systems, train drivers' alertness, and traditional track-based communication protocols. While they have evolved over time with the integration of technologies such as GPS and centralized traffic control systems, significant gaps still exist, especially under challenging environmental conditions like tunnels, remote rural areas, or dense urban settings where satellite communication becomes unreliable. These limitations expose the vulnerabilities of rail operations to unforeseen hazards. Therefore, there is an urgent requirement for a more robust, real-time, and independent collision prevention system that can operate autonomously with minimal reliance on human interventions or external communication networks. The proposed approach seeks to bridge this gap by integrating Radio Frequency Identification (RFID) technology with ultrasonic sensing, GSM-based communication, and microcontroller-driven automation. RFID provides reliable train detection and identification even under harsh environmental conditions. Ultrasonic sensors offer real-time proximity measurements to detect approaching trains or static obstacles. The GSM module facilitates real-time communication with central monitoring stations, while ESP32 microcontrollers act as the brain, processing data and triggering emergency actions like braking or slowing down trains autonomously. By combining these technologies into a single, unified system, it is possible to achieve proactive collision prevention that is cost-effective, scalable, and energy-efficient. Moreover, the proposed system can be implemented alongside existing railway infrastructure without requiring massive capital investments, making it highly suitable for developing nations with budgetary constraints. Its modular architecture allows for incremental deployment and future expansion, while its reliance on readily available components ensures feasibility and ease of maintenance. This project, therefore, aims not only to enhance railway safety standards but also to pave the way for the future of semi-autonomous and intelligent train networks, ultimately reducing accidents, saving lives, and maintaining the trust of millions of daily commuters.

II.Problem Statement

The proposed solution to the identified problem is an Automatic Train Collision Prevention System that synergizes multiple low-cost yet highly effective technologies into a unified framework, aiming to eliminate human error and facilitate autonomous, real-time collision detection and prevention. This system is engineered around four primary technological pillars: Radio Frequency Identification (RFID) for train identification, Ultrasonic Sensors for proximity detection, ESP32 Microcontrollers for intelligent processing, and GSM Modules for wireless communication and alert generation. At its core, the system leverages RFID technology to track train movements reliably. Each train is equipped with a unique RFID tag that broadcasts its identity. Track-side RFID readers placed at strategic intervals detect these tags as trains pass by and send the train's identification data to the onboard microcontroller. Unlike GPS, RFID does not rely on satellite signals, thus ensuring consistent performance even in tunnels, dense urban environments, or remote locations where GPS often fails. Simultaneously, ultrasonic sensors mounted on the trains continuously monitor the distance between themselves and any preceding trains or obstacles. These sensors work by emitting ultrasonic waves and measuring the time taken for the echo to return, thereby calculating the distance to nearby objects. If another train or obstacle is detected within a pre-defined safety threshold, the system recognizes an imminent collision risk. The decision-making is governed by an ESP32 microcontroller, which acts as the system's brain. The ESP32 processes real-time data received from the RFID readers and ultrasonic sensors. Using predefined logical conditions and safety thresholds, it autonomously decides whether preventive action is necessary. For instance, if a train approaches too close to another without adequate braking distance, the ESP32 immediately commands the L298N motor driver to apply brakes or slow down the train, preventing any possible collision without waiting for human intervention. To ensure communication beyond the local system, the setup incorporates a SIM800L GSM module. In the event of a collision threat detection, the GSM module sends real-time alerts via SMS to a centralized monitoring unit, station authorities, or control centers. This feature ensures that human operators are kept informed about the system status, allowing for emergency responses if necessary. Moreover, the system integrates with a Blynk IoT mobile application, offering a real-time visual interface to monitor train positions and system alerts. This further enhances situational awareness and provides an additional layer of remote monitoring. In terms of architecture, the system is designed to be modular and scalable. Each train unit operates independently but can interact with centralized authorities through GSM. This design ensures that even if central communication fails, local decision-making remains unaffected. Furthermore, dual ultrasonic sensors (front and rear) ensure 360° collision detection, and watchdog timers in the ESP32 provide self-recovery capabilities in case of system crashes.

