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Design and Implementation of an Automatic Gate for Cars at Railway Crossings

Damilare L. ADEKEYE[1*], Isiyaku SALEH[2], Yemisi E. AKINSELI[3]

[1*,2]Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria
[3]Department of Computer Engineering, Federal University of Technology, Minna, Nigeria

[1*]damilare@damilareadekeye.com, [2]isiyaku.saleh@futminna.edu.ng, [3]yemiakins90@gmail.com

Abstract

The growing volume of vehicular traffic at railway crossings has heightened the demand for advanced safety measures to prevent accidents and collisions between trains and vehicles. This project presents the design and implementation of an automated railway crossing gate system, developed to enhance safety and minimize human intervention. The proposed system utilizes infrared (IR) proximity sensors to detect the presence and movement of trains, enabling the timely closure and reopening of crossing gates. When a train approaches, the entrance IR sensor detects its presence and triggers the immediate closure of both gates, preventing vehicles and pedestrians from entering the crossing. Once the train has fully passed, the exit IR sensor detects its absence and signals the gates to reopen promptly, thus minimizing unnecessary traffic delays while ensuring maximum safety. The system's performance was evaluated using response time metrics, which measure the interval between train detection and actuator activation (buzzer, LEDs, and gate mechanism). The prototype achieved an overall response time of 4.6 seconds, with delay times ranging between 0.5 and 2.1 seconds, demonstrating high sensitivity and operational efficiency. These findings confirm the system's capability to respond swiftly and accurately under real-world conditions. This work presents a cost-effective, responsive, and reliable solution for railway safety infrastructure, offering significant potential to reduce accidents and enhance safety at level crossings through the use of automated train detection and gate control.

Keywords: *Railway crossings, accident, IR sensor, automatic gate, Atmega328P.*

1.0 Introduction

Electrical Railway crossings, where roadways intersect with railway tracks, are critical junctures where vehicular and train traffic converge [1]. These intersections are known to be accident-prone due to the inherent challenges in ensuring the safety of both road users and train passengers. In many parts of the world, railway crossings remain problematic areas in terms of transportation safety due to the lack of comprehensive safety measures [2]. Incidents at these crossings can lead to severe consequences due to the high speeds and large masses of trains. The traditional manual or semi-automated gate systems employed at many railway crossings have limitations that contribute to accidents. Delays in gate closure, human error, and inaccurate train arrival predictions have all been identified as factors in accidents at railway crossings utilizing IoT [3].

The incident in Lagos State, Nigeria, underscores the importance of addressing safety issues at railway crossings [4]. This unfortunate event necessitates the implementation of effective safety measures to prevent such accidents and protect the lives of road users. To mitigate the risks associated with railway crossings, there is a growing interest in adopting advanced technologies to enhance safety measures. Integrating automation and sensor-based systems offers the potential to create more efficient and reliable solutions [5]. Train-sensing automated gate systems ensure crossing safety. The development of automatic gates for cars and humans at railway crossing paths has become a fundamental requirement for human development and safety [6].

Researchers have proposed different techniques for the implementation of an automatic gate system. Thus, this chapter focuses on the related work of an automatic gate system in diverse dimensions and its fundamental characteristics, functions, advantages, and limitations.

In [7], a prototype model of an unmanned automatic level crossing system using a piezoelectric sensor was introduced. The piezoelectric accelerometer is used to plan a robotized automated level intersection framework. A model has been developed that successfully validates the door's opening and closing during the train's appearance. Also examined in [8] was an automated railway gate control system designed to enhance safety at level crossings and mitigate accidents. The system incorporated an automated railway switching mechanism to prevent head-on collisions resulting from manual switching failures. It also served as an anti-collision system, capable of identifying impediments on the track within a designated range. The device notified the locomotive engineer in advance, therefore reducing the danger of possible train accidents. This method underscored the efficacy of automation in improving railway safety. A similar study in [9] focused on a system utilizing IR detectors and loud alerts for automatic gate control based on train movement that was developed. The system added an ultrasonic sensor to identify obstacles and an IoT module to send real-time information. Infrared sensors identified the train approach, while an Arduino UNO and servomotor facilitated gate action. The addition of NodeMCU and GPS technology addressed delays in spotting compartment combustion events, improving the system's usefulness for both normal operations and emergencies.

