

Research Article

Automated Railway Crossing System Using Multi-Sensor Integration for Enhanced Safety

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Abstract

Since then, railway-level crossings have become a significant cause of road and rail accidents, claiming dozens of lives each year, not only in Bangladesh but also at every railway crossing in the world. These accidents are increasing alarmingly owing to manual gate operation, staff negligence, and inadequate infrastructure. This situation creates a considerable challenge that must be overcome in a sophisticated way. To neutralize this issue, our project proposes a cutting-edge automated gate control system for railways that opens and closes the rail crossing gates automatically whenever a train is approaching. The system is equipped with advanced features such as obstacle detection, manual control override, and an emergency stop mechanism. It is built to be future-ready with integrations of solar power, IoT, and AI technologies. Moreover, there is also an arrangement to remotely control all the adjacent gates from an intermediate control room. In addition, the suggested system offers a safe and intelligent solution, particularly designed for rural and semi-urban areas in Bangladesh, where conventional railway crossing mechanisms are often outdated or absent. The system intends to significantly reduce the risk of accidents, ensure smoother train operations, and enhance public safety by maximizing automation and innovative technologies in regions that are typically underserved by modern infrastructure. It also holds potential for adoption in other countries facing frequent railway crossing mishaps. Our motto remains clear: "Automation for a Safer Bangladesh."

Keywords

Railway Automation, Obstacle Detection, IR Sensors, Servo Gate, Real-time Monitoring, AI Integration

1. Introduction

In many countries, including Bangladesh, railway crossings are still controlled manually. Thus, accidents frequently occur due to human error. Unstable management and the absence of adequate personnel drop the reliability of continuous monitoring. This problem is mainly prevalent in rural

and semi-urban areas. To solve this critical problem, an automatic railway gate control system has been developed. This project operates in real-time and is faithfully integrated with a sensor-based input system, making the gate control more reliable and secure. As an output, while a train is detected,

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the gate works automatically. Also, if any object is present near or under the gate, then the system displays a signal that helps decrease the likelihood of accidents. It uses updated characteristics like auto train detection and obstacle sensing, manual override options, and urgency shutdown capability, as well as audible and visual alerts plus real-time status indicators.

The main contributions are as follows:

- 1) Automated Detection: Multiple IR sensors detect train arrival and departure to trigger gate control.
- 2) Obstacles Detection under Gate: An IR sensor beneath the gate halts closure if any obstacle is detected.
- 3) Manual control Buttons: Dedicated buttons simulate IR triggers for emergency manual control.
- 4) Emergency Stop Button: In case of emergencies, an emergency stop button can instantly halt system activities.
Auditory Alerts: A buzzer provides sound as an alarm during gate operation and obstruction detection.
- 5) Traffic Signal: Simulate traffic signals to manage vehicle and pedestrian movement.
- 6) Control Room Indicators: LED indicators in a central control room identify which gate is malfunctioning or facing delays, allowing faster human response.

The whole set of modules works together to decrease human intervention, enhance operational efficiency, and prevent accidents.

2. Related Works

Automating railway gate operations has been a significant focus for researchers seeking to improve safety and reduce human errors. Early systems, such as the automated railway gate control system by Md. Mahmud et al. [1] and the Arduino-based gate signal control by Md. Emon et al. [2], primarily focused on basic gate automation to minimize manual intervention. While these approaches were effective in reducing human error, they lacked critical safety features like obstacle detection and manual override options, limiting their effectiveness during emergencies.

Subsequent research incorporated more advanced technologies. For example, Emran Hossen et al. [3] and Y. Maheswar et al. [4] leveraged IoT-based control to automate gates and monitor track integrity. These systems represented a technological advancement by enabling remote sensing and automated responses; however, they still did not address real-time obstacle detection or emergency manual controls. Similarly, Aditi Golder et al. [5] and Md. Abdullah Al Ahasan et al. [6] emphasized secure and resilient gate operations, focusing on operational reliability, yet the absence of obstacle detection mechanisms and manual override remained a common limitation.

Integration of sensors and microcontrollers offered incremental improvements. Vakiti Sreelatha Reddy [7] proposed an IoT-based accident preventive model using infrared sen-

sors and ESP32 microcontrollers to detect approaching trains at unmanned gates. This system enhanced detection capabilities compared to previous IoT-only approaches but did not incorporate real-time communication with central control rooms or mobile applications for remote monitoring. Mobile-based control solutions, such as Himanshu [8], introduced remote gate operation via smartphone apps, increasing user convenience and operational flexibility, though these systems relied heavily on internet connectivity and lacked fail-safe mechanisms for emergencies.