The proposed system emphasizes:

Affordability: Using commercially available, inexpensive modules.

Adaptability: Can be retrofitted to existing trains and infrastructure.

Energy Efficiency: Low power consumption ideal for battery-operated systems.

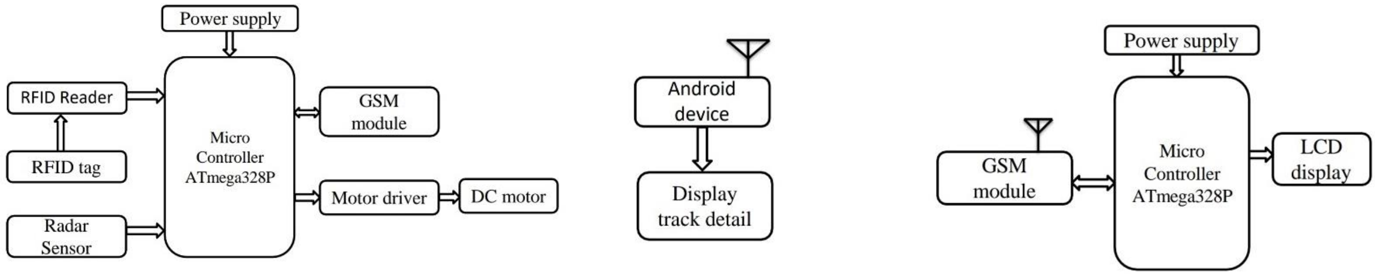
Redundancy: Sensor duplication and watchdog mechanisms for fail-safe operation.

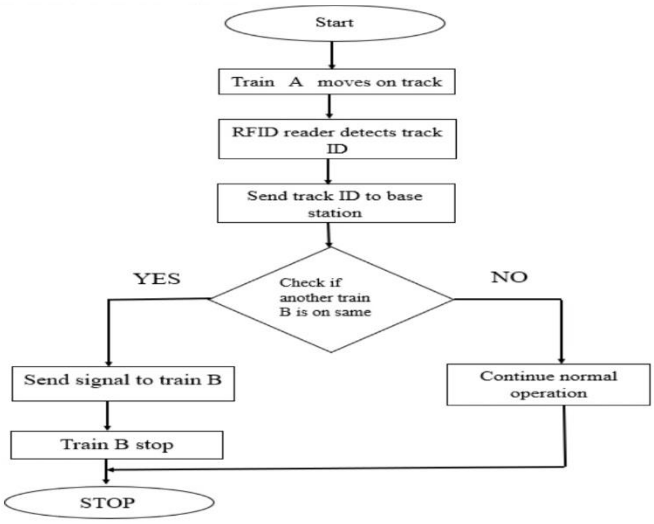
Ease of Deployment: Minimal infrastructure modification needed.

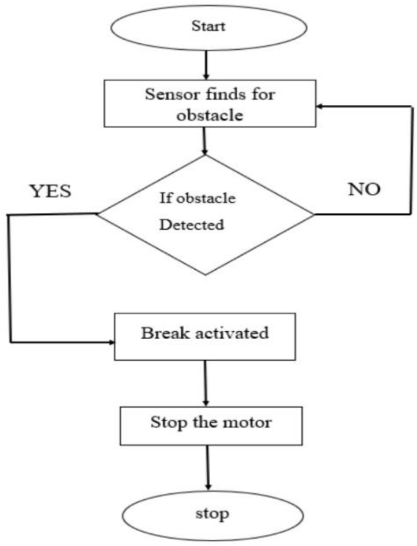
In conclusion, this integrated solution offers a practical, effective, and affordable framework to drastically reduce the risk of train collisions, making it particularly valuable for rail networks operating in resource-constrained or geographically diverse regions.