In [10], a sensing device for identifying and localizing items such as people and cars at level crossings was developed. The system applied a radar-based "two out of two" logic interlocking device to ensure fail-safety. Deep learning models were studied for object recognition, with the MobileNet model getting 88% classification accuracy and a loss metric of 0.092. Future goals included refining detection algorithms and expanding uses to improve dependability. Similarly, an Artificial Intelligence-based Surveillance System for Railway Crossing Traffic (AISS4RCT) was created in [11]. This system combined real-time image processing and deep neural networks to track dangerous situations at crossings. GPU-accelerated image processing allowed quick recognition, and YOLO tiny model field tests gave an 89% average recall rate, showing the system's efficiency. Privacy and security steps were also stressed, ensuring compliance with data protection standards. The study in [12] suggested a Bayesian network (BN)-based approach for risk analysis at level crossings (LX). The framework involved describing risk scenarios, data gathering, model building, and validation. Applied to LX crashes in France, the BN model helped both forward inferences (predicting accidents) and backwards inferences (identifying high-risk factors). Sensitivity studies offered deeper insights into the impact of causal factors, making this approach useful for accident prevention strategies.

However, a comparative study of automatic versus railway-controlled crossings on public roads was conducted in [13]. Railway-controlled crossings, though safer, caused bigger delays. A formula was created to determine user delays based on daily road and train traffic. Findings showed that while automatic crossings reduced delays, the value of reduced delays often trumped the higher casualty risks. Britain's choice to keep railway-controlled crossings showed the prioritization of safety over convenience. An automatic railway gate control system equipped with high-speed warning capabilities was suggested in [14]. The system utilized remote detectors to identify train arrival and exit, triggering alarms and controlling gates via microcontrollers. The system was created to handle the rising accidents at unmanned crossings, making it suitable for both manned and unmanned situations to remove manual mistakes.

Furthermore, the method introduced in [15] aimed to reduce gate closure times and human work at crossings. Using two IR sensors and a controller designed with National Instruments LabVIEW, the system improved the accuracy of train position recognition. The enhanced design provided reliable operation at high-risk crossings, resulting in fewer accidents and better safety.

A cloud-based solution was also integrated into the study [2] to improve traffic near train gates. By displaying real-time gate status and conditions, the system reduced traffic congestion, fuel waste, and environmental impact. The integration of centralized monitoring gave travellers informed choices on alternative routes, improving traffic flow efficiency. A similar work was carried out in [16], which suggested an IoT-enabled automatic gate system utilizing ultrasound sensors, Arduino microcontrollers, and NodeMCU ESP8266. The system identified trains at a set cutoff distance and updated gate status in real-time to the cloud. Warning signs guaranteed road user safety during train passing, and the design minimized accidents and cut manpower reliance.

To overthrow a manual system, the study in [5] developed an automated train crossing aid system that operates at an optimized speed. The system showed gate state, timestamped closures, and traffic density. By handling problems such as human mistakes and traffic delays, this design greatly improved accident prevention and traffic control. [3] proposed a fully automated gate control system to remove human involvement at crossings. The system identified train arrival and exit using infrared sensors, automatically handling gate operations. Integration with the Blynk app gave users map navigation choices, ensuring smooth traffic control and safety.

These studies collectively stress methods that address human error, improve detection accuracy, and optimize traffic flow at the railway crossing. Systems like cloud-based tracking and AI-driven surveillance show the potential to improve safety at crossings, reduce delays, and ensure effective traffic management. These results underscore the transformative effect of technology in modernizing train crossing systems while favouring safety and efficiency.

In this study, the authors demonstrated the effectiveness of an automated gate control system using Atmega328P, and IR proximity sensors. The sensors are implemented at different strategic spots to detect the arrival and exit of trains to authenticate gate opening or closure. Utilizing technologies such as IR Proximity Sensors and IR Sensors, the system aims to provide timely responses to train movements, ensuring the gates close as trains approach and reopen after the train passes. This approach seeks to enhance safety by minimizing the possibilities of accidents and collisions at railway crossings

2.0 Materials and Methods

This study uses a compendium of advanced techniques and materials to develop the proposed system. This section highlights the methodology adopted in designing a prototype of the proposed system, showcasing the real-world operation of the automatic gate control analogy.

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2.1 Material

The circuit design for creating a prototype of an automatic gate for cars at railway crossings includes the following:

i. IR proximity sensor

A pair of infrared-emitting and receiving tubes makes up the sensor module, which can adjust to ambient light. The transmitting tubes emit a specific frequency of infrared when they identify the direction of an obstacle (a reflective surface), while the reception tube receives the reflected infrared. Following a comparator circuit processing, the green light is on; nevertheless, the signal output interface outputs a digital signal, which is a low-level signal. The detecting distance knob potentiometer may be adjusted, with a working voltage of 3.3V to 5V and an effective distance range of 2 to 30 cm. By adjusting the potentiometer, the sensor's detection range can be obtained with minimal interference. Its features are simple to assemble and operate, and it can be applied to a variety of situations, such as robot obstacle avoidance, avoiding cars, line counting, and tracking of black and white and other lines.