Emerging technologies like computer vision and AI have also been explored. Rafid Umayer Murshed et al. [9] utilized Raspberry Pi and deep learning for automated train detection, marking a significant innovation in intelligent sensing. However, vision-based systems are prone to environmental disruptions, such as low visibility or adverse weather, and do not provide manual override options. Similarly, Y. A. Jesuraj and K. Hemalatha [10] employed piezoelectric sensors for train detection, offering an alternative to visual and infrared sensing but still lacking comprehensive safety mechanisms.

In general, the literature shows a clear technological evolution from simple automation to IoT-enabled, sensor-based, and AI-driven systems. Each successive approach introduced incremental innovations—improved sensing, remote operation, or AI-based detection—but none fully integrated all critical safety features, namely real-time obstacle detection beneath gates, manual emergency controls, and reliable remote monitoring. This highlights a persistent gap in creating a comprehensive, fail-safe railway gate automation system that ensures safety under diverse operational and environmental conditions.

3. Methodology

The system uses several infrared (IR) sensors, microcontrollers, servo motors, LEDs, buzzers, and push buttons to mechanize the control of the railway gates for enhanced safety. The system also contains an obstacle-detection system and manual override systems for emergency cases.

3.1. Components

Arduino Nano

It is a microcontroller board based on the ATmega328P chip named Arduino Nano. It has 22 digital I/O pins, 14 of which are digital and 8 are analog. For programming, it has a USB Mini-B port, and it operates at 5 V. This microcontroller is the brain of this system - it receives input signals and delivers outputs. In this offered system, the Arduino nano gets input signals from IR sensors and a manual Switch. On the other hand, output components are Buzzer, Traffic Light, Led and Buzzer. It's smaller than Arduino UNO. Comparatively small size, and low power consumption makes it suitable for embedding in projects [1, 8].

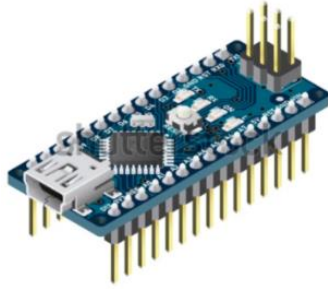


Figure 1. Arduino Nano.

IR Sensor

An IR sensor is an electronic component that is utilized to detect and measure infrared radiation in the environment. In this project, the IR sensor is crucial because it enables the sensing of a train or any other vehicle at the crossing. It sends an infrared beam to an LED and detects the reflected beam using a photodiode. When an object approaches the sensor, the IR light bounces off the object, and the sensor detects a change, which sends a signal to the Arduino Nano, and the Arduino Nano performs as required. IR sensors find applications primarily in proximity detection, counting, and object automatization [2, 3].



Figure 2. IR sensor.

Servo Motor

Is a motor that is easily controllable in position or rotational angle. That is why it is well-adapted explicitly in uses where an angle or a position must be shifted or rotated. It generally comprises a DC motor, a gearbox system, a position sensor (usually a potentiometer), and a control circuit. The servo motor is also connected to the Arduino Nano and provides it with a PWM (Pulse Width Modulation) signal. The signal instructs the servo motor at what angle the motor shaft is to rotate. The internal control circuit will then keep watch of the current position and match it against the desired position, making a correction to the movement of the motor if required. After the motor has reached the target angle, it stops moving. In this project, the gate opens and closes automatically, with the help of a servo motor, when the train is there and has passed the railway crossing [3, 4].



Figure 3. Servo motor.

Buzzer

A buzzer is a warning sound device that is usually employed to produce alarm or warning sounds. On a power connection, it produces a beep or buzz sound. There are two types of buzzers, which are active and passive. An active buzzer has an internal oscillator and will start buzzing the moment power is applied to it. A passive buzzer, on the other hand, needs to be provided with an external signal (e.g., a PWM signal) to switch it on and make it buzz. The project requires the use of the buzzer to inform drivers, humans, and animals prior to closing the gate. The buzzer will give a warning to prevent accidents when the IR sensors detect an approaching train [5, 6].



Figure 4. Buzzer.

Traffic Light

It guides cars and people to show their intentions through a visual display. In this project, LEDs show whether the crossing is safe or dangerous. They are green and red LEDs, easy to operate, and ideal for traffic lights, making railway crossings more visible in the event of accidents [6, 7].



Figure 5. Traffic Light.

LED

An emergency light is also called standby lighting equipment, which is primarily turned on in case of an unexpected incident, such as a setback or obstruction. In the project, an alarm signal is triggered as soon as an obstacle gets wedged beneath the gate, warning adjacent rooms and traffic to be cautious [6].