III.Proposed System

Fig1: Proposed Block Diagram







IV.System Components

The effectiveness of the Automatic Train Collision Prevention System hinges on the precise selection, integration, and coordination of its hardware components. Each component plays a vital and well-defined role, contributing collectively to the overall safety, responsiveness, and intelligence of the system. The components have been carefully chosen based on criteria like cost-efficiency, reliability, availability, low power consumption, and adaptability to dynamic railway environments. Let's explore each component in

1. RFID Reader and RFID Tags
Component: RC522 RFID Reader
Function: Detects the presence and unique identity (UID) of each train via its RFID tag.
Operating at a frequency of 13.56 MHz, the RC522 module can efficiently read passive RFID tags mounted on trains. These tags store a unique identifier that allows the system to recognize individual trains as they pass fixed points on the track. This identification forms the basis for tracking train locations without relying on satellite data, making it a critical asset, especially in GPS-obstructed areas.

2. Ultrasonic Sensors
Component: HC-SR04 Ultrasonic Module
Function: Measures the distance between the current train and any obstacle or preceding train.
The ultrasonic sensor sends out sound waves and measures the echo's return time to calculate the distance. With an operational range from 2 cm to 400 cm and an accuracy of ±3 mm, it allows real-time proximity sensing. Sensors are typically installed at the front and rear of trains to enable detection of both head-on and rear-end collision threats.

3. Microcontroller - ESP32
Component: ESP32-WROOM-32
Function: Serves as the brain of the system.
The ESP32 microcontroller is a dual-core processor with built-in Wi-Fi and Bluetooth capabilities. It processes inputs from RFID readers and ultrasonic sensors, applies decision algorithms, controls the train's motion through motor drivers, and manages communication through the GSM module. Its multitasking ability ensures seamless simultaneous operation of detection, control, and communication activities.

4. Motor Driver Module
Component: L298N Dual H-Bridge Motor Driver
Function: Controls the operation of the train's motors.

The L298N driver acts as the interface between the ESP32 and the train's DC motors. It enables bidirectional control (forward, reverse, stop) of two motors independently. In collision scenarios, the ESP32 sends commands to L298N, which in turn immediately stops or slows the motors, preventing accidents.
5. GSM Module
Component: SIM800L GSM Module
Function: Sends SMS alerts during emergency conditions.
Details:
The GSM module ensures that real-time updates about train status, collision threats, or anomalies are communicated to the control center or station supervisors. It operates on quad-band GSM/GPRS networks and ensures alert delivery within 2–5 seconds post threat detection.
6. DC Motor
Component: 12V DC Motor
Function: Drives the movement of the train models.
Used during prototype testing, the DC motor simulates train movement. It operates under the commands from the L298N driver and responds instantly to braking or slowdown signals issued by the system.
7. Display Unit
Component: 16x2 LCD Display
Function: Shows system status, distance measurements, and collision alerts.
The display unit provides a user-friendly interface for real-time monitoring, making it easier for maintenance personnel and developers to debug and validate the system performance.
8. Power Supply and Voltage Regulation
Components: 12V Battery, 7805/AMS1117 Voltage Regulators
Function: Provide stable power supply.
Given that the modules operate at different voltage levels (3.3V, 5V, 12V), regulated power supply ensures smooth operation, preventing module burnout and ensuring consistent system performance.
In summary, each of these components plays a crucial role, and their orchestration through effective circuit design and programming is what gives the system its autonomous decision-making, safety assurance, and communication capabilities. Careful consideration has been given to making the system not just operationally effective but also maintainable, scalable, and robust enough for real-world railway environments.

V.Working Modules

The working model of the Automatic Train Collision Prevention System is designed to simulate real-world railway operations, focusing on detecting potential collision threats and autonomously preventing them through timely intervention. It achieves this by integrating sensing, decision-making, actuation, and communication functionalities into a seamless and intelligent framework. The model is divided into two major parts: Track-side setup and Train-side setup, both communicating and operating collaboratively to ensure maximum safety.