ii. Buck converter

One kind of DC-DC converter is a buck converter, sometimes known as a step-down voltage regulator (switching converter). It is a converter that lowers the input DC voltage to a predetermined DC voltage. The buck converter's high efficiency makes it a better DC-DC converter than a linear regulator for jobs like lowering a computer's main supply voltage to a level that the CPU, USB, and other components require.

iii. Arduino Nano

Arduino Nano is a complete microcontroller board that is suitable for use with a breadboard. The ATmega328P microprocessor is used in the construction of the Nano. It has 32 pins and a thin quad flat pack (TQFP) built in. Instead of a DC power jack, it contains a Mini-B USB port that may be used for serial monitoring and programming.

iv. MG996R Servo motors

The MG996R servo motor is well-known for its adaptability, accuracy, and simplicity of integration in a wide range of robotics, automation, and hobbyist projects. Understanding its fundamental principles is essential for effectively utilizing its capabilities. A metal gear servo motor having a maximum stall torque of 11 kg/cm is called the MG996R.

The motor rotates from 0 to 180 degrees per the duty cycle of the PWM wave applied to its signal pin, just like other RC servos. The precision of the control circuitry and the internal feedback mechanism determine how accurate the motor is. This accuracy makes MG996R servos suitable for tasks requiring precise angular positioning.

v. Buzzer

A buzzer is a simple and widely used electroacoustic device that generates sound, frequently in the shape of a recognizable buzzing or buzzer noise. It finds applications in various electronic circuits, alarms, notifications, and user interface feedback mechanisms.

The buzzer's pin arrangement is displayed in red and black below. Positive and negative pins are the two that are included. It can have a longer terminal or the '+' symbol to indicate its positive termination. The negative terminal, denoted by the '-' sign or short terminal, is connected to the GND terminal, whereas this terminal is powered by 3.3V–6V.

Other essential materials employed include a 13Amp AC plug, a switch, resistors, capacitors, LED lights, a Veroboard, and jumper wires.

2.2 Methods

The functionality of this system involves a cutting-edge hardware design with meticulous software integration that monitors and coordinates the system's operation about the condition of the railway track. Figure 1 illustrates the system architecture. It includes the power supply unit, microcontroller, IR Sensor, LED indicator, Motor, and Buzzer. The subsequent sections explain each of the components involved.

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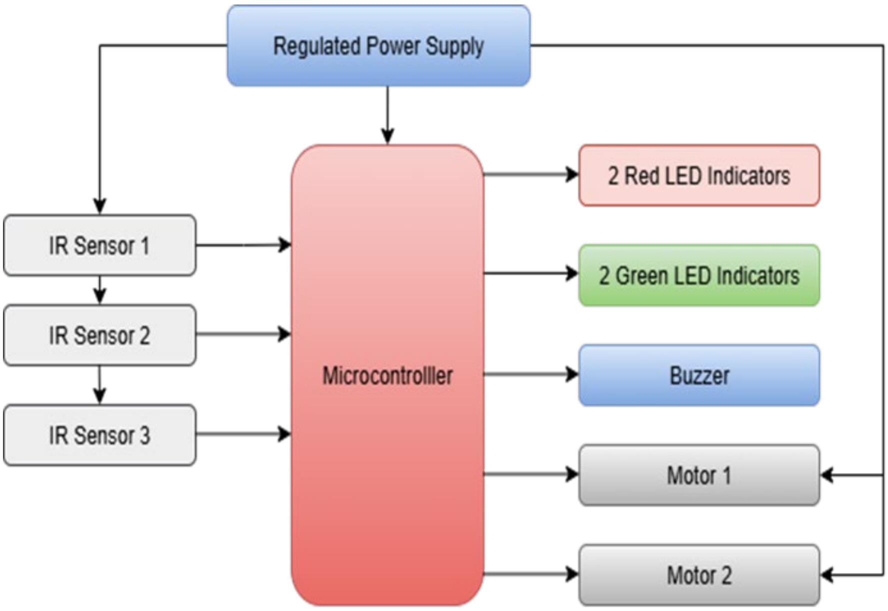

Figure 1: System design architecture

2.2.1 System Hardware Design

The system comprises several units that interact to ensure adequate functionality. This includes the power supply unit, control, sensing, and output units.

i. Power Supply Unit

The power supply unit ensures consistent and reliable operation of the system by converting and regulating electrical energy. A regulated DC power supply was designed to step down the 230V AC mains supply to a stable 5V DC output. This process involved the use of a transformer, a bridge rectifier, a filtering capacitor, and an LM7805 voltage regulator, working together to achieve efficient power delivery. A buck converter was also incorporated to enhance efficiency by stepping down the voltage with minimal energy loss. Figure 2 shows the regulated power supply's circuit diagram designed on Proteus software.

