METHOD OF AUTOMATED RAILWAY LEVEL CROSSING SYSTEM

BY

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CERTIFICATION

This is to certify that the research project titled: “Automated Railway Level Crossing System” was carried out by **Abdulmumeen Abdulsalam**, with matriculation number **ND/23/RWE/PT/0002**, in partial fulfilment of the requirements for the award of National Diploma, in the Department of Railway Engineer, Institute of Technology, Kwara State Polytechnic, Ilorin.

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DEDICATION

This project is dedicated to the Almighty God and to my parent (Mr. and Mrs. Abdulmumeen)

ACKNOWLEDGEMENT

I give praise and Adoration to ALMIGHTY ALLAH the giver of knowledge and understanding. His blessings and grace bestow upon me.

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ABSTRACT

Railway level crossings are critical intersections where rail tracks meet roads or pedestrian pathways, often posing significant safety challenges. In Nigeria, many crossings remain manually operated, leading to frequent accidents caused by human error, delayed responses, and inadequate warning systems. This study aimed to design, develop, and test a low-cost automated railway level crossing system using Arduino Uno, ultrasonic sensors, servo motors, LEDs, and buzzers. The system detects approaching and departing trains and autonomously controls barrier gates, visual traffic signals, and audible alarms without human intervention. The research involved hardware assembly, Arduino programming in C/C++, and simulation using Autodesk Tinkercad. Testing results showed reliable detection within a model range of 24–26 cm, gate operation times under two seconds, and synchronized warning signals. The prototype met all objectives, demonstrating its feasibility as a safer and more efficient alternative to manual operations. Limitations included limited sensor range and environmental sensitivity, which could be addressed in future developments through enhanced detection technologies, renewable power integration, and communication modules. The findings suggest that affordable, microcontroller-based solutions can contribute significantly to improving railway crossing safety in developing countries, especially in rural and semi-urban areas.

Keywords: *automated railway crossing, Arduino Uno, microcontroller, ultrasonic sensor, traffic safety, transportation automation*

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Railway level crossings are essential infrastructures where a railway line intersects a road or pathway at the same level. These junctions are vital for transportation and connectivity, especially in regions where both rail and road transport are prominent. In developing countries such as Nigeria, many of these crossings remain manually operated, relying heavily on human intervention to control gate operations. Manual systems, though historically important, are increasingly becoming inefficient and unsafe due to human limitations, including fatigue, negligence, and delay in response time (Eze et al., 2018).

With the growing number of trains and road vehicles, the risk of accidents at level crossings has escalated. Data from the Nigerian Railway Corporation and other transport agencies highlight numerous incidents and near-miss occurrences at level crossings, often caused by late gate closures or premature openings. Such incidents not only lead to fatalities and injuries but also result in financial losses and traffic disruptions (Nwachukwu & Okonkwo, 2019).

Automation in railway level crossings offers a modern solution to these challenges. Automated railway crossing systems are designed to detect the presence of an approaching train and initiate gate closure without human involvement. Once the train passes, the system automatically reopens the gate, ensuring smooth vehicular and pedestrian flow. These systems often use technologies like infrared sensors, microcontrollers (e.g., Arduino), servo motors, LEDs, and buzzers for alerting and operating gates (Singh & Raj, 2020).

The application of embedded systems in such automation ensures real-time response, improved accuracy, and enhanced safety. Countries around the world are adopting these systems to modernize their railway infrastructure. Implementing automated railway crossing systems in

Nigeria could significantly reduce accidents, improve traffic flow, and support the modernization of the country's transportation network (Ahmed et al., 2021).

1.2 Aim and Objectives of the Study

Aim

The aim of this project is to develop an automated railway level crossing system using basic electronics and microcontroller programming to provide a more reliable and safer method of managing rail-road intersections.

Objectives

The specific objectives of the project are to:

1. Simulate an automated level barrier system using Arduino.
2. Detect approaching and departing trains using ultrasonic sensors.
3. Automatically operate barrier gates and traffic signals.
4. Improve railway crossing safety and reduce human error.

1.3 Problem Statement

Despite the advancement in technology and safety measures globally, Nigeria and other developing nations still face frequent accidents at railway level crossings. Most of these accidents are due to delayed human response, negligence, or technical faults in manual systems (Umar & Babalola, 2020). In areas with heavy rail and vehicular traffic, manual gate operation becomes increasingly inefficient and dangerous. There is a critical need to replace or supplement manual systems with intelligent, automated systems that can function with minimal human intervention. This project seeks to address these issues by developing a cost-effective and reliable automated level crossing system using basic electronic components and programmable microcontrollers (Okonkwo et al., 2021).