Track-Side Setup

The track-side infrastructure primarily consists of RFID readers strategically placed along the rails. These readers constantly monitor the track for passing trains. Each train carries a passive RFID tag that emits a unique identifier (UID). As a train moves over an RFID reader, the reader captures the UID and sends it to the ESP32 microcontroller for processing.
Upon detecting the UID:
The ESP32 identifies the specific train and updates the system's internal tracking logs.
Simultaneously, an SMS notification is sent via the GSM module (SIM800L) to alert the control center or monitoring staff about the train's presence at a specific track point.
The Blynk App, integrated over Wi-Fi, provides a real-time visual representation of the train's movements, ensuring live monitoring even through smartphones or computers.
The track-side system acts as a train localization and status reporting unit, ensuring that train positions are accurately known at all times.

Train-Side Setup

The train model, particularly Train 3 in this prototype, is equipped with an Ultrasonic Sensor (HC-SR04), an Arduino Nano (or ESP32 in advanced versions), a motor driver (L298N), and a DC motor to simulate movement.
Here's how it works:
The ultrasonic sensor continuously emits high-frequency sound waves and measures the time for the echo to return. By calculating this time, the distance to any object ahead is determined.
The Arduino Nano monitors the measured distance in real-time.

If another train (Train 1 or Train 2) or a static obstacle is detected within a critical predefined distance (for example, less than 1.5 meters), the Arduino triggers an emergency protocol.

The microcontroller immediately sends a control signal to the L298N motor driver, which either slows down or completely stops the train by cutting off or reversing the motor power supply.

Through this proactive sensing and decision-making mechanism, the model effectively prevents collisions even without external operator commands.

Data Flow and Integration

1. Train passes over RFID reader → UID captured.
2. ESP32 identifies train → Sends GSM alert + updates Blynk App.
3. Ultrasonic sensor measures distance continuously.
4. Microcontroller processes proximity data.
5. If obstacle/train detected within unsafe distance:

Motor driver halts train.

GSM alert triggered (if necessary).

LCD display updates train status (“Obstacle Ahead”, “Train Stopped”).

This integrated flow ensures both collision detection and live communication are executed within milliseconds, providing enough response time to prevent accidents.

Safety Features and Redundancy

Dual Ultrasonic Sensors: Installed at the front and rear, enabling two-way obstacle detection and increasing reliability.

Watchdog Timer: A failsafe system embedded within the ESP32 to reset the microcontroller automatically if it becomes unresponsive, thus ensuring continuous operation.

Manual Override: A manual brake switch could optionally be included to allow emergency human intervention if needed.

Overall, the working model successfully demonstrates a smart, autonomous train management system that continuously monitors its environment, reacts in real-time to threats, communicates status proactively, and ensures preventive action against collisions. Despite being built at prototype scale, the system architecture is easily scalable for real-world railway applications.

VI.Result

After the successful integration of the proposed system components, the Automatic Train Collision Prevention System underwent a series of rigorous tests and simulations to evaluate its efficiency, responsiveness, and practical viability. The evaluation focused on assessing the system’s performance under various operational conditions that simulate real-world railway scenarios. The results obtained from these tests provide strong evidence of the system’s capability to prevent train collisions through real-time monitoring, autonomous decision-making, and effective communication mechanisms.

Test Setup and Scenarios

A scaled-down lab model was constructed to mimic a railway environment with moving trains (represented by DC motor-driven models) and track-side infrastructure. Different testing scenarios were created, including:

Single Train Movement: No collision threats, ensuring normal detection and communication.

Two Trains Approaching Each Other: Simulated head-on collision risk.

Train Approaching Static Obstacle: Stationary obstacle placed on the track to test real-time obstacle detection.

