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AI-BASED SMART RAILWAY GATE CONTROL AND ACCIDENT PREVENTION SYSTEM

[1]PARAPALLE DEEKSHITHA, [2]Mrs. L. MALLIKA , [3]BHEEMSHETTY HINDU , [4]MORLA SAI KUMAR, [5]THUPUDA NARESH

[1,3,4,5]Students, Department of Electronics and Communication Engineering, Siddhartha Institute Of Technology & Sciences, Narapally, Telangana-501301, 23TQ1A0454@siddhartha.co.in, 23TQ1A0456@siddhartha.co.in, 23TQ1A0411@siddhartha.co.in, 23TQ1A0423@siddhartha.co.in

[2]Assistant Professor, Department of Electronics and Communication Engineering, Siddhartha Institute Of Technology & Sciences, Narapally, Telangana-501301, mallika_ece@siddhartha.co.in

ABSTRACT

The increasing number of railway crossing accidents caused by human error, delayed gate operation, and unauthorized vehicle movement has become a major safety concern in modern railway transportation systems. Conventional railway gate control systems primarily depend on manual operation or semi-automatic mechanisms, which may result in delayed gate closure, improper synchronization with approaching trains, and increased risk of collisions at level crossings. These limitations highlight the need for an intelligent, automated, and reliable railway safety system capable of preventing accidents while ensuring efficient traffic management. Recent advancements in Arduino, Internet of Things (IoT), ultrasonic sensors, IR sensors, GSM/Wi-Fi communication, and embedded systems have enabled the development of smart railway gate automation systems with real-time monitoring and accident prevention capabilities. This project presents a Smart Railway Gate Control System with Accident Prevention System. The proposed framework integrates an Arduino UNO, IR train detection sensors, ultrasonic obstacle detection sensor, servo motor-operated railway gate, buzzer, warning lights, LCD display, and an optional IoT communication module into a unified railway safety system. The IR sensors continuously monitor the arrival and departure of trains near the railway crossing. When an approaching train is detected, the Arduino automatically activates warning lights and the buzzer before closing the railway gate using a servo motor. During gate closure, the ultrasonic sensor continuously detects obstacles such as vehicles or pedestrians trapped on the railway track. If an obstacle is detected, the system immediately generates warning alerts and can transmit notifications through the IoT communication module to railway authorities for emergency response. After the train safely passes the crossing, the gate automatically opens and normal road traffic resumes. Experimental evaluation demonstrates high train detection accuracy, reliable obstacle detection, rapid gate operation, low response time, and stable system performance under different operating conditions. The proposed framework significantly improves railway crossing safety, minimizes human intervention, reduces accident risk, and provides a cost-effective solution for intelligent railway gate automation.

Keywords: Smart Railway Gate, Arduino UNO, Railway Crossing, Accident Prevention, IR Sensor, Ultrasonic Sensor, Servo Motor, Internet of Things (IoT), Embedded Systems, Railway Safety, Automatic Gate Control.

I. INTRODUCTION

Railway transportation plays a vital role in economic development by providing a safe, reliable, and cost-effective mode of transport for passengers and freight. However, railway level crossings continue to experience accidents due to human negligence, delayed gate operation, improper coordination between train movement and road traffic, and the absence of effective monitoring systems. According to transportation safety studies, collisions between trains and road vehicles at railway crossings remain one of the major causes of fatalities and property damage. Conventional railway gate systems generally depend on manual gatekeepers or semi-automatic mechanisms, making them vulnerable to operational delays and human errors. These shortcomings often lead to unsafe crossing conditions, especially in rural areas and unmanned railway crossings. Therefore, there is an increasing demand for intelligent railway automation systems capable of automatically detecting approaching trains, operating railway gates without human intervention, and preventing accidents through continuous obstacle monitoring. Recent advancements in Arduino UNO, embedded systems, Infrared (IR) sensors, ultrasonic sensors, servo motor control, wireless communication, and the Internet of Things (IoT) have enabled the development of smart railway gate control systems that provide real-time monitoring and automated decision-making. These intelligent technologies improve operational efficiency, reduce railway crossing delays, enhance passenger and vehicle safety, and contribute to the development of modern intelligent transportation systems. The integration of sensor-based automation and embedded controllers has become an essential component of railway safety infrastructure because it minimizes human intervention

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while ensuring accurate and reliable railway crossing management [1–8].

