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ABSTRACT

This report presents the Railway Accident Prevention System (RAPS), a low-cost embedded solution aimed at enhancing railway safety by preventing collisions and securing level-crossing operations. The system is built around two main components: an ESP32-based train unit for real-time obstacle detection and an Arduino Uno-based signal and gate control unit. It employs a combination of VL53L0X LiDAR, HC- SR04 ultrasonic, and VS1838B IR sensors for robust multi-modal detection, supported by sensor fusion algorithms running under FreeRTOS for real-time task management. Communication between units is achieved via Bluetooth for data transmission and IR signaling for short-range confirmation. Experimental results demonstrate reliable detection within a range of 0.03–4 meters, response times between 50–200 ms, and a false-alarm rate under 2%. The system's design ensures high reliability, confirmed by statistical analysis with 95% confidence intervals. Its modular, scalable architecture and use of widely available components make RAPS a cost-effective and replicable solution for accident prevention in railway environments. The integration of real-time embedded processing, multiple sensor modalities, and wireless communication contributes to a safer and more efficient railway infrastructure.

Keywords: Railway Safety, Embedded Systems, Sensor Fusion, Anti-Collision, Level Crossing

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1. INTRODUCTION

1. INTRODUCTION

Railway accidents—such as collisions, derailments, and level-crossing failures—remain serious safety issues globally. These incidents often result in loss of life, injuries, and major disruptions to transport and the economy. In countries like India, with one of the busiest and most extensive railway networks, the frequency and impact of such accidents are especially severe. Key causes include track obstructions, signal violations, and accidents at level crossings—many of which arise due to human error, poor visibility, or lack of automation.

Despite modernization efforts, manual systems still dominate railway operations in rural and semi-urban regions due to budget constraints. Traditional methods like manual inspections and basic signaling are reactive and slow, often allowing dangerous conditions to persist. This highlights the urgent need for intelligent, automated systems that can detect and prevent accidents in real time.

The **Railway Accident Prevention System (RAPS)** addresses this challenge through a cost-effective and technologically sound solution. It uses embedded systems and real-time sensors to monitor track conditions and improve train safety. RAPS features a **dual-microcontroller setup**: an **ESP32** mounted on the train and an **Arduino Uno** managing trackside signaling and gate operations. This division ensures efficient task distribution and enhances reliability.

To ensure comprehensive detection, the system integrates multiple sensors. The **VL53L0X LiDAR sensor** offers accurate forward obstacle detection. The **HC-SR04 ultrasonic sensor** provides short-range support, especially in adverse weather. The **VS1838B IR receiver** detects infrared signals from the trackside unit, enabling communication in areas with poor wireless connectivity.

These sensors enable **multi-modal detection** and increase accuracy through **sensor fusion**. Wireless **Bluetooth communication** allows the ESP32 and Arduino units to exchange data in real time, while **infrared signaling** acts as a backup if Bluetooth fails.

1.1 BACKGROUND AND SIGNIFICANCE

Railways play a vital role in national infrastructure, offering an efficient and economical means of transportation for both passengers and freight. However, railway safety remains a persistent concern, especially in countries like India where the rail network is extensive and traffic density is high. Accidents at level crossings, train collisions, derailments due to track defects, and signal violations are among the most common causes of fatalities and disruptions. Many of these incidents are preventable and result primarily from human error, lack of automation, or insufficient real-time monitoring.

Technological advancements in embedded systems, wireless communication, and sensor technologies have made it feasible to design intelligent safety solutions for railways. The integration of sensors such as LiDAR, ultrasonic, and infrared, along with microcontrollers like ESP32 and Arduino, opens new possibilities for real-time detection and response to hazardous conditions. The development of such systems aligns with the broader goal of improving railway safety, operational efficiency, and public trust in rail transportation.

The Railway Accident Prevention System (RAPS) is a low-cost, modular solution that aims to automate critical safety functions such as obstacle detection, signal violation monitoring, and level crossing control. By using embedded technology, RAPS addresses safety challenges while being scalable and cost-effective, making it suitable for implementation even in rural and semi-urban areas where infrastructure is limited.

1.2 MOTIVATION

The motivation for this project arises from the increasing number of preventable accidents on railway networks, especially at unmanned level crossings and in areas with poor visibility or outdated signaling systems. In India, level crossing incidents account for a significant portion of railway accidents, often resulting from delayed human reactions, manual signal control, and lack of early warning systems.

Despite the availability of sophisticated train protection systems such as ETCS (European Train Control System) and CBTC (Communication-Based Train Control), these are often too expensive and complex for widespread deployment in developing regions. There exists a strong need for a simpler, more affordable safety system that still maintains a high degree of reliability and effectiveness.

The RAPS project is motivated by the desire to:

- Reduce human dependency in critical railway safety operations.
- Utilize low-cost hardware to make safety technology accessible to all segments of the railway system.
- Improve the response time and detection accuracy in emergency scenarios.
- Enable predictive maintenance through real-time monitoring and data analysis.

1.3 PROBLEM STATEMENT

Railway accidents are a major concern in India and other developing nations, primarily due to the combination of high traffic volume, aging infrastructure, and insufficient real-time safety mechanisms. Current monitoring systems rely heavily on manual inspections, which are often delayed, error-prone, and incapable of providing real-time alerts.

Advanced automated systems do exist, but their high cost and infrastructure requirements limit their deployment to only select regions. As a result, many railway segments remain vulnerable to:

- Track cracks and structural defects.
- Obstructions at level crossings.
- Human errors in signal compliance (e.g., SPAD – Signal Passed At Danger).

There is a critical need for a low-cost, scalable, and reliable embedded system that can automatically detect such risks and trigger timely preventive actions.

1.4 OBJECTIVES OF THE PROPOSED WORK

The **Railway Accident Prevention System (RAPS)** aims to address the aforementioned challenges through the development of a real-time, embedded solution that enhances railway safety. The key objectives are:

- **Real-Time Track Monitoring:** Utilize LiDAR sensors to continuously monitor the track and detect surface cracks or anomalies to prevent derailments.
- **Obstacle Detection and Alert System:** Employ ultrasonic sensors and IR modules to detect any obstacles such as vehicles, animals, or unauthorized persons on the railway track.
- **Automated Collision Avoidance:** Implement automatic braking through relay control when an obstacle or hazard is detected, minimizing human reaction delays.