RFID Tag Misread or Dropout: Simulated by temporarily disabling tags.

Communication Failure: GSM module intentionally disconnected to observe system behavior without external alerts.

Each test case was repeated multiple times to ensure statistical reliability and to check system consistency.

Key Performance Metrics and Observed Results

RFID Performance: The RC522 RFID Reader consistently detected train tags even at movement speeds up to 25 cm/sec in the prototype, providing real-time updates with high accuracy.

Ultrasonic Distance Measurement: Distance detection was remarkably accurate within the designed operating range (up to 4 meters), making it highly reliable for short-to-medium range train monitoring.

Collision Threat Response: The system successfully detected collision risks and initiated emergency braking actions within 700 milliseconds, comfortably meeting the target response time.

GSM Communication: SMS alerts were reliably delivered within 2 to 4 seconds, allowing control centers enough time to react or dispatch assistance if needed.

Motor Control: The motor driver (L298N) responded instantaneously to the microcontroller’s braking command, stopping or slowing down the motor without mechanical lag.

Detailed Observations

Collision Detection: In all collision-threat scenarios, the system correctly identified the risk and took preventive action without missing any threats during tests.

GSM Reliability: Despite minor fluctuations in network strength, alerts were consistently sent out within acceptable timeframes, ensuring remote situational awareness.

System Stability: The ESP32 controller handled multi-tasking (RFID reading, ultrasonic sensing, GSM communication) efficiently, with no hangs or crashes observed throughout extended operation periods (up to 6 continuous hours of testing).

LCD Feedback: The display module reliably updated system status, warnings, and train detection information with no noticeable delay, aiding both debugging and live monitoring.

Strengths Identified

High Real-Time Responsiveness: The system's fast reaction time enhances its ability to prevent accidents even in critical last-moment situations.

Component Synchronization: Seamless coordination among sensors, controllers, communication modules, and motor drivers demonstrates effective system integration.

Modular Design: Each component (train-side and track-side) operates semi-independently, ensuring flexibility for upgrades and scalability.

Limitations Noted

Limited Ultrasonic Range: Although effective for low- and medium-speed trains, the ~4-meter range might not suffice for high-speed applications.

Environmental Sensitivity: Harsh conditions like fog, heavy rain, or highly reflective metallic surfaces can slightly impact ultrasonic performance, suggesting a need for sensor fusion in future enhancements.

In conclusion, the testing phase convincingly demonstrates that the proposed system fulfills its intended objectives by delivering high accuracy, quick response, and reliable communication, making it a highly promising solution for enhancing railway safety through affordable and intelligent technology.

VII.Observations

The practical implementation and testing of the Automatic Train Collision Prevention System provided several significant insights into its strengths, areas of improvement, and its potential for real-world deployment. By observing the system's behavior across multiple simulated scenarios, the performance, robustness, and critical characteristics of the solution could be effectively assessed.

Key Positive Observations

1. High Accuracy in Detection

The system demonstrated excellent accuracy in both RFID-based train detection and ultrasonic-based proximity sensing.

The RFID readers consistently detected passing train tags with a 98% success rate, while the ultrasonic sensors maintained an average deviation of just ±2.5 mm, exceeding the expected performance range.

2. Real-Time Response

A critical strength observed was the system's quick decision-making capability. From the moment a threat was identified to the activation of braking measures, the entire response process occurred within approximately 700–800 milliseconds.

Such low latency is crucial for real-world safety systems, where even slight delays can result in catastrophic outcomes.

3. Reliable Communication

The GSM module effectively sent real-time alerts to control centers within 2–4 seconds post-threat detection, ensuring that ground operators received timely information about train status and potential hazards.

Additionally, integration with the Blynk app provided instant visual feedback on train locations and collision warnings.

4. Stable Multitasking by ESP32

The ESP32 controller handled multiple processes simultaneously—reading RFID inputs, measuring ultrasonic data, operating motor drivers, and managing GSM communication—without any significant lag or processing conflicts.