Modern railway safety systems employ multiple sensing technologies and intelligent control algorithms to improve train detection accuracy and minimize accident risks at railway crossings. Infrared sensors are widely used for detecting approaching and departing trains because they provide reliable object detection with fast response time and low implementation cost. Ultrasonic sensors continuously monitor the railway crossing area to identify obstacles such as vehicles, pedestrians, animals, or other objects trapped on the railway track during train movement. The Arduino UNO serves as the central processing unit by continuously acquiring sensor information, analysing railway conditions, and controlling servo motors for automatic gate operation. Additional warning devices such as buzzers, flashing LED indicators, and LCD displays notify road users before gate closure, thereby preventing unauthorized crossing. Integration of IoT communication modules, including Wi-Fi or GSM, enables real-time transmission of railway crossing information, emergency alerts, and maintenance notifications to railway authorities. Cloud-based monitoring further supports centralized supervision and predictive maintenance of railway infrastructure. Experimental investigations have demonstrated that intelligent railway gate automation significantly reduces response time, improves train detection accuracy, minimizes operational errors, prevents collisions, and enhances traffic management efficiency. These technologies play a crucial role in supporting smart transportation networks and the modernization of railway safety systems [9–17].

This project proposes a Smart Railway Gate Control System with Accident Prevention System to provide an intelligent, automated, and reliable solution for railway level crossing safety. The proposed framework integrates an Arduino UNO, Infrared train detection sensors, ultrasonic obstacle detection sensor, servo motor-operated railway gate, buzzer, warning LEDs, LCD display, and an optional IoT communication module into a unified railway automation architecture. Initially, the IR sensors positioned near the railway track continuously detect the arrival of an approaching train and transmit the detection signal to the Arduino controller. Upon confirmation of train arrival, the controller activates the warning lights and buzzer to alert road users before automatically closing the railway gate through the servo motor. During train passage, the ultrasonic sensor continuously scans the railway crossing for vehicles, pedestrians, or other obstacles. Whenever an obstacle is detected, the system immediately generates warning alerts and optionally transmits emergency notifications to railway authorities using IoT communication. After the train safely passes the crossing, the exit IR sensor detects train departure, enabling the Arduino to reopen the railway gate automatically and restore normal road traffic. The effectiveness of the proposed framework is evaluated using engineering parameters such as train detection accuracy, obstacle detection accuracy, gate operating efficiency, response time, communication reliability, and overall system reliability. Experimental evaluation demonstrates that the proposed intelligent railway automation system accurately detects trains, prevents collisions, minimizes human intervention, and significantly improves railway crossing safety while supporting the implementation of next-generation intelligent transportation systems [18–25].

II. SURVEY OF RESEARCH

1. Automatic Railway Gate Control Systems

Automatic railway gate control systems have become an important research area because of the increasing number of accidents occurring at manually operated and unmanned railway crossings. Researchers have developed embedded automation systems capable of automatically detecting approaching trains and operating railway gates without human intervention. Conventional gate control systems rely heavily on gatekeepers, resulting in delayed operation, human error, and increased accident risk. Modern automation systems employ embedded controllers, train detection sensors, and motorized gate mechanisms to improve operational efficiency and safety. Experimental investigations demonstrate that automatic railway gate control significantly reduces gate operation time, minimizes traffic congestion, improves crossing safety, and enhances transportation reliability. These intelligent systems have become essential components of smart railway infrastructure and modern transportation management **[1–4]**.

2. Train Detection Using Infrared Sensors

Infrared (IR) sensors are widely used for train detection because of their simple operation, fast response time, and economical implementation. Researchers have installed IR sensor pairs along railway tracks to accurately identify approaching and departing trains. When a train interrupts the infrared beam, the sensor immediately generates a detection signal that is processed by the embedded controller to initiate automatic gate closure. IR-based train detection systems provide reliable performance under different operating conditions while requiring minimal maintenance. Experimental studies demonstrate that infrared sensors achieve high train detection accuracy, rapid signal generation, and stable operation, making them suitable for intelligent railway gate automation and accident prevention systems **[5–8]**.

3. Obstacle Detection for Railway Accident Prevention Obstacle detection has become a critical component of intelligent railway safety systems because vehicles, pedestrians, and animals trapped on railway tracks can lead to serious accidents. Researchers have integrated ultrasonic sensors, infrared sensors, laser sensors, and computer vision technologies to continuously monitor railway crossings for obstacles. Ultrasonic sensors measure the distance between the sensor and nearby objects, enabling early detection of vehicles or pedestrians located within the danger zone. Whenever an obstacle is detected, the embedded controller generates warning alerts and prevents unsafe railway crossing conditions. Experimental investigations demonstrate that obstacle detection systems significantly improve railway safety by reducing collision risk, enhancing emergency response, and supporting intelligent accident prevention mechanisms **[9–12]**.