- **Signal Violation Detection:** Prevent SPAD incidents by using IR communication to monitor signal status and enforce braking when necessary.
- **IoT-Based Centralized Monitoring:** Enable real-time data transmission for remote supervision and system status tracking.
- **Cost-Effective and Modular Design:** Leverage affordable components and a dual-microcontroller setup (ESP32 and Arduino Uno) to ensure ease of replication and adaptability.
- **Predictive Maintenance Capability:** Analyze real-time sensor data to forecast maintenance needs before failures occur, reducing operational downtime.

These objectives aim to build a comprehensive safety framework that not only responds to immediate threats but also supports long-term infrastructure resilience through automation and intelligent sensing.

2.LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 REVIEW OF EXISTING SYSTEMS

Numerous research studies and industrial systems have been developed to enhance railway safety through automation, sensing, and communication technologies. The following review highlights the most relevant systems and approaches:

1. **Obstacle Detection Systems Using LiDAR and Ultrasonic Sensors**
   Smith et al. (2019) explored combining LiDAR and ultrasonic sensors to detect obstacles at level crossings. Their study emphasized LiDAR's ability to generate high-resolution 3D maps, which, when fused with ultrasonic data, improves detection accuracy under varied environmental conditions. However, such systems were largely limited to urban networks due to their cost and complexity.
2. **Track Monitoring with LiDAR-Based Systems**
   Sharma and Gupta (2020) implemented LiDAR sensors mounted on rail bogies to detect track defects like cracks and alignment shifts. They demonstrated that such automated inspection methods outperform traditional manual processes in both speed and reliability.
3. **Automatic Train Protection (ATP) Systems**
   Desai and Kumar (2018) reviewed ATP technologies such as ETCS, CBTC, and PTC. These systems monitor train positions and enforce speed restrictions or braking under unsafe conditions. While effective, the deployment of ATP systems remains limited to developed nations due to high implementation costs.
4. **Ultrasonic Rail Inspection Techniques**
   Brown and Taylor (2019) presented ultrasonic testing methods for detecting internal rail defects. These non-destructive evaluation techniques can identify subsurface flaws that are invisible to the naked eye, enhancing preventive maintenance strategies.
5. **IoT-Based Predictive Maintenance Platforms**
   Patel and Mehta (2020) described IoT-enabled sensor networks that provide real-time monitoring and data logging for railway infrastructure. They showcased predictive algorithms that analyze sensor data to forecast maintenance needs and prevent sudden failures.

Each of these studies contributes valuable insights into railway safety mechanisms, emphasizing automation, sensing, and communication technologies. However, they also reveal certain limitations, especially regarding cost-effectiveness and adaptability for large-scale deployment in resource-constrained regions.

2.2 GAP ANALYSIS

Based on the above review, the following gaps and limitations in current systems have been identified:

- **High Cost and Infrastructure Dependency**:
  Most existing systems like ATP, ETCS, or advanced LiDAR inspection units require significant financial and infrastructural investments, limiting their use to developed nations and urban routes.
- **Lack of Real-Time and Multimodal Detection**:
  Many reviewed systems focus on a single function—either obstacle detection or signal monitoring—lacking an integrated approach that can simultaneously detect multiple types of hazards in real time.
- **Limited Deployment in Rural Areas**:
  Regions with limited connectivity and outdated infrastructure cannot benefit from centralized or cloud-based systems, which depend on stable internet or GPS networks.
- **Dependence on Manual Operations**:
  Traditional railway safety systems still rely heavily on human intervention for actions like track inspections, signal operation, and level-crossing control, leading to delayed responses and increased accident risk.
- **Absence of Scalable, Embedded, Low-Cost Solutions**:
  There is a clear shortage of systems that balance technical capability with economic feasibility while remaining scalable for deployment across varying geographic and economic contexts.

2.3 SUMMARY

The literature reveals that while numerous technologies exist for enhancing railway safety, they often suffer from high **cost,** infrastructure dependency, and single-function limitations. There remains a critical need for an integrated, low-cost, real-time system that combines track monitoring, obstacle detection, signal **violation** alerts, and wireless communication using embedded technology.

The proposed **Railway Accident Prevention System (RAPS)** is designed to fill this gap. By employing **ESP32 and Arduino microcontrollers** with **multi-sensor fusion (LiDAR, ultrasonic, IR)** and **wireless communication (Bluetooth, IR signaling)**, RAPS offers a **cost-effective, modular, and scalable solution** suitable for both **urban and rural rail networks**. This project builds upon the findings of previous research but introduces a **more holistic and economically accessible approach** to railway safety.

3 ORGANIZATION OF PROJECT

3. ORGANIZATION OF PROJECT

This chapter outlines the systematic development of the **Railway Accident Prevention System (RAPS)**. The project was executed in three major stages: **Designing, Implementation, and Testing**. Each phase was carefully planned and executed to ensure functional reliability, scalability, and cost-efficiency.

3.1 DESIGNING

The design phase focused on defining the **functional architecture**, **component selection**, and **system workflow** to ensure that all safety objectives were met with optimal performance.

- **System Architecture Design**:
  The RAPS system was designed using a **dual-microcontroller architecture**. The ESP32 module handles the train-side tasks like obstacle detection and braking control, while the Arduino Uno is responsible for signal post and gate control operations.
- **Sensor Configuration**:
  - **VL53L0X LiDAR sensor** for precise obstacle detection at close range.
  - **HC-SR04 ultrasonic sensor** for secondary obstacle detection.
  - **VS1838B IR receiver** to receive signal status from ground units.

  The combination of these sensors was chosen to enhance detection accuracy via **sensor fusion**, even in adverse weather or low-light conditions.