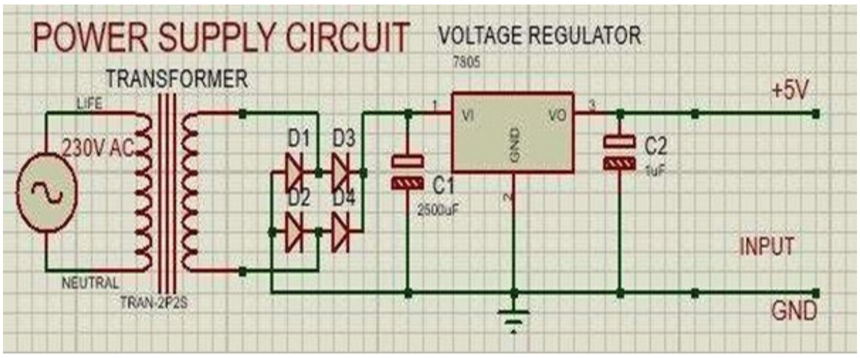

Figure 2: Power supply unit circuit diagram

The bridge rectifier converts the AC input into DC, offering advantages such as reduced ripple voltage and greater frequency compared to a half-wave rectifier. A filtering capacitor was chosen to smooth out the ripple and ensure safety in the circuit.

The equations (1-4) determined the choice of the capacitor. The capacitor's major function in the circuit is to smooth the ripple rectifier output.

The LM7805 voltage regulator maintained a fixed 5V DC output with minimal fluctuations. Additionally, the buck converter increased power efficiency by reducing energy losses associated with linear voltage regulation. When choosing a capacitor, the important parameters to consider are the capacitance, working voltage, and, assuming an ideal transformer, i.e., *input power = output power*.

$$V_p \, . \, I_p \;=\; V_s \, . \, I_s$$

$$I_p \;=\; \frac{V_s \, . \, I_s}{V_p} \qquad (1)$$

where V_p = primary voltage, V_s = secondary voltage, I_p = primary current, and I_s = secondary current.
For Peak voltage:

$$V_{peak} = V_{rms}\ x\ \sqrt{2} \qquad (2)$$

Where, V_{rms} = root mean square of AC voltage, V_{peak}= peak or maximum voltage after rectification.
Then, the ripple voltage is given by;

$$V_R = V_{peak} - V_{rms} \qquad (3)$$

where V_R = Ripple voltage.
Thus, the capacitance is calculated;

$$Capacitance, C = \frac{I_s}{2\ x\ f\ x\ V_R} \qquad (4)$$

where C = capacitance, f = frequency of the AC supply, I_s= load current.

ii. Microcontroller

The microcontroller serves as the system's central processing unit, where data is collected, analyzed, and distributed to other components. An Arduino Nano (ATmega328P) was chosen for this purpose due to its versatility, cost-effectiveness, and computational efficiency. It features 13 digital input/output pins, 8 analogue input pins, a mini-USB port, and a 16 MHz clock speed.

The Arduino Nano (as shown in Figure 3) is well-suited for this project because of its ease of programming, compatibility with breadboards, and ability to handle multiple input/output operations simultaneously. Additionally, its reduced power consumption and expanded ADC functionalities make it an ideal choice. Programming was conducted using the Arduino IDE with the C++ programming language, ensuring optimal system performance. Table 1 itemizes the features of the Arduino Nano, while Table 2 presents the description of the controller as used in this study.

Table 1: Features of the Arduino Nano

S/N	Features	Arduino Nano
1.	MCU	ATmega328P
2.	Voltage	5 volts
3.	The Flash Memory	32kb of which 2kb is used by the Boot-loader
4.	SRAM	2kilobyte
5.	Clock Speed	16 Mega Herts
6.	The Analogue pins	8
7.	The EEPROM	1kilobyte
8.	Ampere per pin	40 milliamps
9.	Input Voltage	7 -12 volts

Source: Adekeye *et al.* (2025)

Table 2: Description of the Arduino Nano pin

Pin of Arduino Nano	Nano Pin Name	Functions of the Pins
Vin	Power	Supply power
GND	Power	Supply ground
VCC	Power	5V DC Supply voltage
Pin 2	Output	Buzzer
Pin 3, 4, 5,	Input	The corresponding infrared sensors 1, 2, and 3.
Pin 6, 7, 8, and 9	Output	Red LED 2, Green LED 2, and Red LED 1 are the corresponding LEDs.
Pin 10	output	First Servo Motor PWM signal.
Pin 11	output	Second Servo Motor PWM signal.

Source: Adekeye *et al.* (2025)

iii. Sensing Unit

The sensing unit incorporates an IR Proximity Sensor to detect obstacles and measure distances. This sensor uses a pair of infrared emitting and receiving tubes to detect objects within a range of 2 to 30 cm. It operates by emitting infrared signals that reflect off nearby surfaces and are received by a detector, triggering a digital output signal.