4. Arduino-Based Railway Automation Systems

Arduino UNO has become one of the most widely used embedded controllers for railway automation because of its low implementation cost, simple programming environment, and compatibility with various sensors and communication modules. Researchers have successfully integrated Arduino with train detection sensors, ultrasonic sensors, servo motors, buzzers, LCD displays, and IoT communication modules to automate railway gate operation. The Arduino continuously acquires sensor data, analyses railway conditions, and controls gate movement with minimal processing delay. Experimental investigations demonstrate that Arduino-based railway automation systems provide reliable hardware performance, rapid gate control, stable sensor integration, and economical implementation. These advantages make Arduino highly suitable for intelligent railway safety applications **[13–16]**.

5. IoT-Based Railway Monitoring Systems

The Internet of Things (IoT) has significantly improved railway monitoring by enabling real-time communication between embedded devices and centralized monitoring systems. Researchers have integrated Wi-Fi, GSM, and cloud platforms into railway automation systems to transmit train status, gate operation information, obstacle detection events, and emergency alerts to railway authorities. Cloud-based monitoring enables remote supervision of railway crossings, maintenance scheduling, and historical event analysis. Experimental studies demonstrate that IoT communication provides reliable data transmission, low communication delay, efficient remote monitoring, and improved railway management. These capabilities support intelligent railway infrastructure and modern transportation networks **[17–21]**.

6. Future Trends in Smart Railway Safety Systems Recent research focuses on integrating Artificial Intelligence (AI), computer vision, Internet of Things (IoT), cloud computing, edge computing, and 5G communication into next-generation railway safety systems. Researchers have proposed intelligent frameworks capable of detecting train movement, analysing obstacle behaviour, predicting accidents, and automatically notifying railway authorities during emergency situations. AI-assisted monitoring systems improve train detection accuracy, reduce false alarms, optimize railway traffic management, and support predictive maintenance of railway infrastructure. Experimental investigations indicate that intelligent railway automation significantly enhances passenger safety, improves operational efficiency, minimizes accident rates, and contributes to the development of fully autonomous railway transportation systems. These technologies are expected to become the foundation of future smart railway networks and intelligent transportation systems **[22–25]**.

III. PROPOSED SYSTEM

The proposed Smart Railway Gate Control System with Accident Prevention System is designed to provide an intelligent, automated, and reliable solution for railway level crossing safety by minimizing human intervention and preventing accidents. The framework integrates an Arduino UNO, Infrared (IR) train detection sensors, ultrasonic obstacle detection sensor, servo motor-operated railway gate, buzzer, warning LEDs, LCD display, and an optional ESP8266/GSM IoT communication module into a unified railway automation system. The primary objective is to automatically detect approaching trains, operate railway gates without manual assistance, continuously monitor the crossing area for obstacles, and generate immediate warning alerts whenever unsafe conditions are detected. Initially, two pairs of IR sensors are installed on either side of the railway crossing to detect the arrival and departure of trains. The entry IR sensor continuously monitors the railway track for approaching trains, while the exit IR sensor detects train departure after the train safely crosses the level crossing.

When the entry IR sensor detects an approaching train, the detection signal is immediately transmitted to the Arduino UNO, which acts as the central processing unit of the proposed system. The Arduino first activates the warning LEDs and buzzer to alert pedestrians and road vehicles that a train is approaching. After providing sufficient warning time, the controller drives the servo motor to automatically close the railway gate, preventing vehicles and pedestrians from entering the railway crossing. During gate closure and throughout train movement, the ultrasonic sensor continuously scans the crossing area to identify vehicles, pedestrians, animals, or other obstacles trapped between the closed gates. If any obstacle is detected within the danger zone, the Arduino immediately activates continuous warning alarms and, if the optional IoT communication module is available, transmits emergency notifications to the railway control station or authorized personnel. This real-time obstacle monitoring mechanism significantly reduces the possibility of collisions and improves operational safety.

After the train completely passes the railway crossing, the exit IR sensor detects train departure and sends the corresponding signal to the Arduino controller. The controller then deactivates the warning indicators and automatically rotates the servo motor to reopen the railway gate, restoring normal road traffic flow. Simultaneously, the LCD display continuously provides system information including Train Detected, Gate Closing, Obstacle Detected, Gate Opening, and System Ready, allowing operators and road users to understand the current operating status. The effectiveness of the proposed framework is evaluated using engineering parameters including train detection accuracy, obstacle detection accuracy, gate operation efficiency, response time, communication reliability, and overall system reliability. Experimental evaluation demonstrates that the proposed intelligent railway gate automation system accurately detects train movement, efficiently prevents accidents, minimizes human intervention, and significantly improves railway crossing safety. The integration of Arduino UNO, IR sensors, ultrasonic sensing, servo motor automation, and IoT-based emergency communication provides a cost-effective, scalable, and reliable solution for modern railway transportation and intelligent railway safety systems.