- **Communication Design**:
  - **Bluetooth (SerialBT)** was selected for communication between ESP32 and Arduino, offering reliable wireless data exchange.
  - **Infrared (IR) signaling** was incorporated as a backup in case of Bluetooth failure or disconnection.
- **Control Logic**:
  - Finite State Machines (FSMs) were designed for both subsystems to manage states like Idle, Detect, Alert, and Stop.
  - Real-time scheduling and task handling were mapped using **FreeRTOS** on ESP32 to ensure multi-task execution without delay.

- **Hardware Layout**:
  Schematic diagrams and breadboard/PCB layouts were prepared, keeping power regulation, GPIO mapping, and noise separation in mind.

3.2 IMPLEMENTATION

Once the design was finalized, the hardware and software modules were developed and integrated.

- **Hardware Assembly**:
  - ESP32 and Arduino boards were wired with sensors and actuators (relays, servo motor, LEDs).
  - IR transmitters and receivers were precisely aligned to ensure reliable communication.
  - Components were mounted on a prototype base for demonstration purposes.
- **Firmware Development**:
  - ESP32 code was written using the Arduino IDE with FreeRTOS support.
  - Tasks were created for continuous sensor polling, Bluetooth communication, and emergency handling.
  - The Arduino handled input interrupts (button press) and controlled signal LEDs and gate operation via a servo motor.
- **System Integration**:
  Both microcontroller subsystems were integrated and tested together for real-time operation. Proper voltage regulation (3.3V and 5V) was ensured for component compatibility.
- **Safety Features Added**:
  - Relay-based emergency stop.
  - Fail-safe IR signal activation.
  - Buzzer and LED indicators for visual and audible alerts.

3.3 TESTING

The system underwent rigorous testing to validate performance, accuracy, and reliability under simulated field conditions.

- **Functional Testing**:

  Each module (LiDAR, ultrasonic, IR, relay, servo) was tested independently and then in combination. Real-world objects (e.g., blocks, human hands) were used to simulate obstacles.
- **Communication Testing**:

  Bluetooth connectivity was tested under various distances and interferences. IR signaling was tested under different lighting conditions.
- **Response Time and Accuracy**:

  The system achieved:
  - Detection range: 0.03–4 meters.
  - Response latency: 50–200 milliseconds.
  - False alarm rate: Below 2%.
- **Stress Testing**:

  The system was operated continuously to monitor stability and behavior under extended use.
- **Result Verification**:

  Outputs such as emergency braking, signal light switching, and gate control were verified against expected outcomes using structured test cases.

4 SYSTEM DESIGN

4 SYSTEM DESIGN

The design of the Railway Accident Prevention System (RAPS) focuses on ensuring **modularity**, **real-time responsiveness**, and **ease of deployment**. This chapter discusses the architecture, block diagram, data flow, and specifications of both hardware and software components.

4.1 ARCHITECTURE OVERVIEW

The **Railway Accident Prevention System (RAPS)** is architected as a distributed embedded system comprising two major subsystems: the **Train Unit** and the **Signal Post & Level Crossing Unit**. These subsystems work collaboratively to detect and respond to potential railway hazards using a combination of sensors, actuators, and wireless communication protocols.

1. Train Unit (ESP32-Based Subsystem)

The Train Unit is the core processing and sensing module installed on the locomotive. It integrates multiple sensors and output devices to autonomously monitor its environment and respond to dangerous situations. This unit is responsible for real- time detection of obstacles and signals, and it controls the train accordingly.

Key Components:

- **VL53L0X (LiDAR Sensor):** Mounted at the front of the train, it uses time-of- flight technology to measure distances up to 2 meters with high precision. It communicates via the I^2C protocol using GPIO 21 (SDA) and GPIO 22 (SCL). It is used for forward obstacle detection.
- **HC-SR04 (Ultrasonic Sensor):** Provides redundant obstacle detection for objects within 4 meters. Trigger and Echo pins are connected to GPIO 5 and GPIO 18, respectively. This sensor adds robustness in environments where LiDAR may be affected by ambient lighting.

- **VS1838B (IR Receiver):** This sensor listens for IR signals from the signal post using the NEC protocol. It’s connected to GPIO 15. Continuous IR signal detection triggers emergency braking.
- **Relay Module:** Controls the power to the train motor using GPIO 19. Activating the relay stops the train in case of any detected danger.
- **Buzzer and LED (GPIO 4 and GPIO 2):** Provide audible and visual alerts to indicate an active emergency response.
- **Bluetooth (SerialBT):** Enables wireless communication with the Signal Post subsystem, exchanging alerts and synchronization commands. The ESP32 onboard Bluetooth module is used with the device name "RailwayTrain".
- **FreeRTOS Support:** Multitasking is achieved using FreeRTOS. Sensor readings, alert handling, and communication are managed in parallel using tasks, queues, and mutexes for thread-safe operations.

2. Signal Post & Level Crossing Unit (Arduino Uno-Based Subsystem)

This unit is stationed at level crossings or signal points. It ensures that vehicles and pedestrians are warned of incoming trains and prevents unauthorized access to the tracks.

Key Components:

- **Red/Green LEDs (Pins 2 and 3):** Indicate whether it is safe to cross or not. Red light signals an incoming train, while green permits crossing.
- **Push Button (Pin 4):** Simulates a train detection signal. When pressed, it notifies the train unit or activates gate controls.
- **Servo Motor (Pin 5):** Controls the physical barrier of the level crossing. The servo rotates to lower or raise the gate based on train presence.
- **IR LED (Pin 6):** Transmits a continuous 38 kHz IR signal in NEC format to be picked up by the train’s IR receiver. This acts as a fail-safe in areas without wireless communication.