The detection range is adjustable via a potentiometer, and the sensor is designed to work in varying light conditions. Its features, such as ease of installation, stable output, and compatibility with microcontrollers, make it suitable for tasks like obstacle avoidance and line tracking. The sensor's reliable performance enhances the overall functionality of the system.

iv. Output Unit

The output unit comprises a buzzer, LED indicators, and a servo motor, each playing a specific role in the system.

a. ***Buzzer*:**

The buzzer provides audible feedback, emitting a consistent beep sound when activated. Its compact design and low power requirements make it a practical choice for integrating sound into the system. The buzzer operates at 6V and is controlled via a switching circuit for precise activation.

b. ***LED Indicator*:**

LEDs act as visual indicators, signalling the system's operational status. Resistors are connected in series with the LEDs to protect them from excessive voltage or current, ensuring longevity.

c. ***Motor*:**

The MG996R Servo Motor was used for its high torque and precise control. It operates within a range of 0° to 180°, driven by a PWM signal. This motor was programmed to open and close a gate efficiently, enhancing the system's mechanical functionality.

2.2.2 Software Design

Proteus simulating software and Fritzing are the software that were utilized in building and designing the circuit diagrams, while the *Arduino IDE,* which uses the C++ programming language, was used in encoding the microcontroller. The *Proteus Software* is used for the circuit diagram of each module of the prototype, and the Fritzing software was used for the overall circuit diagram before the construction was made. The Arduino Nano microcontroller was encoded with its IDE in the C++ language and saved to the ATmega328p, which gives commands to the Arduino in the overall system working process. Figure 4 depicts the overall circuit design that was implemented for this project.

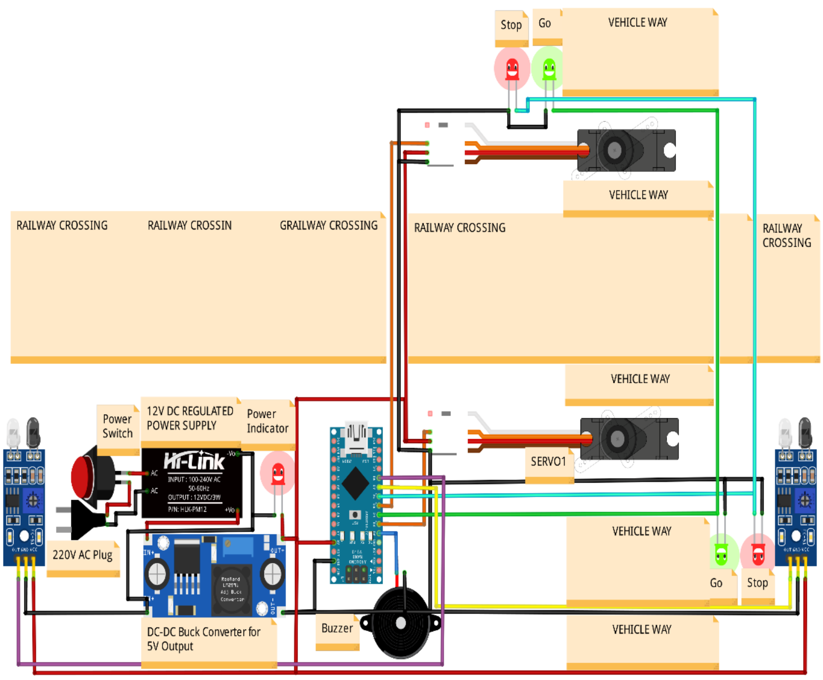

Figure 4: System circuit diagram

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2.2.3 System Integration and Operation

Figure 5 illustrates the system's operational flowchart, describing how the integrated devices communicate to ensure seamless system performance. The system operates at a regulated DC voltage supplied by the LM7805 voltage regulator, powering the microcontroller that automates the whole process.

The microcontroller is programmed with instructions to ensure safe railway crossings. When a train approaches the crossing, a proximity sensor detects its presence and sends a signal to the microcontroller, which is processed for further operation. This triggers the activation of the Buzzer and Red LED, alerting road users of the approaching train.

Upon receiving input from the IR sensor, the microcontroller initiates the gate-closing mechanism to block movement across the railway track. Once the exit IR sensor confirms the complete evacuation of the train in the proximity of the crossing area, the microcontroller reopens the gate, deactivates the buzzer and the red LED, and activates the green LED to indicate safe passage. This operational architecture exhibited the system's ability to guarantee safety at railway crossings by automated detection, signalling, and barrier management, therefore solving critical safety issues in railway transportation.