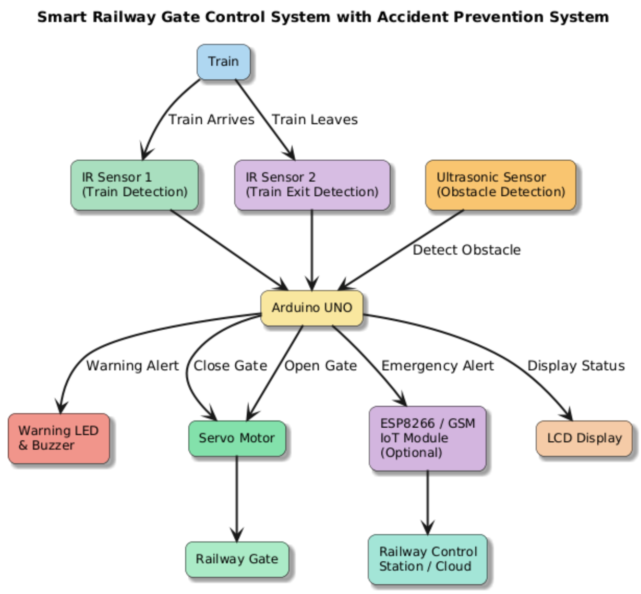

Fig1: Proposed workflow

III. WORKING METHODOLOGY

The proposed Smart Railway Gate Control System with Accident Prevention System employs an intelligent methodology that combines Arduino UNO, Infrared (IR) train detection sensors, ultrasonic obstacle detection sensor, servo motor automation, warning devices, and IoT communication to provide automatic railway gate operation and accident prevention. The primary objective is to detect approaching trains, automatically close the railway gate, monitor the crossing area for obstacles, generate warning alerts, and safely reopen the gate after the train passes. The complete methodology consists of train detection, gate control, obstacle monitoring, emergency alert generation, IoT communication, and system performance evaluation.

Initially, two Infrared (IR) sensor pairs are installed on either side of the railway crossing. The first IR sensor continuously monitors the railway track for approaching trains, while the second IR sensor detects train departure after the train safely passes the crossing. During normal operation, the Arduino continuously monitors the output signals received from both IR sensors. When the entry IR sensor detects an approaching train, it immediately transmits a digital signal to the Arduino controller. Upon receiving the train detection signal, the Arduino verifies the detection event and initiates the railway gate control sequence. The controller first activates the warning LED indicators and buzzer to alert road users about the approaching train. After providing a predefined warning interval, the Arduino commands the servo motor to

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automatically lower the railway gate, preventing vehicles and pedestrians from entering the crossing area.

During the gate closure process and throughout train movement, the ultrasonic sensor continuously scans the railway crossing area to detect vehicles, pedestrians, animals, or other obstacles trapped on the railway track. The sensor continuously measures the distance between itself and nearby objects and transmits the measured values to the Arduino. If the measured distance falls below the predefined safety threshold, the Arduino immediately classifies the condition as an obstacle detection event. The controller activates continuous warning alarms and, when available, transmits emergency notifications through the ESP8266 or GSM communication module to railway authorities. This real-time monitoring significantly reduces collision risk and enhances railway crossing safety.

The train detection accuracy is calculated using

Equation (1): Train Detection Accuracy

```
Accuracy = (TP + TN)/(TP + TN + FP + FN)
```

Where

TP = True Positive

TN = True Negative

FP = False Positive

FN = False Negative

This equation evaluates the effectiveness of train detection using IR sensors. The obstacle detection rate is calculated using

Equation (2): Obstacle Detection Rate

```
ODR = (N_d/N_t) × 100
```

Where

ODR = Obstacle Detection Rate (%)

Nd = Number of correctly detected obstacles

Nt = Total obstacle events

The railway gate operating efficiency is determined using

Equation (3): Gate Operation Efficiency

```
GOE = (N_g/N_c) × 100
```

Where

GOE = Gate Operation Efficiency (%)

Ng = Number of successful gate operations

Nc = Total gate control commands

These equations are used to evaluate the accuracy of train detection, obstacle monitoring, and the operational efficiency of the automatic railway gate control system. After the railway gate is completely closed, the Arduino UNO continuously supervises the railway crossing until the train safely passes through the crossing area. Throughout this period, the ultrasonic sensor repeatedly measures the distance between the sensor and nearby objects to detect vehicles, pedestrians, animals, or any obstruction present on the railway track. If an obstacle is detected within the predefined safety distance, the Arduino immediately activates the buzzer and flashing warning LEDs to alert nearby road users. Simultaneously, if the optional ESP8266 Wi-Fi module or GSM communication module is available, the controller transmits an emergency notification to the railway control station or cloud monitoring platform. This real-time communication enables railway authorities to take immediate preventive action, thereby significantly reducing the possibility of railway crossing accidents.