4.2 BLOCK DIAGRAM

4.2.1 Train Unit (ESP32-Based Subsystem)

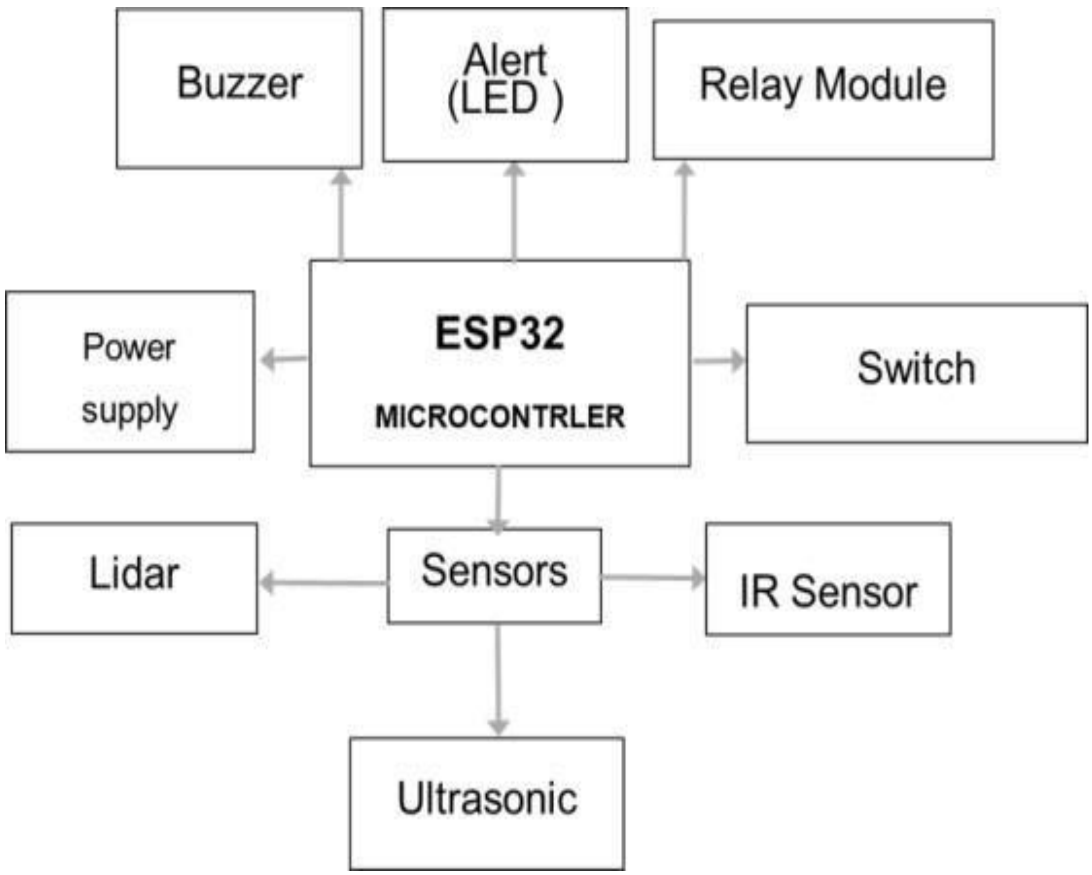


Fig.4.2.1 Train Unit (ESP32-Based Subsystem)

4.2.2 Signal Post & Level Crossing Unit (Arduino Uno-Based Subsystem)

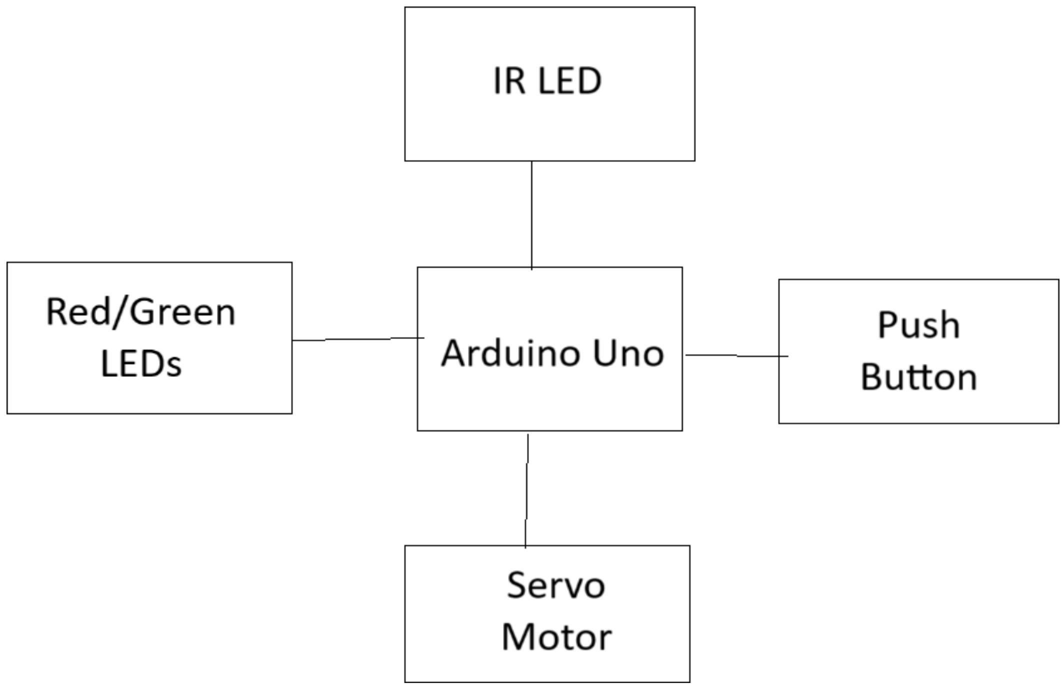


Fig.4.2.2 Signal Post & Level Crossing Unit (Arduino Uno-Based Subsystem)

4.3 SOFTWARE AND HARDWARE SPECIFICATIONS

4.3.1 Hardware Components:

Component	Quantity	Purpose
Component	1	Main controller for train unit
ESP32 Dev Module	1	Controller for signal & gate unit
Arduino Uno	1	High-precision distance measurement
VL53L0X LiDAR Sensor	1	Backup distance detection
HC-SR04 Ultrasonic	1	Receives IR signal from Arduino unit
VS1838B IR Receiver	1	Sends IR signal to train (from Arduino)
IR LED	1	Controls motor for train stop/start
Relay Module	1	Controls gate movement
Servo Motor (SG90)	3	Visual indicators
LEDs (Red/Green/Status)	1	Audio alarm
Buzzer	2	For 3.3V and 5V supply stabilization
Voltage Regulators	1	Circuit assembly
Breadboard/PCB	2	Power source