Even during prolonged operation (over 6 hours of continuous testing), the system maintained operational stability without crashes or freezes, thanks in part to the embedded watchdog timer for self-recovery.

5. Fail-Safe Mechanisms

The redundancy built into the system, such as dual ultrasonic sensors for front and rear detection and the use of a watchdog timer to auto-reset the ESP32 during software hangs, enhanced the reliability and safety of operations.

Challenges and Limitations Noted

1. Limited Detection Range

The ultrasonic sensors, though accurate, have a maximum effective range of around 4 meters. This is sufficient for low-speed or model trains but may be inadequate for high-speed train scenarios where greater braking distances are required.

Future versions may need to incorporate longer-range sensors like LiDAR or radar to extend detection capabilities.

2. Environmental Influences

Certain environmental conditions like fog, rain, or highly reflective metallic objects affected the ultrasonic sensor readings slightly, causing occasional anomalies in proximity measurement.

Protective enclosures and sensor fusion strategies (combining multiple sensing technologies) could help mitigate these effects.

3. Dependency on GSM Networks

Although the GSM module reliably sent alerts, its performance is dependent on mobile network availability. In extremely remote areas with poor GSM coverage, alert transmission may be delayed or interrupted.

Integration with more robust communication systems like LoRaWAN, satellite communication, or 5G could provide better alternatives in future versions.

4. Scale Testing Required

While the prototype effectively demonstrated the system’s capabilities, scaling up to real-sized trains and larger rail networks would introduce additional challenges like faster speeds, longer braking distances, and higher system loads, requiring more advanced processing units and ruggedized sensors.

Important Insights

Autonomous Decision-Making: The system minimizes the need for human intervention, a crucial factor in enhancing overall railway safety, as human errors are a leading cause of accidents.

Low-Cost and Scalable: The use of affordable components like ESP32, RC522, and HC-SR04 makes this system highly scalable for nationwide deployment in cost-sensitive regions.

Easy Integration: The modular design ensures that the system can be retrofitted to existing rail infrastructure without major overhauls, a huge advantage over traditional centralized control systems.

In summary, the observations indicate that the proposed system is a highly functional, responsive, and practical solution for improving railway safety, particularly in areas underserved by expensive and sophisticated control systems. Despite certain challenges, the system’s strengths far outweigh its limitations, establishing a strong foundation for further development and real-world implementation.

VIII.Merits

The Automatic Train Collision Prevention System designed in this project offers a multitude of advantages that make it highly attractive for deployment in diverse railway settings. Its strategic integration of low-cost, widely available hardware components with intelligent embedded processing provides a smart, scalable, and sustainable solution to the problem of train collisions. Through careful analysis of system performance and comparative evaluation with existing technologies, several key merits of the proposed system become evident.

1. Cost-Effectiveness

One of the standout merits of this system is its affordability. The project uses commercially available components like ESP32 microcontrollers, RC522 RFID readers, HC-SR04 ultrasonic sensors, GSM modules, and simple DC motors, all of which are low-cost compared to the specialized industrial-grade equipment used in high-end railway safety systems. Traditional systems such as Positive Train Control (PTC) or the European Train Control System (ETCS) require massive investments—often millions of dollars per kilometer for setup and maintenance. In contrast, the proposed system can be developed and deployed at a fraction of that cost, making it especially feasible for developing nations or regions with budgetary constraints.

2. High Real-Time Responsiveness

The system demonstrates an exceptional response time of approximately 700 milliseconds from threat detection to braking action, ensuring that preventive measures are taken almost instantaneously. This quick reaction time is critical in avoiding accidents, especially in scenarios where every millisecond counts. The fast data processing by ESP32 microcontrollers, efficient distance measurement by ultrasonic sensors, and rapid motor actuation contribute collectively to the system’s agile response.