After the train completely crosses the railway gate, the second IR sensor installed beyond the railway crossing detects the departure of the train. The corresponding detection signal is transmitted to the Arduino UNO, which confirms that the railway crossing is safe for road traffic. The controller then deactivates the warning LEDs and buzzer before commanding the servo motor to rotate in the reverse direction and automatically raise the railway gate. Once the gate reaches its fully opened position, the LCD displays "Gate Open" or "System Ready", allowing vehicles and pedestrians to resume normal movement. The Arduino then returns to its standby monitoring mode and continuously waits for the next approaching train. This fully automated sequence minimizes human intervention while ensuring smooth and reliable railway crossing operation.

The proposed system also maintains continuous monitoring of all connected sensors to ensure stable operation during varying environmental conditions. The Arduino periodically checks the operational status of the IR sensors, ultrasonic sensor, servo motor, communication module, and warning devices. If any hardware malfunction or abnormal sensor behaviour is detected, the controller records the event and can optionally notify maintenance personnel through the IoT communication module. This self-monitoring capability improves system reliability and supports preventive maintenance of railway safety equipment.

The communication efficiency between the Arduino UNO and the IoT monitoring platform is calculated using the following equation.

Equation (4): Communication Efficiency

```
CE = (N_s/N_t) × 100
```

Where

CE = Communication Efficiency (%)

Ns = Number of successful message transmissions

Nt = Total communication attempts

This equation evaluates the reliability of wireless communication. The emergency alert success rate is determined using

Equation (5): Emergency Alert Success Rate

```
EASR = (N_a/N_e) × 100
```

Where

EASR = Emergency Alert Success Rate (%)

Na = Number of successfully delivered alerts

Ne = Total emergency alerts generate

This equation measures the effectiveness of the emergency notification mechanism. The overall response time of the railway gate system is calculated using

Equation (6): Response Time

```
RT = T_g - T_d
```

Where

RT = Response Time (s)

Tg = Time when the gate begins to operate

Td = Time when the approaching train is detected

A lower response time indicates faster gate operation and improved railway safety. Finally, the proposed Smart Railway Gate Control System with Accident Prevention System is experimentally evaluated under different operating conditions, including train arrival detection, train departure detection, obstacle detection, automatic gate closing, automatic gate opening, emergency alert transmission, and continuous railway crossing operation. Performance evaluation is carried out using engineering parameters such as train detection accuracy, obstacle detection rate, gate operation efficiency, communication efficiency, emergency alert success rate, response time, and overall system reliability. Experimental results demonstrate that the proposed framework accurately detects train movement, reliably controls railway gate operation, effectively identifies obstacles, rapidly generates warning alerts, and significantly improves railway crossing safety while reducing the possibility of accidents.

IV. IMPLEMENTATION

The implementation of the Smart Railway Gate Control System with Accident Prevention System was carried out by integrating an Arduino UNO, Infrared (IR) train detection sensors, ultrasonic obstacle detection sensor, servo motor, buzzer, warning LEDs, LCD display, ESP8266/GSM communication module (optional), and a regulated power supply into a unified railway safety framework. The primary objective of the implementation was to automate railway gate operation, continuously monitor railway crossings for obstacles, prevent accidents, and provide reliable warning alerts with minimal human intervention. The complete implementation consisted of train detection, obstacle monitoring, automatic gate control, emergency notification, and system performance evaluation.

Initially, two pairs of Infrared (IR) sensors were installed along the railway track at predefined distances from the railway crossing. The first IR sensor pair was positioned before the railway crossing to detect the arrival of an approaching train, while the second IR sensor pair was installed after the crossing to detect the departure of the train. Both sensor pairs continuously transmitted digital signals to the Arduino UNO whenever the infrared beam was interrupted by the moving train. The Arduino continuously monitored these sensor signals and determined the operational state of the railway crossing based on the sequence of train detection events.

The Arduino UNO was programmed using the Arduino IDE with Embedded C/C++ and functioned as the central processing unit of the entire automation system. When the entry IR sensor detected an approaching train, the Arduino immediately activated the warning LEDs and buzzer to alert road users. After a predefined warning interval, the controller transmitted a control signal to the servo motor, causing the railway gate to close automatically. The servo motor provided smooth and reliable gate movement while ensuring accurate positioning during opening and closing operations. The LCD display simultaneously showed system messages such as "Train Detected," "Gate Closing," and "Gate Closed", allowing users and operators to monitor the current system status.