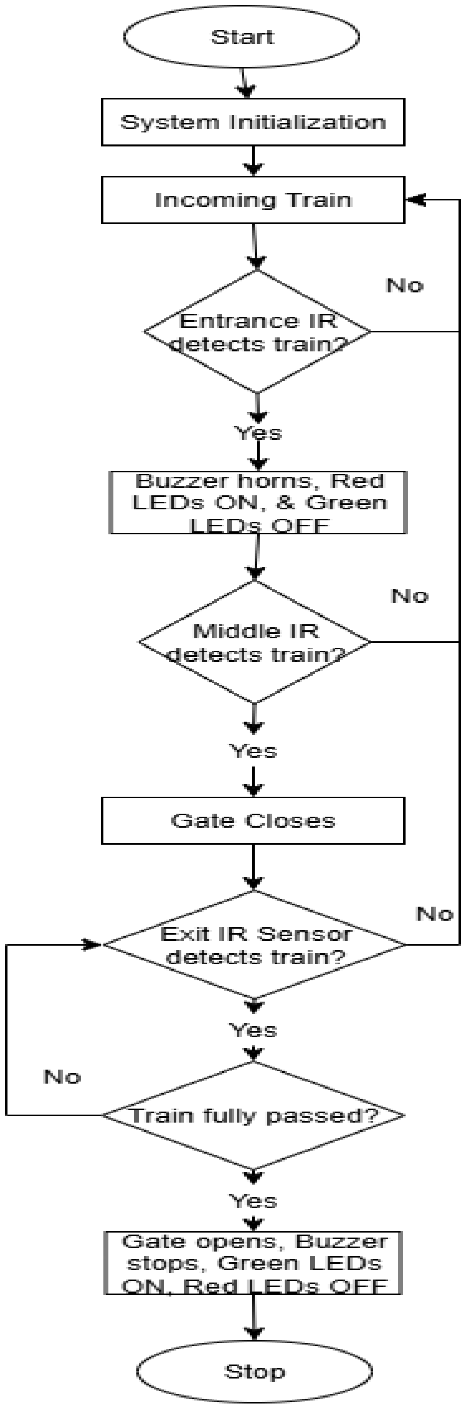

Figure 5: System operational flowchart

2.3 System Response Time

System response time is a key performance metric used to evaluate the sensitivity and efficiency of the railway crossing automation system. It measures the interval in seconds between the train detection by IR proximity sensors and the corresponding activation of system components such as the buzzer, LEDs, and gate mechanism. The response time encompasses three major parameters: detection time, actuation time, and delay, each measured in seconds.

3.0 Results and Discussion

This section presents the results obtained during the testing and evaluation of the automation system for railway crossings. Figure 6 presents the developed system prototype. The system was tested using a prototype setup that features three strategically positioned infrared (IR) proximity sensors—namely, IR Sensor 1 (Entrance), IR Sensor 2 (Middle), and IR Sensor 3 (Exit). It thus controls the corresponding system responses, including gate operation, alert signalling (buzzers and LEDs), and overall train state detection.

Figure 6: System prototype setup

The main aim of the system is to automate gate control in response to the real-time detection of a train. This is achieved through successive detection and actionable decision-making implemented within the microcontroller. Table 3 below presents the informed outcomes based on different combinations of input signals. It provides data that explains the overall system functionality at the railway crossing. The 1s and 0s in the table represent ON and OFF states, respectively. The gate closes and opens based on the signal received from the sensors. Thus, providing a safe condition for road users at the train station.

Table 3: Overall system test result

Input signal		**Output response**					
Train State Detector	**Train State**	**Buzzer**	**LED 1**		**LED 2**		**Gate**
			Red	**Green**	**Red**	**Green**	
IR Sensor 1 (Entrance)	Present	1	1	0	1	0	Close
	Absent	0	0	1	0	1	Open
IR Sensor 2 (Middle)	Present	1	1	0	1	0	Close
	Absent	1	1	0	1	0	Close
IR Sensor 3 (Exit)	Present	1	1	0	1	0	Close
	Absent	0	0	1	0	1	Open

Source: Adekeye *et al.,* (2025)

3.1 System Response and Logic Flow

Taking every necessary precaution, the circuit diagram was constructed, and the designed system gave the expected results. The developed system was tested to validate its functionality, and the test results presented in Table 3 analyzed the responses obtained at different stages of train detection via the prototype developed. The stages of the *input signal* are designed and assigned to be the *Entrance IR Sensor, Middle IR Sensor***,** and *Exit IR Sensor.*

i. The *Entrance IR Sensor* detects the initial approach of the train at the station
before reaching the crossing. Upon activation, it signals the Trafficator to activate the Red LED to the ON state and sound the *Buzzer* to make an alerting noise to the neighbourhood and initiate the gate closure as shown in Figure 7. Finally, informs the designed system's memory of the train's presence to act upon the *Middle IR sensor's*

input signal. Upon the train passing beyond this sensor (i.e., detection = absent), the system does not immediately reopen the gate – instead, it waits for further sensor confirmations.