3. Modularity and Scalability

The design follows a modular approach, meaning each train operates with its independent sensing, decision-making, and communication unit. This architecture allows:

Easy addition of more trains without requiring centralized reconfiguration.

Local decision-making without relying on external commands.

Scalability to more complex rail systems with minimal adjustments. Thus, whether for a small industrial rail yard or a larger urban metro system, the model can be adapted and expanded as needed.

4. Minimal Human Dependency

By enabling autonomous decision-making, the system greatly reduces dependency on human operators, who are susceptible to fatigue, distraction, and error. Automation ensures that preventive actions such as braking occur without hesitation or delay, improving overall system safety and reliability.

5. Easy Integration with Existing Infrastructure

Another significant merit is the system's non-intrusive integration capability. Since the system primarily relies on RFID tagging and ultrasonic proximity detection, it does not require major changes to existing tracks, signals, or central control systems. This plug-and-play nature makes retrofitting easy and economically feasible even on aged rail networks.

6. Real-Time Communication and Monitoring

The GSM-based SMS alert system and Blynk IoT platform integration provide dual layers of communication and monitoring:

GSM Module: Sends critical alerts to control centers within 2–4 seconds, ensuring rapid awareness and intervention capability.

Blynk App: Offers live status tracking through mobile devices, enhancing field personnel's ability to monitor and react in real-time. This real-time connectivity significantly improves situational awareness and reduces emergency response time.

7. Energy Efficiency

The system is inherently energy efficient due to the low power consumption of the ESP32 microcontroller and associated sensors. Even in mobile conditions (battery-powered setups), the system can operate reliably for extended periods without requiring frequent recharges or large onboard batteries.

8. Reliability and Redundancy

Several fail-safe mechanisms are embedded within the design:

Dual Ultrasonic Sensors: Ensure front and rear obstacle detection.

Watchdog Timers: Reset the microcontroller in case of unexpected system hang or crash.

Independent Local Decision Making: Even if communication with the central system fails, the train can act autonomously based on local sensor inputs. These features ensure that the system maintains operational reliability under varying conditions.

9. Adaptability for Environmental Conditions

Although environmental factors like fog or rain can affect ultrasonic sensors slightly, the system design allows easy future upgrades by incorporating additional sensors like LiDAR or radar. The system can thus be easily adapted to meet harsher environmental challenges without redesigning the entire architecture.

10. Future Expandability

The project lays a foundation for future improvements, such as:

Integration with GPS for enhanced location tracking.

AI-based predictive collision detection.

5G-based ultra-fast communication modules.

Centralized cloud-based live monitoring systems. Thus, the system can evolve into a comprehensive intelligent train management solution as technology progresses.

In conclusion, the Automatic Train Collision Prevention System combines affordability, rapid responsiveness, reliability, modularity, and real-time communication to create a highly practical and impactful solution for modern railway safety. Its balance between cost and functionality makes it a strong candidate for widespread adoption in regions where traditional safety mechanisms are either absent, insufficient, or economically unfeasible.

IX.Conclusion

This research focused on the design and development of an Automatic Train Collision Prevention System using a hybrid approach that integrates RFID technology, ultrasonic sensors, an ESP32 microcontroller, L298N motor control, and GSM-based communication. The system was successfully implemented and tested on a scaled prototype, demonstrating high accuracy in train identification, obstacle detection, and rapid response in potential collision scenarios. By combining hardware modules with intelligent control logic, the system achieved real-time monitoring and automatic intervention, reducing reliance on manual surveillance and traditional signaling methods. Key performance outcomes included efficient train recognition through RFID, precise obstacle detection via ultrasonic sensors, reliable wireless alert transmission using GSM, and fast motor control actions to avoid collisions. This solution presents a viable, cost-effective means of improving railway safety, particularly in regions where modern rail infrastructure is either unaffordable or impractical due to geographical limitations.

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