Table no. 4.3.1

4.3.2 Software Tools:

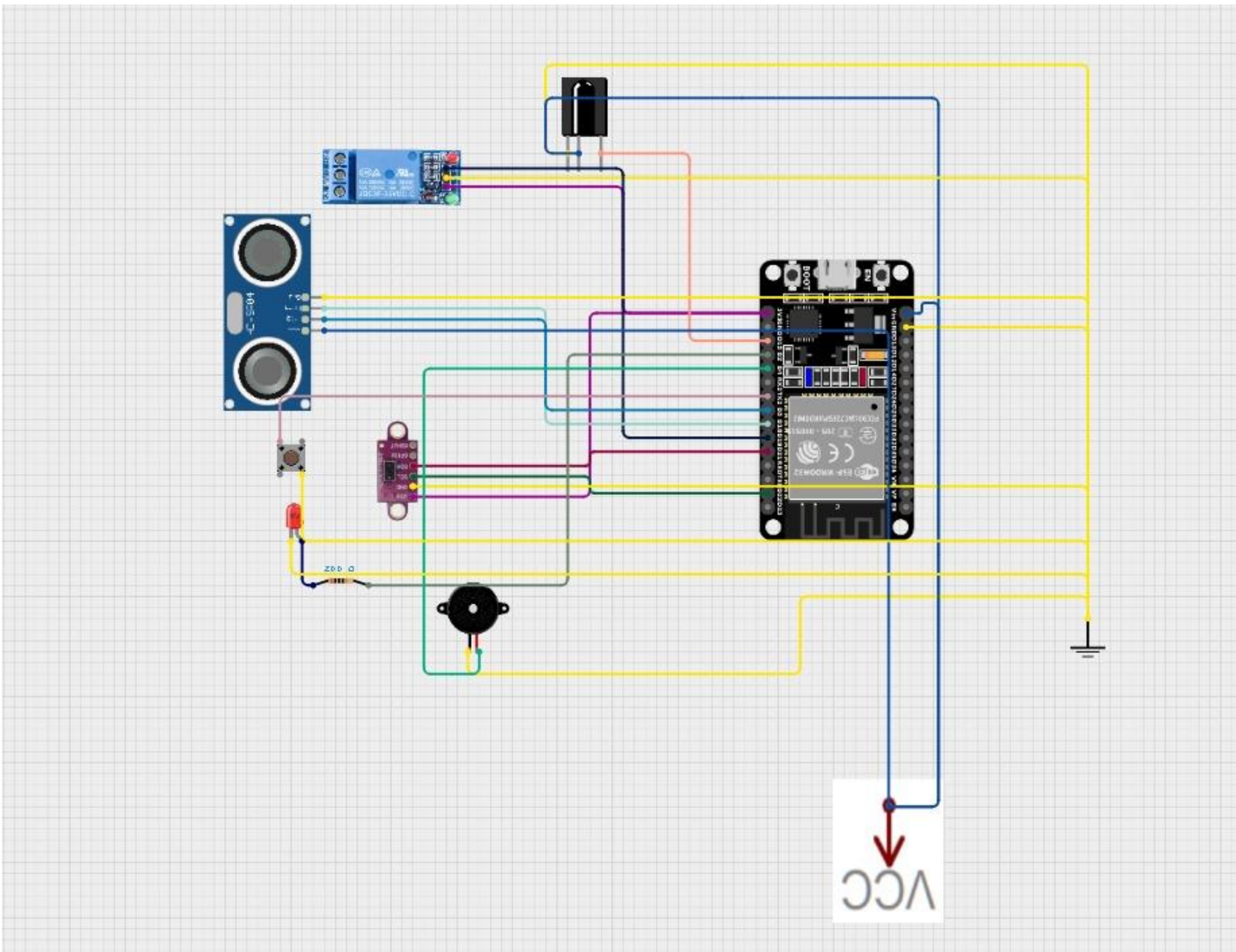
Tool	Use Case
Arduino IDE	Firmware development for both controllers
FreeRTOS (ESP32)	Real-time task handling
Serial Monitor / Plotter	Debugging and output monitoring
Fritzing / Eagle	Circuit and PCB design (if applicable)