ii. The *Middle IR sensor* serves to critically confirm the presence of the train at the crossing region. Irrespective of its state (present or absent), the sensor triggers the actions of the gate to remain closed, as presented in Figure 6, and maintains the alert signals. The vehicles in motion had stopped before the detection of the *Middle IR sensor,* while the Red LED Light remains ON until the train passes through the *Exit IR Sensor* and lastly updates the memory of the designed system with the current state of the system to act upon the detection of the *Exit IR Sensor*. This state activation in the middle sensor is programmed to ensure that even temporary detection due to gaps in the train compartment does not lead to early gate opening.

iii. The *Exit IR Sensor* detects the presence of the train and keeps the state of the train on hold until the train fully exits the zone. When the train is still present, the gate remains closed, and the alerts stay active. As the exit sensor confirms the train has fully cleared, the system deactivates the buzzer and turns ON the green LED. It signals the gate opening, as displayed in Figure 8.

3.2 Gate Control Function

The *Servo Motors* implemented for the gate design are equal and responsively triggered based on the system's intelligence. The motors listen to the overall logic obtained from the input signals (IR Proximity Sensors) to detect the presence of the train at each stage of the IR Proximity sensor until the last stage of the input signals is reached. The decision-making sequence ensures safety by implementing the following rules:

i. The gate closes immediately when the Entrance or Middle sensor detects the train.

ii. The gate remains closed even if the Middle sensor reads absent until the Exit sensor confirms full train departure.

iii. The gate opens only after the Exit sensor reads absent, signalling the end of the train's presence.

This sequential logic guarantees that the gate does not open while any part of the train remains within the crossing, thereby eliminating the risk of accidents.

Figure 7: Gate closed

Figure 8: Gate opened

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The system functionality test successfully demonstrated the detection of the arrival and exit of the train for early closure and opening of the gate at the railway crossings. Thus, it prevents possible accidents that might occur at the railway crossing.

To enhance clarity, Figure 9 depicts the activation state of system components (buzzer, LEDs, gate) corresponding to each sensor. It shows the sequence of system state transitions as the train progresses across the Entrance, Middle, and Exit sensors. When the train is present, the entrance and exit sensors trigger the activation of the output units (RED LED and Buzzer) and gate closure, as represented in the chart. The green LED is activated only when the entrance and exit sensors detect the absence of the train.

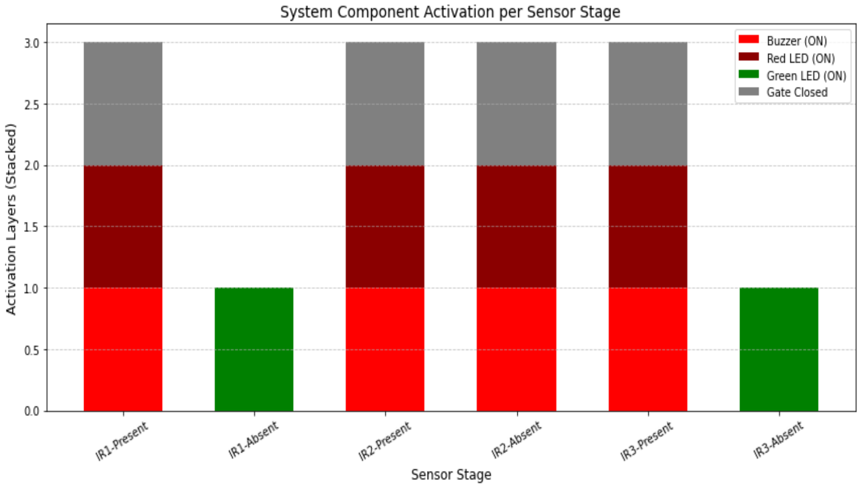

Figure 9: System component activation

3.3 Performance Evaluation

Table 4 presents the system response time recorded during the prototype testing phase. The data highlights the time elapsed between sensor detection and actuator response at different positions along the track.

Table 4: System response time evaluation

Sensor	Detection Time (s)	Actuation Time (s)	Delay (s)
IR sensor 1 (Entrance)	0.00	0.5 (Red LED, Buzzer, and Gate closure)	0.5
IR sensor 2 (Middle)	1.25	1.25 (No action, gate remains closed)	0.00
IR sensor 3 (Exit)	2.5	4.6 (Green LED + Gate Reopening)	2.1

Source: Adekeye *et al.* (2025)

In this study, system response time is used as the core performance metric to evaluate the efficiency and sensitivity of the railway crossing automation system. The total response time was measured to be 4.6 seconds, representing the duration from the train's initial detection at the entrance sensor to the final activation of the gate reopening after the train exits. The response time evaluation of the system is illustrated in Figure 10.