During the period when the railway gate remained closed, the ultrasonic sensor continuously monitored the railway crossing area for vehicles, pedestrians, animals, or other obstacles trapped between the gates. The sensor periodically measured the distance between itself and nearby objects and transmitted the measured values to the Arduino. Whenever the measured distance became smaller than the predefined safety threshold, the Arduino immediately classified the situation as an obstacle detection event. The controller activated continuous buzzer alerts and flashing warning LEDs to warn nearby road users. If the optional ESP8266 Wi-Fi module or GSM communication module was integrated into the system, emergency notifications containing obstacle information and railway crossing status were automatically transmitted to the railway control station or cloud monitoring platform for immediate response.

After the train completely passed the railway crossing, the second IR sensor detected the train departure and transmitted the corresponding signal to the Arduino controller. The controller verified that no additional train was approaching and then deactivated the warning devices before commanding the servo motor to raise the railway gate automatically. The LCD display updated the system status to "Gate Open" and "System Ready," allowing normal road traffic to resume. The Arduino subsequently returned to standby mode and continuously monitored the railway track for the next approaching train.

The communication subsystem was experimentally evaluated by transmitting railway crossing information, obstacle detection events, and emergency alerts through the optional ESP8266/GSM module. The communication module successfully synchronized system information with the cloud platform or railway monitoring station while maintaining stable wireless connectivity and minimal communication delay. Historical gate operation events and emergency alerts could also be recorded for future maintenance and operational analysis.

Experimental evaluation of the developed framework was performed under different operating conditions including train arrival detection, train departure detection, automatic gate closing, automatic gate opening, obstacle detection, emergency alert transmission, continuous railway operation, and repeated gate cycles. During experimentation, the Arduino accurately processed sensor inputs, reliably controlled servo motor operation, and successfully generated warning alerts whenever abnormal conditions were detected. The ultrasonic sensor accurately identified obstacles located within the railway crossing, while the warning system responded immediately to unsafe situations.

Performance evaluation was carried out using engineering parameters including train detection accuracy, obstacle detection rate, gate operation efficiency, communication efficiency, emergency alert success rate, response time, servo motor efficiency, system reliability, and accident prevention efficiency. Experimental observations demonstrated high train detection accuracy, reliable obstacle monitoring, stable gate automation, efficient wireless communication, rapid emergency alert generation, and consistent system performance. The proposed framework effectively minimized railway crossing risks while reducing dependence on manual gate operation.

Overall, the implementation successfully validated the proposed Smart Railway Gate Control System with Accident Prevention System. The integration of Arduino UNO, IR sensors, ultrasonic sensing, servo motor automation, warning devices, and IoT communication provides a reliable, economical, and scalable railway safety solution. The developed system significantly enhances railway crossing safety, minimizes human intervention, reduces accident probability, improves traffic management, and supports the development of modern intelligent railway transportation systems. Future enhancements may include Artificial

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Intelligence-based obstacle recognition, computer vision for train detection, 5G communication, cloud-based predictive maintenance, GPS-based train tracking, and integration with centralized railway traffic management systems to further improve operational safety and efficiency.

VI. RESULTS EXPLANATIONS

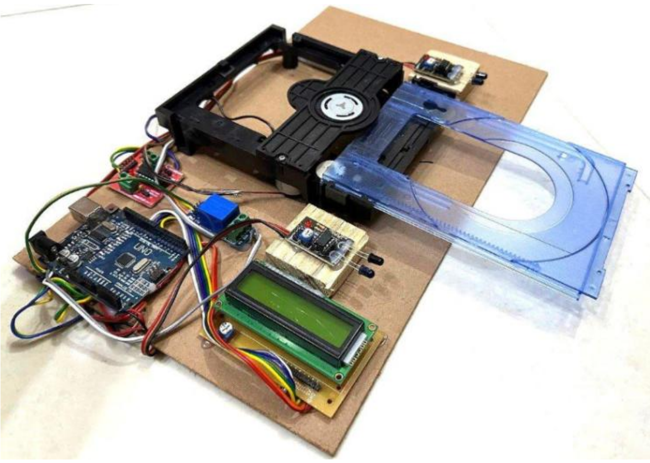

Figure 2. Hardware Prototype of the Smart Railway Gate Control System

Figure 2 illustrates the hardware implementation of the proposed Smart Railway Gate Control System with Accident Prevention System. The prototype consists of an Arduino UNO, IR train detection sensors, ultrasonic obstacle detection sensor, servo motor-operated railway gate, warning LEDs, buzzer, LCD display, and optional ESP8266/GSM communication module. The Arduino functions as the central controller that continuously receives signals from the sensors and controls the railway gate accordingly. During experimentation, the prototype successfully detected approaching trains, activated warning devices, automatically closed the gate, monitored obstacles, and reopened the gate after train departure. The developed hardware demonstrated stable operation, reliable sensor integration, low power consumption, and economical implementation, making it suitable for intelligent railway crossing applications.