Figure 6. LED.

An ON/OFF manual switch is a simple electrical switch that gives the operator first-level control of the operation of



Figure 7. Manual (ON/OFF) Switch.

3.2. System Components

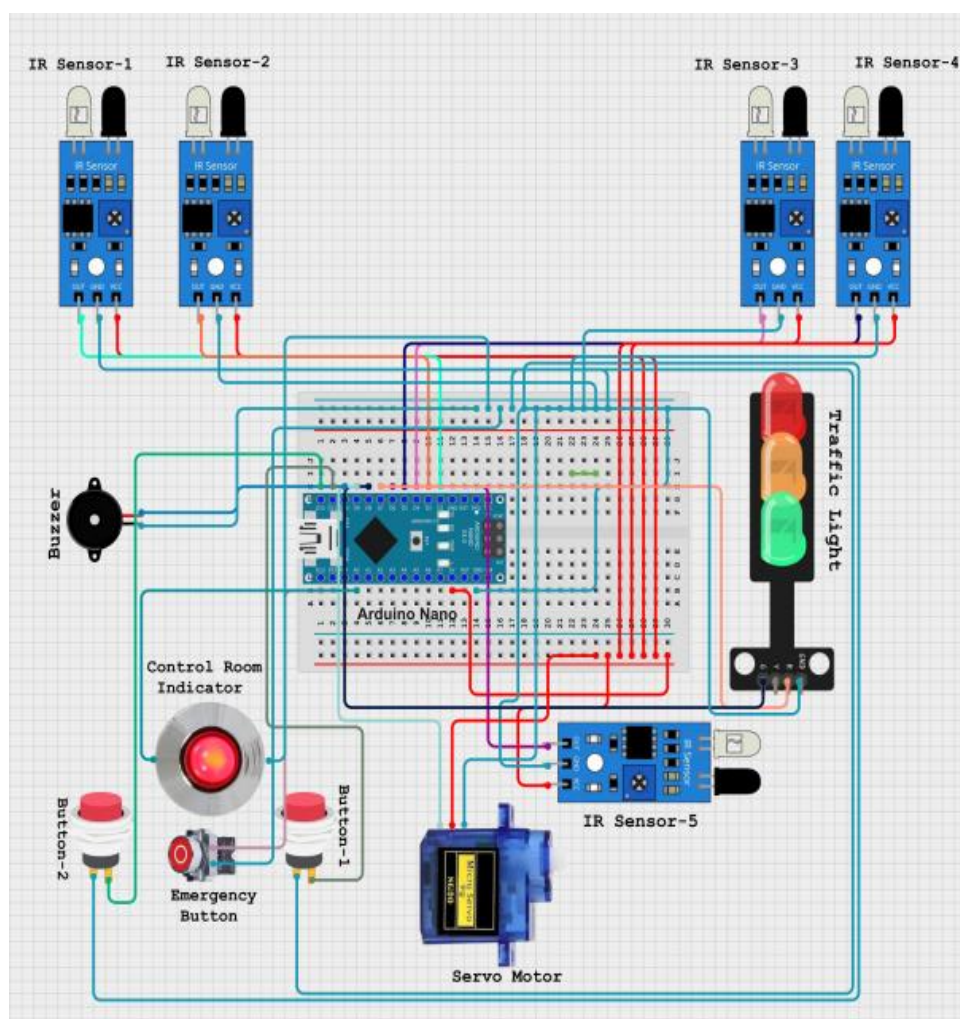


Figure 8. System Components of the proposed system.

In Figure 8 it clearly shows all the components are connected to the Arduino Nano with the correct settings. Whenever train approaching, IR sensors give input to the Arduino, and it runs the servo motor, LED, and buzzer accordingly. Based on this connection the entire system has been made functional and responsive.

3.3. System Architecture

From the Figure 9 the entire system is designed around the Arduino Nano, which is used as the master controller. It receives input signals from a series of infrared (IR) sensors and push buttons. The Arduino does the processing of data and controls set of output devices to properly control the railway gate operation based on these input conditions.