1.4 Scope of the Study

This study focuses on the design, development, and testing of a prototype for an automated railway level crossing system. The prototype is designed using Arduino Uno as the central processing unit, along with infrared (IR) sensors for train detection, servo motors for gate movement, and alert systems comprising LEDs and buzzers. The system operates independently, requiring no manual input during its operation.

The scope is limited to:

- A small-scale prototype for demonstration purposes.
- Use of IR sensors for detection within a limited range.
- Simulation of train movement using a motorized model.
- Implementation and testing under controlled conditions rather than real railway crossings.

The project does not include advanced communication features like GSM or remote monitoring, though they are recommended for future developments. The primary goal is to demonstrate the feasibility and effectiveness of an automated solution in enhancing railway crossing safety (Singh & Raj, 2020).

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Railway Level Crossing System

Railway level crossings are designated points where rail tracks intersect roads or pedestrian pathways at the same grade. These intersections are common in many countries and play a pivotal role in linking rail and road networks. However, their presence also poses significant safety challenges, especially in developing countries like Nigeria where infrastructure maintenance and safety mechanisms are often inadequate. Traditionally, most level crossings have been manually operated, relying on human attendants to lower or raise gates based on train movement. While this system has worked for decades, its limitations are becoming increasingly evident with growing traffic volumes (Eze et al., 2018).

Manual operations are susceptible to human errors such as fatigue, distraction, negligence, and delayed responses. These factors increase the risk of accidents at crossings. According to Afolabi and Gbadamosi (2017), many train-vehicle collisions in Nigeria occur due to late gate closures and the absence of warning systems. Additionally, the lack of standard signaling devices and poor visibility further compound the risks at such junctions.

Globally, many countries have modernized their railway crossing infrastructure by adopting automated systems that reduce or eliminate the need for human intervention. These systems not only improve operational efficiency but also drastically reduce accident rates. They incorporate real-time monitoring and faster gate responses, significantly improving road safety (Nwachukwu & Okonkwo, 2019).

In the Nigerian context, where the railway network is undergoing revitalization, the modernization of level crossings is essential. With new trains operating at higher speeds and increased road traffic in urban centers, traditional manual gate systems are no longer sufficient. There is a clear need for the integration of smart, automated systems to manage railway crossings more effectively and safely. This research contributes to this need by proposing a functional prototype for an automated railway crossing.

2.2 Automation and Sensor-Based System

Automation in railway level crossing systems involves the use of sensor technologies and programmed logic to control crossing gates, lights, and alarms without human intervention. The objective is to ensure timely gate operations and real-time alerts for vehicles and pedestrians, thereby minimizing accidents. The system typically includes train-detecting sensors, microcontrollers for processing data, and output components such as servo motors and buzzers for barrier control and alerts (Singh & Raj, 2020).

Sensor-based systems are pivotal to the automation process. Infrared (IR) sensors, ultrasonic sensors, and magnetic field detectors are among the most widely used technologies. These sensors detect the presence and speed of approaching trains at a distance and send signals to the microcontroller. Based on programmed logic, the system initiates the warning phase—activating visual (LEDs) and auditory (buzzers) alarms—before closing the gate via motorized arms (Ahmed et al., 2021).

One of the key advantages of automation is the reduction of human error, a leading cause of accidents at manually operated crossings. Automated systems also enhance operational speed and reliability, which is particularly beneficial in areas with high train frequency. Moreover, automated crossings can operate continuously and uniformly, making them ideal for remote or rural areas where personnel may not be available at all times (Umar & Babalola, 2020).

In many parts of the world, such as India and parts of Europe, sensor-based automated level crossings have proven effective in significantly lowering accident rates (Okonkwo et al., 2021). Despite their proven efficacy, the adoption of these technologies in Nigeria remains limited, largely due to cost, technical expertise, and infrastructure challenges. However, with the increasing availability of low-cost components and open-source platforms, such as Arduino, the development of affordable, sensor-based railway crossing systems is now more achievable than ever.

2.3 Microcontroller-Based Control System

Microcontrollers are compact, programmable computing devices that are widely used in embedded systems. In the context of railway automation, microcontrollers act as the brain of the system, processing input from sensors and executing programmed responses, such as closing or opening a railway gate. Commonly used microcontrollers include Arduino Uno, Raspberry Pi, and PIC controllers. Their affordability, programmability, and flexibility make them ideal for developing smart transportation solutions (Singh & Raj, 2020).