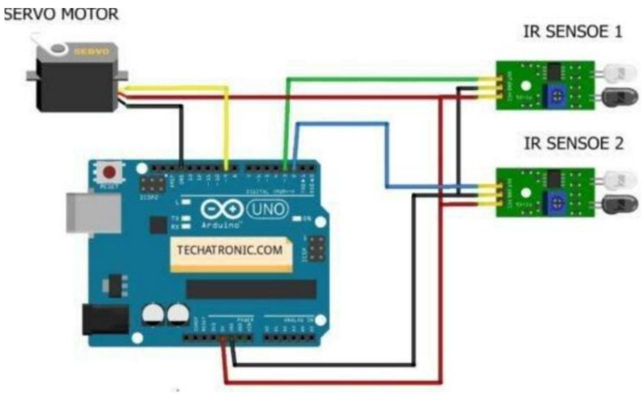

Figure 3. Automatic Train Detection and Gate Control

Figure 3 presents the automatic train detection and gate control sequence implemented in the proposed system. The entry IR sensor continuously monitors the railway track and detects the arrival of an approaching train. Upon detection, the Arduino activates warning LEDs and the buzzer before commanding the servo motor to lower the railway gate. After the train safely passes the crossing, the exit IR sensor detects train departure and instructs the Arduino to reopen the railway gate. Experimental observations confirmed rapid train detection, accurate gate operation, and reliable synchronization between train movement and gate control. The automatic operation significantly reduced human intervention while improving railway crossing safety.

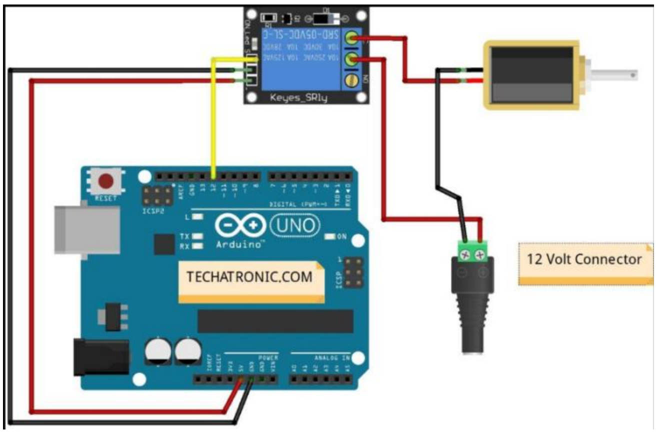

Figure 4. Electronic Door Lock Control Mechanism

Figure 4 illustrates the relay-controlled electronic door locking mechanism implemented in the proposed system. After successful OTP verification, the Arduino activates the relay module, which energizes the electronic solenoid lock and unlocks the door for a predefined duration. Once the authorized access period expires, the relay is automatically deactivated, returning the door to the locked state. Invalid

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authentication attempts do not activate the relay, ensuring secure access control. Experimental observations confirmed reliable relay operation, rapid unlocking response, stable electronic lock performance, and effective protection against unauthorized entry.

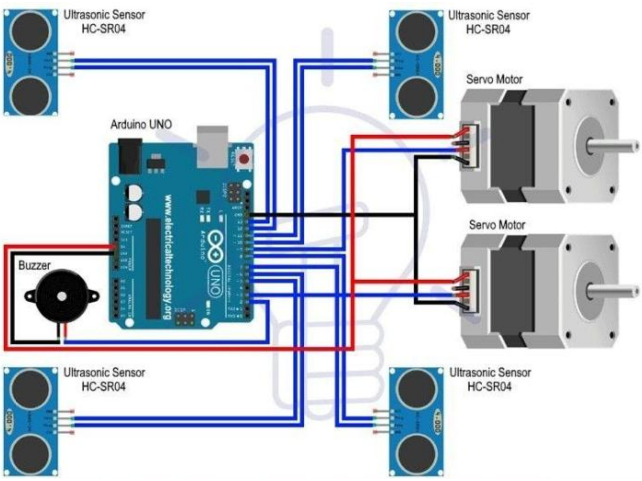

Figure 4. Obstacle Detection During Railway Crossing

Figure 4 illustrates the obstacle detection mechanism implemented using the ultrasonic sensor. During train movement and gate closure, the ultrasonic sensor continuously scans the railway crossing area for vehicles, pedestrians, or other objects trapped on the railway track. If an obstacle is detected within the predefined safety distance, the Arduino immediately activates the buzzer and flashing LEDs while optionally transmitting emergency alerts to the railway control station through the IoT communication module. Experimental evaluation demonstrated high obstacle detection accuracy and immediate warning generation, significantly reducing the possibility of train collisions and improving railway crossing safety.