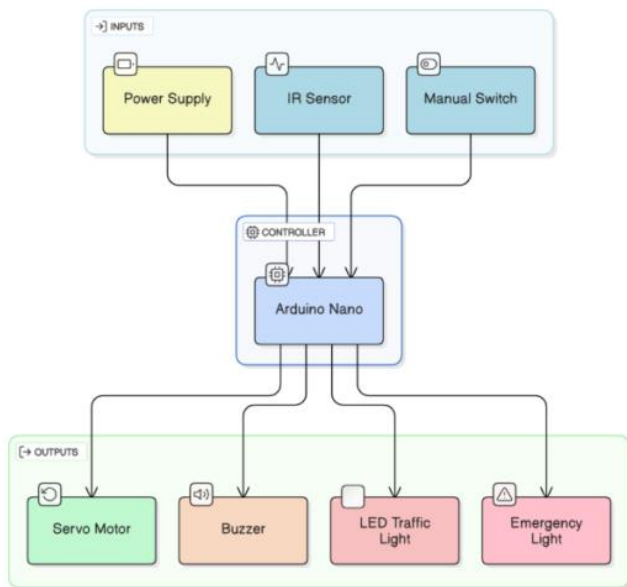


Figure 9. System Architecture of the Proposed System.

3.4. Operational Flowchart

IR1 & IR2: When both sensors are sensing the train at the gate, the gate will slowly close, the red LED will glow, and the buzzer will beep.

IR3 & IR4: When both sensors are detecting the train at the exit point, then the gate opens slowly, the red LED is off, the buzzer is off, and the green LED is on. The green LED is on for a few seconds for clearance.

IR5 (Obstacle Detection): Activated when the gate is closing. If any object (vehicle or human) is detected under the gate, it halts immediately, and both red LEDs and the control room light start blinking along with the buzzer until the path is cleared.

Manual Operation: Button 1 simulates IR1 and IR2 to close the gate manually. Button 2 simulates IR3 and IR4 to open the gate.

Emergency Stop: Pressing this switch instantly shuts down all system operations. Pressing again restarts it.

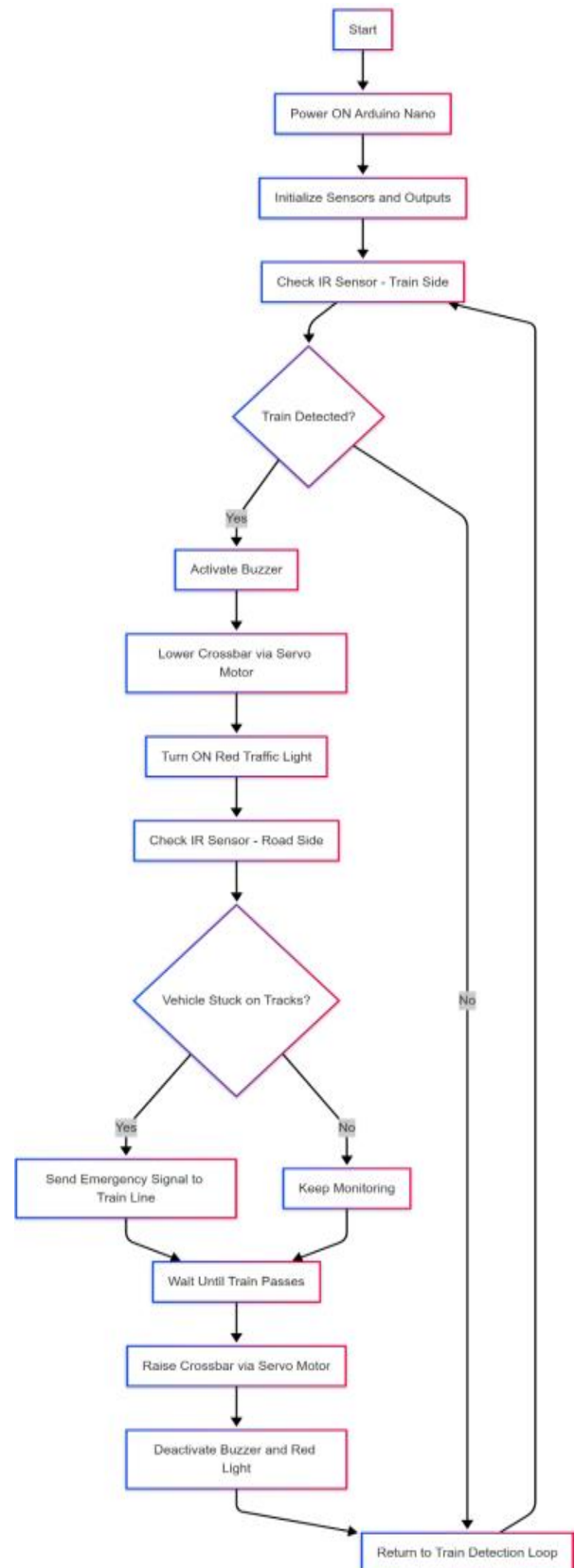


Figure 10. Operational Flowchart of the Proposed System.