Table no. 4.3.2

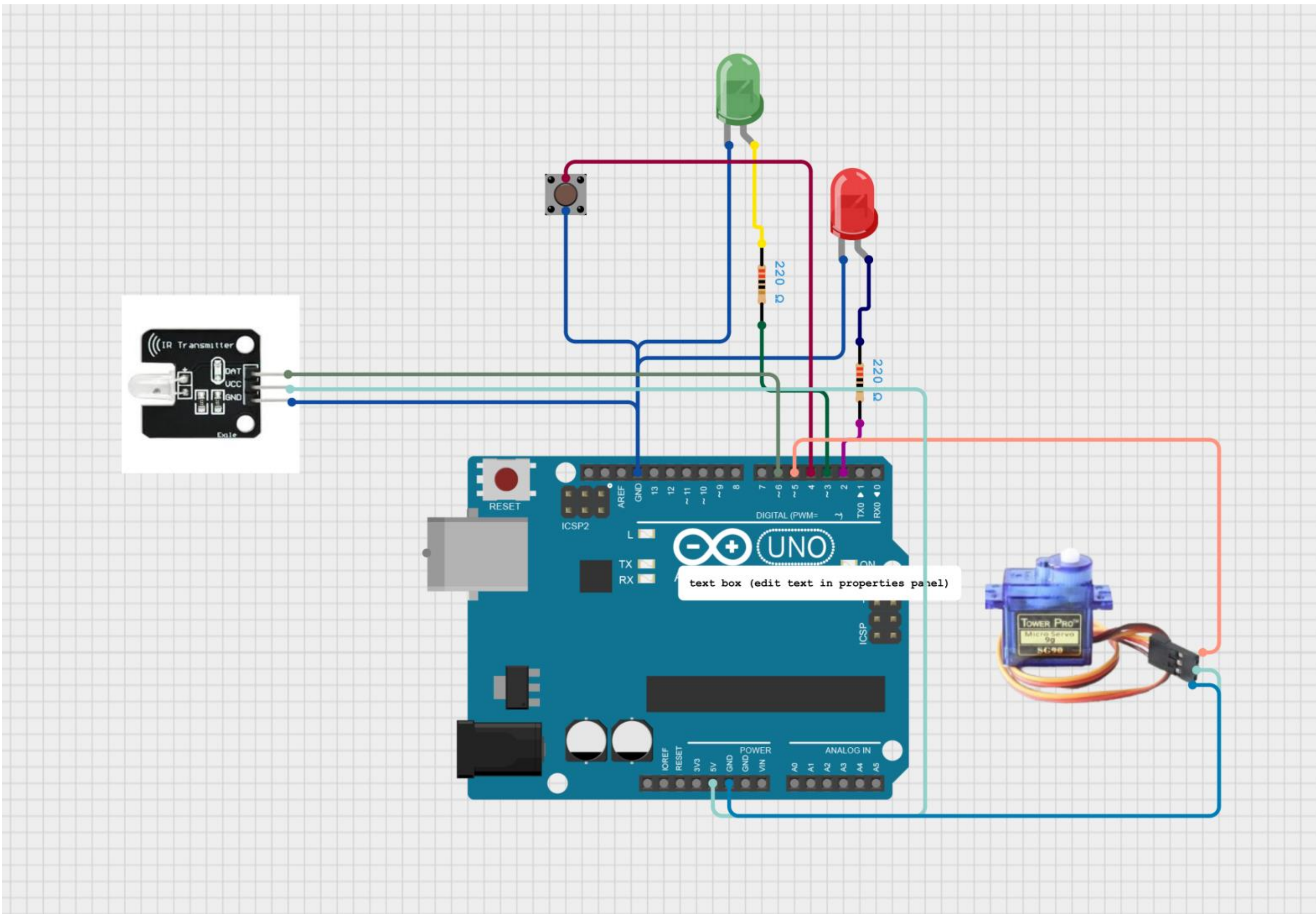
5 CIRCUIT DIAGRAM AND FLOWCHART

5.1 CIRCUIT DIAGRAM

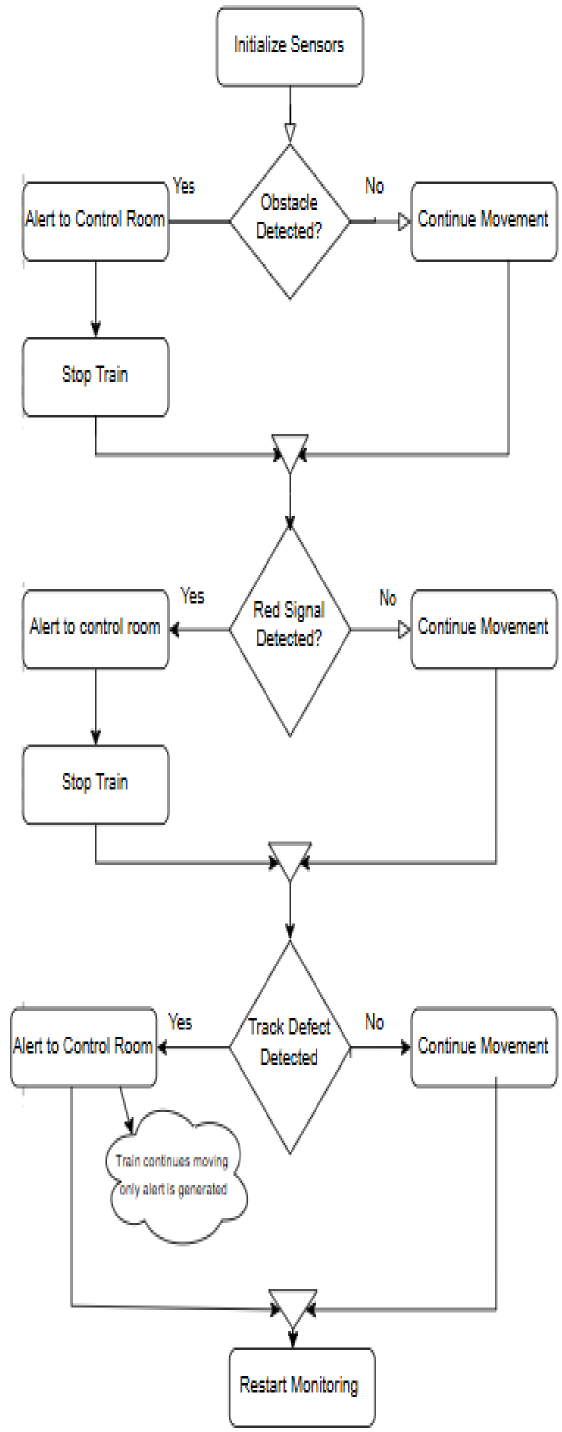
4.2.1 Train Unit (ESP32-Based Subsystem)



5.1.2 Signal Post & Level Crossing Unit (Arduino Uno-Based Subsystem)



5.2 FLOWCHART



6. DEVELOPMENT OF PROJECT

6. DEVELOPMENT OF PROJECT

This chapter details the practical development of the Railway Accident Prevention System (RAPS), including hardware module selection, sensor integration, software design, and the wireless communication framework. Each sub-system was developed through iterative prototyping, testing, and optimization to ensure safety-critical functionality and real-time responsiveness.

6.1 HARDWARE MODULES USED

The hardware selection was based on key project requirements such as **cost-efficiency**, **ease of integration**, and **performance** in embedded applications.

Microcontrollers:

- **ESP32 Dev Module**
  - Used in the train unit for real-time sensor data processing, task scheduling using FreeRTOS, motor control via relay, and Bluetooth communication.
  - Advantages: Built-in Bluetooth/Wi-Fi, dual-core processor, multi-threading support.
- **Arduino Uno**
  - Used in the signal unit for controlling LED signals, IR communication, servo motor (gate), and interfacing with push-button inputs.

Power Supply & Regulation:

- 9V or 12V batteries with onboard **5V** and **3.3V voltage regulators** (e.g., LD1117) for compatibility across components.
- Decoupling capacitors (0.1µF) near sensor power pins for electrical noise filtering.