The system demonstrated minimal delay times, ranging from 0.5 to 2.1 seconds, indicating a high degree of responsiveness in handling critical transitions. Upon detection by the entrance IR sensor, the system immediately activates the alarm units, specifically, the Red LED and the buzzer, followed by the closure of the gate, which occurs with a 0.5-second delay.

As the train progresses to the middle IR sensor, no new action is initiated; however, the gate remains securely closed, maintaining safety throughout the train's passage. Once the train reaches the exit sensor, the system confirms the train's full evacuation, then activates the Green LED and reopens the gate after a 2.1-second delay.

Overall, the results confirm that all sensing and actuator units responded accurately and efficiently to the train movement. Under controlled test conditions, the system achieved 100% functional accuracy, reinforcing its potential for real-world deployment in enhancing safety at railway crossings.

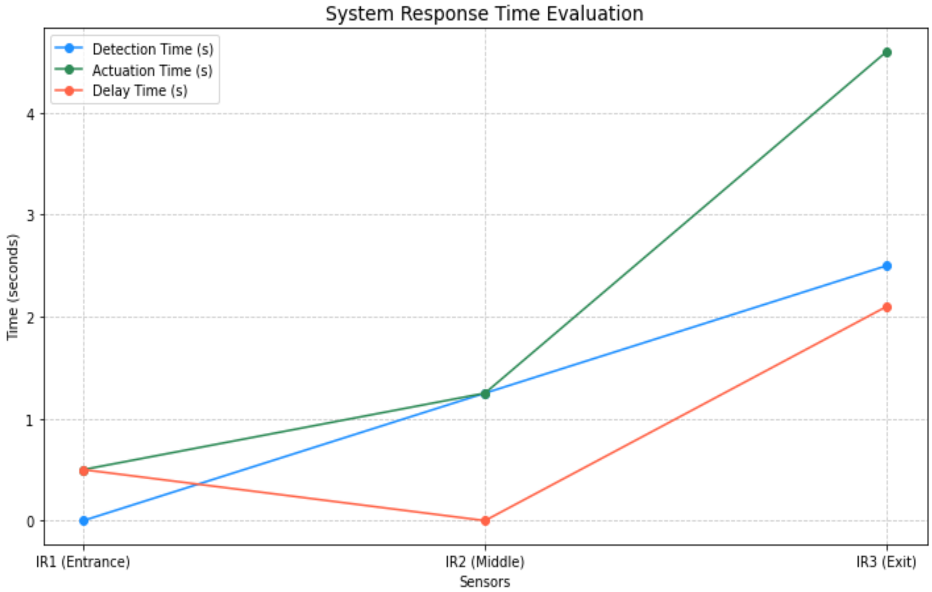

Figure 10: System response time evaluation

The delay time refers to the time interval between the moment of train detection and the activation of the signal. From the response time analysis displayed in Figure 10, the time delay at the entrance region is significantly shorter than at the exit region. This indicates that the system is highly sensitive to approaching trains and effective in sending a timely evacuation alert to the users at the railway intersection.

3.4 Summary

The prototype testing confirmed the reliable operation of the railway crossing automation system. The use of three IR sensors, along with a structured decision-making algorithm, ensured accurate detection of train presence and a safe control mechanism of the gate. The gate only reopened when the track was fully cleared, thereby validating the system's design intent to improve safety and reduce human intervention at railway crossings. The system exhibits an overall delay time range of 0.5 to 2.1 seconds to activate the signals. However, the overall system testing demonstrates 100% system component functionality and accuracy. The addition of visual tools provides a comprehensive understanding of the logic flow and verifies the system's responsiveness in real-time testing scenarios.

4.0 Conclusion

This project employed microcontroller-based sensors to construct an automatic car gate system at railway crossings, boosting traffic safety and operating efficiency. The system successfully prevents vehicular accidents, reduces fatalities from train-vehicle collisions, minimizes the need for manual intervention, and streamlines evacuation through timely responses. The resulting system displayed remarkable sensitivity to the train approach with a shorter time delay range of 0.5 to 2.1 seconds at the entrance and exit regions. Its efficacy demonstrates the necessity of integrating smart technology like sensors and automated controls into railway safety infrastructure to decrease crossing-related risks.

To ensure continuous performance, regular system monitoring and maintenance are needed. Future developments may involve incorporating vehicle-to-infrastructure communication for better synchronisation and traffic flow. Additionally, public outreach efforts can enhance acceptability and safety compliance, while engagement with important stakeholders, such as transport authorities and railway operators, will give valuable assistance for sustaining and increasing the system's impact.

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