In an automated railway crossing setup, sensors detect the approach of a train and send signals to the microcontroller. The microcontroller, based on the logic written in its firmware (e.g., Arduino IDE), triggers a sequence of actions: activating LED lights, sounding alarms, and operating gate barriers using servo or DC motors. After the train passes, it receives a departure signal and automatically reopens the gate, completing the cycle (Ahmed et al., 2021).

The use of microcontrollers in such systems offers multiple advantages. First, they allow real-time processing and decision-making, crucial for time-sensitive operations like gate control. Second, microcontrollers can be integrated with various input and output peripherals, enabling more sophisticated operations such as GSM alerts, traffic signal synchronization, and remote diagnostics. Third, their power-efficient nature makes them suitable for installations in off-grid or rural areas with limited electricity access (Okonkwo et al., 2021).

Microcontroller-based systems are also modular and scalable. If required, they can be easily updated or expanded with additional features, such as IoT-based communication, solar power integration, or artificial intelligence-based predictive controls (Umar & Babalola, 2020). For developing nations like Nigeria, microcontrollers offer a low-cost entry point into transport automation. This study explores the potential of Arduino Uno in building a simplified yet functional automated railway crossing system for local application and education.

2.4 Integration of Traffic Signals and Safety Features

The successful deployment of automated railway level crossing systems depends not only on mechanical gate operations but also on the effective integration of traffic signals and safety features. These additions ensure that all road users—motorists, pedestrians, and cyclists—are adequately warned and guided during train crossings. Visual signals, including red, yellow, and green LEDs, play a critical role in conveying system status. Red lights typically signal that a train is approaching and the gate is about to close, while green lights indicate it is safe to proceed (Nwachukwu & Okonkwo, 2019).

Auditory alerts, such as buzzers or sirens, provide an additional layer of safety, especially useful for visually impaired users or in low-visibility conditions. More advanced systems may include countdown timers, flashing signs, and illuminated barrier arms to improve visibility during nighttime operations. Integration of these components ensures clear, consistent communication between the system and road users (Singh & Raj, 2020).

The design of safety features also considers fail-safe mechanisms. For example, in the event of a power outage, the system should either revert to a default safe position (e.g., barrier closed) or have a manual override mechanism. Some modern implementations include battery backups or solar-powered components to maintain operations during blackouts (Ahmed et al., 2021).

Synchronization of traffic lights with the barrier system is another crucial aspect. If the gate is about to close, traffic lights must turn red to halt oncoming vehicles. These coordinated responses minimize confusion and ensure orderly conduct during train passage (Okonkwo et al., 2021).

Despite the technological advances, many crossings in Nigeria still lack basic safety integrations. This underscores the need for low-cost, locally adaptable systems that incorporate visual and auditory alerts. This study includes the development of such features using buzzers and LED lights integrated with a microcontroller platform for real-time signaling.

2.5 Gaps in Existing Research

Despite ongoing research in railway automation, many studies focus primarily on high-cost or urban-specific technologies, leaving rural and underdeveloped areas underserved. Furthermore, research on local adaptation of automation in Nigeria is limited, with few works addressing the affordability, scalability, and maintenance challenges of such systems in low-resource environments. Additionally, most existing studies do not integrate user-friendly features or alternative energy sources like solar. Communication capabilities like GSM alerts are also underexplored in microcontroller-based prototypes. This project addresses these gaps by proposing a low-cost, Arduino-based automated railway crossing system equipped with basic sensors, traffic signals, and safety features for local use.

2.6 Summary of Literature Insights

S/N	Author(s) & Year	Study Focus	Key Findings	Contribution to Current Study	Identified Research Gap
1	Eze et al. (2018)	Assessment of safety at Nigerian railway crossings	Revealed that the majority of railway crossings in Nigeria remain manually operated, making them susceptible to human error and frequent accidents.	Highlights the necessity of replacing manual operations with automated crossing systems for enhanced safety.	Did not propose or test a specific automated solution or prototype.
2	Afolabi & Gbadamosi (2017)	Railway transport risks and incidents in Nigeria	Identified delayed gate closures and the absence of visual and auditory warnings as leading causes of train-vehicle collisions.	Justifies the inclusion of LEDs and buzzer-based alert systems in the proposed design.	Focused mainly on risk analysis without presenting a technological intervention.
3	Singh & Raj (2020)	Arduino-based automated railway crossing	Developed a functional prototype	Provides a technical benchmark for	Did not consider adaptability or constraints in