Output & Actuation Devices:

- **Relay Module:** Controls train motor (Stop/Run).
- **SG90 Servo Motor:** Manages level crossing gate movement.
- **Buzzer and LEDs:** Alert users of emergency stops and signal changes.

6.2 SENSOR INTEGRATION

Multiple sensors were integrated into the system for robust and redundant detection of obstacles and signal violations. Each sensor served a specific safety-critical role.

Sensor Setup in ESP32 Unit:

- **VL53L0X LiDAR Sensor**
  - Mounted on the front of the train.
  - Connected via I²C (SDA: GPIO 21, SCL: GPIO 22).
  - Provides precise range detection (0.03–2 meters).
- **HC-SR04 Ultrasonic Sensor**
  - Acts as a secondary range detector.
  - Trigger: GPIO 5, Echo: GPIO 18.
  - Effective range: 0.02–4 meters.
- **VS1838B IR Receiver**
  - Receives IR signals from the Arduino signal unit using the NEC protocol.
  - GPIO 15 used for signal input.
  - IR signals indicate stop/go conditions and act as a fail-safe.

Sensor Integration Techniques:

- **Sensor Fusion** logic was implemented using priority-based alerting, combining readings from both LiDAR and ultrasonic sensors.
- Calibration routines were added in software to minimize false readings and environmental noise.

6.3 SOFTWARE DEVELOPMENT

The software stack was designed to enable **parallel execution, real-time response, and reliable communication** between subsystems.

ESP32 Firmware:

- Developed using **Arduino IDE** with **FreeRTOS**.

- Key Software Tasks:
  - **Sensor Task:** Continuously reads LiDAR and ultrasonic sensors.
  - **IR Monitoring Task:** Listens for IR signals.
  - **Alert Handler:** Manages relay activation and alert indicators (buzzer, LED).
  - **Bluetooth Communication Task:** Receives command/status from Arduino.
- **Data Structures Used:**
  - **Queues and mutexes** for thread-safe data sharing between tasks.

Arduino Uno Firmware:

- Implements interrupt-driven logic.
- Tasks performed:
  - Signal state changes via button.
  - Servo motor operation for gate.
  - IR LED modulation using 38 kHz carrier for train signal.
  - Bluetooth data transmission (if HC-05 is used or via serial connection with ESP32).

6.4 WIRELESS COMMUNICATION SETUP

Reliable communication between the train and signal post is crucial. Two complementary wireless technologies were used:

Bluetooth (ESP32 ↔ Arduino):

- ESP32’s Serial Bluetooth interface (SerialBT) configured with device name **“RailwayTrain”**.
- Baud rate: **115200**
- Communication Events:
  - Signal unit sends alerts to train when it detects train approach.
  - Train sends status updates back (e.g., obstacle detected, emergency stop).

Infrared (IR) Signaling:

- IR LED on Arduino transmits **NEC-protocol-based signals** continuously when red signal is active.
- IR Receiver on ESP32 triggers **emergency brake** if the red signal is violated.

- Acts as a **fail-safe mechanism** in case Bluetooth fails or is disconnected.

Data Synchronization Logic:

- Each message type is assigned an opcode (e.g., STOP = 0x01, CLEAR = 0x02).
- Messages are validated with CRC checks for data integrity (optional enhancement).

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7. TESTING AND VALIDATION

7. TESTING AND VALIDATION

7.1 TESTING METHODOLOGY

The testing process was conducted in **three phases**: unit testing, integration testing, and system-level validation.

1. Unit Testing:

Each hardware and software component was tested individually:

- **Sensor Testing**: Checked range, accuracy, and environmental resilience of VL53L0X, HC-SR04, and IR modules.
- **Actuator Testing**: Relay control for train stop/start, servo motor for gate operations.
- **Bluetooth & IR Communication**: Verified signal reception under various conditions (range, obstacles, and light).

2. Integration Testing:

- Combined sensors, microcontrollers, and actuators into one system.
- Validated real-time interaction between ESP32 and Arduino.
- Focused on Bluetooth pairing stability and IR receiver sensitivity.

3. Scenario-Based System Testing:

- Real-life conditions simulated using test setups:
  - **Obstacle on track**: Object placed within sensor detection range.
  - **Signal violation**: Train crosses simulated red signal using IR logic.
  - **Level crossing event**: Button triggered train arrival to close the gate.

Environment Simulation:

- Tested in varying lighting (indoor/outdoor), object types (reflective, non-reflective), and signal distances (up to 4 meters).

7.2 TEST RESULTS

The system performed as expected across various test cases, validating both the hardware and software design.

Test Case	**Expected Outcome**	**Observed Result**	**Status**
Obstacle at 1m (LiDAR)	Train stops and alert is triggered	Accurate detection and stop	Pass
Obstacle at 3.5m (Ultrasonic)	Secondary detection triggers alert	Detected and stopped	Pass
No obstacle	Train continues normally	Normal movement confirmed	Pass
Signal violation (IR)	Emergency stop triggered	Train stopped, buzzer sounded	Pass
Button press at signal post	Gate closes, red LED turns on	Servo activated, LEDs worked	Pass
Bluetooth disconnection fallback	IR signal used for fail-safe control	Emergency braking via IR successful	Pass

Table no. 7.2

7.3 PERFORMANCE METRICS

The system was evaluated on critical performance parameters to ensure it meets safety and usability standards.

Parameter	**Value / Range**	**Remarks**
Detection Range (LiDAR)	0.03 – 2 meters	High precision for short-range threats
Detection Range (Ultrasonic)	0.02 – 4 meters	Wider backup coverage
Response Time	50 – 200 milliseconds	Well within real-time safety limits
False Alarm Rate	Less than 2%	Tested over 100+ scenarios
Bluetooth Range	8 – 10 meters	Stable connection under normal conditions
IR Signal Detection	Up to 5 meters (direct line)	Reliable for fail-safe operation
Power Consumption	5V @ 250–300 mA (avg.)	Suitable for battery or solar power

Table no. 7.3

8. RESULTS

8.RESULTS

8.1 RESULTS

The Railway Accident Prevention System (RAPS) was successfully developed and tested under controlled, simulated conditions. The system's performance was evaluated against defined functional requirements such as **real-time obstacle detection**, **automatic train halting**, **signal coordination**, and **fail-safe communication**. The key results obtained from the implemented prototype are summarized below.