The operation of this system is well outlined in the flowchart (Figure 10). It starts with the power-up of Arduino and initializing the output devices as well as sensors. IR sensors are used to detect incoming trains, trigger the buzzer, lower the crossbar via a servo motor, and turn on the red traffic light. If it finds a stranded vehicle on the track, it triggers an emergency alert. After the train has passed, the system lifts the crossbar, releases alarms, and returns to standby mode, ever vigilant for incoming train signals.

4. Prototype Design

After observation, the proposed system worked as we planned. The detection of train arrival and departure by the IR sensor reliably closed and opened the gate successfully. Obstacle detection (IR5) reacts immediately when an obstacle is detected, stopping the gate from closing and triggering an alarm. Manual and emergency controls operate as intended, whether in manual or automatic mode, and all have functioned successfully. The system was reliable and consistent when tested with model trains, and there were no real issues. This proposed model finds reduced human dependence with safer manual override. This two-layered control provides reliability and offers flexibility in the case of rare events or emergencies.



Figure 11. Prototype Design of the Proposed System.

5. Limitations

Even though the new system performed well, we encountered some obvious obstacles and practical concerns when attempting to extend it:

- 1) *Sensor Interference*: When an infrared sensor is poorly aligned, sunlight, dust, fog or any other condition of the environment may very easily alter the functioning of that sensor. This causes the equipment to perceive the ambient conditions to be a security breach and send out a phantom alarm or, vice versa, not to detect a moving target, i.e. a train. Increasing the span of the sensor and the redesigning of its enclosure, and the alignment of

the baffles with respect to the prevailing conditions are the most sensible ways of attaining stable data acquisition in all weather conditions.

- 2) *Environmental and weather effects*: The ominous recent appearance of extreme rainfall, dust storms, and high-energy winds is an illustration of meteorological conditions that could become a considerable barrier to sensor usage and component dependability. Typical application in more normal climates can be supported with off the shelf gear, but the longevity alone of treacherous environments demands environmental-resistant housings; especially sealed enclosures, but more often ruggedized architecture as well.
- 3) *Depending on the Power Supply*: Another notable weakness is the reliance on the warning system of the unit to be carbonated to run on a secure source of power to run the IR sensors, servos and Arduino Nano. The bells-and-lights installation shuts down when the voltage drops or goes away in isolated crossings in the roadsides. This is a shortcoming, although it does not come up during bench tests, it might prove an issue when the system is actually implemented on real tracks. As a result, the authors advise installing solar panels, a small battery, or other emergency power supplies, therefore, remaining constantly in use.

Despite these shortfalls, the system has been performing well in the major elements of detecting trains, automated gates as well as safety warning systems. The system will be capable of providing the confidence that it can deliver reliable safety improvements to railway-railroad crossings in semi-urban and rural regions in a way that other options cannot when the power stability of the system and the resilience of the sensors and communications infrastructure are improved.

6. Conclusion & Future Work

This system is designed to reduce human error successfully. Because it is automatic, it can work day and night equally. It requires less cost and manpower. As a result, the kind of problems that occur when a person is tired or makes a mistake will not occur. In addition, it will warn people on the side of the road through light or sound, which will reduce accidents. It also helps save lives in accidents caused by people's unconsciousness by improving safety times. This system can potentially reduce the rate of rail crashes, not only in Bangladesh but everywhere in the world where people face similar rail safety problems. It enhances the whole efficiency of the rail crossing procedure and it has been work well. Although this system has some limitations, it is capable of solving today's complex problems.

To make this project even smarter and more efficient, several advanced technologies can be integrated. *Image processing* can be used to detect vehicles or objects stuck on the tracks in real time, enhancing safety. A *solar power system*

can be implemented to make the system environmentally friendly and energy-efficient. Additionally, *IoT integration and remote control* would allow centralized monitoring and operation from a control room. Combining these technologies would not only modernize the railway gate system but also significantly improve safety, reliability, and sustainability for future implementations.

Abbreviations

IR	Infrared
RFID	Radio-Frequency Identification
IoT	Internet of Things
AI	Artificial Intelligence
LIDAR	Light Detection and Ranging
GSM	Global System for Mobile Communications

Author Contributions

Arifur Rahaman: Conceptualization, Investigation, Project administration, Supervision, Writing – review & editing

Md Hasan: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft

Md Saidul Hasan: Formal Analysis, Project administration, Resources, Software, Writing – original draft

Turjaun Akter Onika: Conceptualization, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft

Abhijit Pathak: Conceptualization, Project administration, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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