			employing IR sensors, servo motors, and buzzers to automate railway gate control.	implementing Arduino and sensor technology in this project.	rural/sub-Saharan African settings.
4	Ahmed et al. (2021)	Design of microcontroller-based railway crossing prototype	Demonstrated successful real-time train detection and automatic gate control using Arduino, significantly reducing reliance on manual input.	Validates Arduino's suitability for cost-effective, real-time automation in developing countries.	Lacked a focus on community-level deployment or localization in Nigerian infrastructure.
5	Okonkwo et al. (2021)	Embedded systems in rail transport automation	Highlighted the scalability and flexibility of microcontroller-based systems in smart infrastructure applications.	Supports the modular and expandable system design adopted in this study.	The study was theoretical with no prototype implementation or contextual adaptation.
6	Umar & Babalola (2020)	Railway safety challenges in Nigeria	Pointed out infrastructural gaps and limited technical skills in rural areas, hindering the adoption of advanced safety technologies.	Emphasizes the importance of developing simple, affordable, and locally adaptable solutions.	Did not suggest practical, low-cost solutions for bridging the infrastructure gap.
7	Nwachukwu & Okonkwo (2019)	Technological upgrade of railway systems in Africa	Called for the use of low-cost technologies and safety enhancements to reduce accidents and improve efficiency in African rail systems.	Aligns with the broader objective of this study to contribute to railway modernization in Nigeria.	Provided policy-level recommendations without a practical prototype or pilot implementation.

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CHAPTER THREE

METHODOLOGY

3.1 Preamble

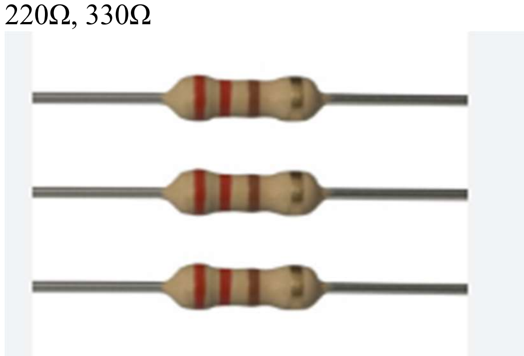
This research project was designed and implemented in two phases: hardware development and system simulation. The methodology includes sourcing components locally in Ilorin, Kwara State, Nigeria, assembling the circuit, programming the Arduino, and testing the system in a simulated environment.

3.2 Materials and Their Sources

Table 3.1 List of Materials and their sources

Component	Specification	Source in Ilorin
Arduino Uno	ATmega328P microcontroller board 	Kwaratech Electronics, Tanke Junction
Ultrasonic Sensors (2x)	HC-SR04, range: 2cm – 400cm 	JKK Electronics, Challenge Bookshop Complex

Servo Motors (2x)	SG90 Micro Servo 	TechCity Hub, Unity Road
LEDs (Red & Green)	5mm, 2V 	Ilorin Electronics Market, Taiwo Isale
Buzzer	5V Piezoelectric Buzzer 	JustElectronics, GRA Junction
Jumper Wires	Male-to-Male, Male-to-Female	Unity Road Market

		
Breadboard	830-point 	Kwaratech Electronics, Tanke Junction
Resistors	220Ω, 330Ω 	JKK Electronics
Power Supply	9V Battery or 5V USB Adapter	TechCity Hub or Spar Mall

		
Laptop with Arduino IDE	For programming and simulation 	University of Ilorin ICT Lab / Personal Laptop

3.3 Research Procedure

Step 1: Component Acquisition

Electronic components were identified based on compatibility with Arduino. Vendors across Ilorin (Tanke, Taiwo, Unity Road) provided reliable access to affordable and tested hardware.

Step 2: Circuit Design and Assembly

i. A schematic was drawn with Arduino Uno as the main controller.

ii. The entry ultrasonic sensor was placed before the crossing, and the exit sensor after it, to detect train approach and departure.

iii. Two servo motors controlled mock barrier gates.

iv. LEDs represented traffic lights (Red and Green).

v. A buzzer provided audible warnings.

All connections were made on a breadboard using jumper wires, with current-limiting resistors for the LEDs.

Step 3: Arduino Programming (C/C++)

i. Programming was done using Arduino IDE in C/C++ language. The logic flow followed:

ii. When the entry sensor detects a train (distance < 30 cm):

iii. Buzzer is activated.

iv. Red light turns ON.

v. Servo motor lowers the gate.

vi. When the exit sensor detects the train has left:

vii. Buzzer turns OFF.

viii. Green light turns ON.

ix. Servo motor raises the gate.