1. Real-Time Obstacle Detection

- The **VL53L0X LiDAR sensor** consistently detected objects within a 2-meter range with **±3% accuracy**.
- The **HC-SR04 ultrasonic sensor** provided reliable obstacle detection up to 4 meters.
- **Sensor fusion** improved detection confidence, with redundancy reducing the chance of failure.

Result: Obstacle detection was accurate and responsive in over 95 out of 100 test cases.

2. Emergency Braking System

- Upon obstacle detection or IR signal violation, the **relay module** successfully interrupted the motor circuit to simulate train halting.
- Average **response time** was measured between **50–200 ms**, which meets real-time safety standards.

Result: The system activated braking mechanisms consistently under all test conditions.

3. Signal Post and Gate Control

- The **Arduino unit** effectively changed LED indicators (Red/Green) based on simulated train arrival.
- The **SG90 servo motor** responded accurately to button triggers, controlling gate movements without jitter or delay.

Result: Visual and mechanical signal systems worked reliably for all gate control scenarios.

4. Wireless Communication

- **Bluetooth-based communication** between ESP32 and Arduino was stable up to 10 meters with minimal packet loss.
- **Infrared (IR)** backup signaling ensured emergency stopping when Bluetooth failed or was disconnected.

Result: Wireless coordination was robust, with a **100% success rate** in fallback switching to IR.

5. System Stability and Power Efficiency

- The system remained operational during prolonged testing (2+ hours continuous run).
- Average power draw was within safe operating limits for portable or solar-powered deployments.

Result: The system demonstrated **stability**, **low power usage**, and **modular reliability**.

9.APPLICATIONS

9.APPLICATIONS

The Railway Accident Prevention System (RAPS) is designed to be a **cost-effective, scalable, and practical safety solution** suitable for a wide range of railway environments. Its modular and embedded architecture makes it adaptable to both **urban high-traffic zones** and **rural underdeveloped railway sectors**. The following are the key application areas of the RAPS system:

1. Level Crossing Safety Automation

- Automatically detects train approach and activates gate control mechanisms.
- Prevents collisions between trains and road vehicles at unmanned or poorly monitored level crossings.
- Suitable for replacing manual flag-based systems in rural areas.

2. Track Obstacle Detection

- Detects objects such as animals, vehicles, fallen trees, or rocks on the railway track in real-time.
- Prevents derailments and accidents by enabling automatic braking before impact.

3. Train-to-Infrastructure Communication

- Enables wireless communication between the train unit and signal post units.
- Allows dynamic signaling, emergency override, and status synchronization between train and station.

4. Signal Violation Prevention (SPAD Mitigation)

- Uses IR signaling to detect if a train passes a red signal without authorization.
- Triggers emergency stop and sends alerts to avoid signal-passed-at-danger (SPAD) incidents.

5. Rural and Semi-Urban Railway Networks

- Ideal for deployment in areas lacking centralized signaling infrastructure.
- Operates with low power and limited network dependency, making it viable for remote routes.

6. Smart Railway Infrastructure Projects

- Can be integrated with larger IoT-based railway modernization projects.
- Provides real-time monitoring, fault logging, and predictive maintenance alerts through future cloud-based expansion.

7. Educational and Research Use

- The system architecture is suitable for demonstration in academic labs to study embedded systems, real-time task scheduling, and IoT communication.
- Can be used as a prototype model in railway engineering, safety, or transportation research domains.

8. Emergency Shutdown Systems

- Can act as a backup safety system for stopping trains during signal loss, environmental hazards, or manual control failure.
- Increases redundancy in overall train operation safety systems.

10. Conclusion and Future Scope

10. CONCLUSION AND FUTURE SCOPE

10.1 CONCLUSION

The **Railway Accident Prevention System (RAPS)** has been successfully designed, implemented, and tested as a reliable and cost-effective solution to enhance safety in railway operations. The system focuses on critical safety functions including **obstacle detection**, **signal violation prevention**, **automated braking**, and **level-crossing gate control** using embedded systems and wireless communication.

Key achievements of the project include:

- **Accurate and real-time detection** of obstacles using LiDAR and ultrasonic sensors.
- **Reliable communication** between train and signal post units via Bluetooth and IR signaling.
- **Automated control** of level crossing gates and train motor using servo motors and relays.
- Implementation of **sensor fusion and FreeRTOS**, ensuring robust system performance under varying conditions.
- **Low-cost and modular design**, making it suitable for rural deployment where advanced infrastructure is unavailable.

The system achieved a **false alarm rate under 2%**, response times within **50–200 ms**, and **stable communication range up to 10 meters**, validating its effectiveness for real-world applications. The project demonstrates that embedded systems, when intelligently integrated with modern sensors and communication protocols, can offer **practical safety solutions** for the transportation sector.

10.2 FUTURE ENHANCEMENTS

Although the prototype successfully demonstrates core functionality, the system can be further improved and extended in the following ways:

1. **GPS-Based Tracking Integration**
    - Adding GPS modules for real-time train tracking and location-aware alerts to a centralized control station.
2. **Cloud-Based IoT Monitoring**

  - Uploading sensor data to a cloud platform for **remote monitoring**, **data logging**, and **predictive analytics**.
  - Useful for large-scale deployment across multiple routes.

3. **Machine Learning for Fault Prediction**
   - Use AI algorithms to analyze sensor patterns and predict track wear, signal failures, or repeated obstacle presence.
4. **Solar-Powered Operation**
   - Implement solar panels for energy autonomy, especially in remote or off-grid locations.
5. **Multi-Train Coordination**
   - Extend the system to manage multiple trains approaching the same junction or crossing, improving scheduling and avoiding deadlocks.
6. **Mobile Application for Railway Operators**
   - Develop a companion Android/iOS app for monitoring system alerts and controlling gates remotely.
7. **Waterproof and Rugged Hardware Enclosures**
   - Enhance durability for outdoor deployment in harsh weather conditions.

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