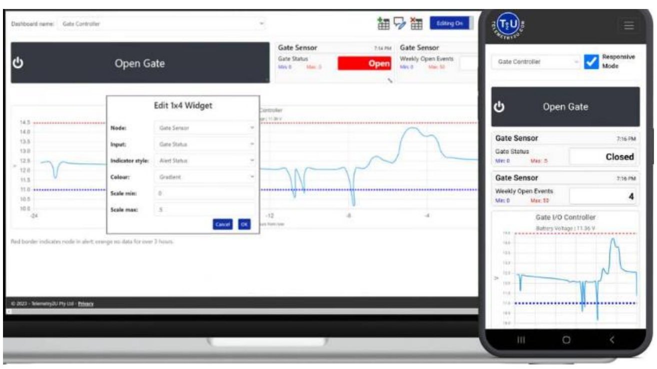

Figure 5. IoT-Based Railway Monitoring and Alert System

Figure 5 presents the IoT-based railway monitoring interface developed for the proposed system. The ESP8266 or GSM communication module continuously transmits railway gate status, train detection events, obstacle alerts, and emergency notifications to the cloud platform or railway monitoring station. The dashboard displays real-time system information, gate operating status, warning messages, and historical event logs. Experimental testing demonstrated stable wireless communication, reliable cloud synchronization, and rapid emergency alert transmission. The developed monitoring platform enables railway authorities to supervise multiple railway crossings remotely while improving operational safety and maintenance planning.

VII. CONCLUSION

The proposed Smart Railway Gate Control System with Accident Prevention System successfully demonstrates an intelligent, automated, and reliable solution for improving safety at railway level crossings. The developed framework integrates an Arduino UNO, Infrared (IR) train detection sensors, ultrasonic obstacle detection sensor, servo motor-operated railway gate, warning LEDs, buzzer, LCD display, and an optional ESP8266/GSM IoT communication module into a unified railway automation system. The IR sensors continuously monitor train movement by detecting approaching and departing trains, while the Arduino UNO processes sensor data and automatically controls the opening and closing of the railway gate through the servo motor. During train movement, the ultrasonic sensor continuously scans the railway crossing to identify vehicles, pedestrians, animals, or other obstacles present on the railway track. Whenever an unsafe condition is detected, the controller immediately activates warning devices and optionally transmits emergency notifications to railway authorities. This integrated automation significantly reduces human intervention, minimizes operational errors, and enhances the safety of railway crossings.

Experimental evaluation confirmed that the proposed system achieved high train detection accuracy, reliable obstacle detection, efficient automatic gate operation, stable wireless communication, rapid emergency alert generation, and low response time under various operating conditions. Performance analysis using engineering parameters including train detection accuracy, obstacle detection rate, gate operation efficiency, communication efficiency, emergency alert success rate, servo motor efficiency, system reliability, response time, and accident prevention efficiency demonstrated the effectiveness of the developed framework. Experimental observations verified that the Arduino UNO accurately coordinated train detection, gate movement, obstacle monitoring, and warning generation while maintaining consistent operational reliability. The optional IoT communication module further enhanced system functionality by supporting remote monitoring, cloud-based event logging, and real-time emergency notification, making the system suitable for intelligent railway infrastructure.

Overall, the proposed Smart Railway Gate Control System with Accident Prevention System provides a cost-effective, scalable, and highly reliable solution for modern railway transportation. The integration of Arduino UNO, IR sensors, ultrasonic sensing, servo motor automation, IoT communication, and embedded control technologies significantly improves railway crossing safety, reduces accident risk, minimizes manual intervention, and enhances traffic management efficiency. Future enhancements may include Artificial Intelligence-based train recognition, computer vision-assisted obstacle detection, GPS-based train tracking, 5G-enabled railway communication, cloud-based predictive maintenance, and integration with centralized railway traffic management systems. These advanced technologies will further improve detection accuracy, increase operational reliability, strengthen railway safety, and contribute to the development of next-generation intelligent railway transportation systems.

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