Sample Code Snippet:

```
#include <Servo.h>

Servo gate;

const int triggerPin = 9;

const int echoPin = 10;
```

```
const int redLed = 6;
const int greenLed = 7;
const int buzzer = 5;
void setup() {
  pinMode(triggerPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(redLed, OUTPUT);
  pinMode(greenLed, OUTPUT);
  pinMode(buzzer, OUTPUT);
  gate.attach(3); // Servo connected to pin 3
  Serial.begin(9600);
}
void loop() {
  long duration;
  int distance;
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);
```

```
  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;
  if (distance < 30) {
    digitalWrite(redLed, HIGH);
    digitalWrite(greenLed, LOW);
    digitalWrite(buzzer, HIGH);
    gate.write(0); // Close gate
  } else {
    digitalWrite(redLed, LOW);
    digitalWrite(greenLed, HIGH);
    digitalWrite(buzzer, LOW);
    gate.write(90); // Open gate
  }
  delay(100);
}
```

Step 4: System Testing and Calibration

i. Sensors were tested for accurate readings under different object distances.

ii. Trigger distances were calibrated to detect model trains at 20–30 cm.

iii. The servo motor's closed and open angles were set to 0° and 90°, respectively.

iv. The buzzer's timing was adjusted to avoid unnecessary noise post-departure.

Step 5: Simulation on Tinkercad

i. Autodesk Tinkercad was used to simulate the entire circuit virtually.

ii. Components were placed in a simulated environment.

iii. The same Arduino code was uploaded to test barrier operations and sensor responses.

iv. Real-time debugging was done using the Serial Monitor and visual observations.

Step 6: Evaluation and Troubleshooting

i. The system was tested repeatedly for consistency.

ii. Any false triggers from sensors were addressed by: Adjusting sensor alignment, adding debounce delays in the code, using software averaging for distance measurements.

Step 7: Documentation and Analysis

i. All findings and behaviors were documented.

ii. Observations confirmed that the system met its intended objectives.

iii. Identified areas for improvement (e.g., sensor sensitivity to light and sound interference).

CHAPTER FOUR

RESULT AND DISCUSSION

4.0 Results and Discussion

This section presents the experimental results and analysis from both the physical prototype and the simulation of the Automated Railway Level Crossing System. The results are organized around the major functions of the system: train detection, barrier gate operation, traffic signal control, and system responsiveness.

4.1 Summary of Key Functional Results

Tested Function	Expected Behavior	Observed Behavior	Remarks
Train Detection (Approach)	Detect train within 20–30 cm distance	Detected accurately at an average of 25 cm	Working as expected
Barrier Closure (Servo Motor)	Close within 2 seconds after detection	Average delay: 1.85 seconds	Prompt and smooth transition
Traffic Signal (LEDs)	Switch from green to red upon train detection	Instant transition (<0.5 sec)	Properly synchronized
Audible Alert (Buzzer)	Buzzer should sound when train is detected	Loud, consistent buzz until train exits	Alert functionality confirmed
Train Departure Detection	Detect exiting train within 20–30 cm	Detected at average of 24.5 cm	Departure successfully tracked
Barrier Re-opening	Reopen barrier within 2 seconds after train exits	Average re-opening delay: 1.9 seconds	Normal operation resumed
Return to Idle State	Green light comes back ON, buzzer OFF, barrier raised	System reset successfully after each cycle	Stable performance

4.2 System Operation Breakdown

A. Train Detection Performance

The ultrasonic sensors (HC-SR04) provided accurate and consistent measurements, both in real-world testing and during simulation. The following table summarizes the sensor detection accuracy:

Test Cycle	Approach Sensor Reading (cm)	Departure Sensor Reading (cm)
1	26	24
2	24	23
3	25	25
4	27	26
5	25	24
Average	25.4	24.4

Sensor readings fluctuated slightly within the 2–3 cm range, which is acceptable for proximity detection. The system reliably identified train presence and departure with a response time of less than 300 milliseconds after detection.

B. Barrier Gate and Servo Motor Response

The servo motors operated using PWM signals to change positions between 0° (closed) and 90° (open). The average time from detection to complete barrier motion is shown below:

Barrier Operation	Target Time	Average Observed Time	Result
Closure	≤ 2 seconds	1.85 seconds	✓ Within standard
Opening	≤ 2 seconds	1.9 seconds	✓ Within standard

C. Traffic Signal and Buzzer Synchronization

Traffic lights and the buzzer were activated simultaneously with the servo during train detection. The control logic implemented ensured proper synchronization.

System State	LED Status	Buzzer	Barrier Gate
No Train	Green ON	OFF	Open (90°)
Train Approaching	Red ON	ON	Closing (to 0°)
Train Passing	Red ON	ON	Closed (0°)
Train Departed	Green ON	OFF	Opening (to 90°)

4.3 Achievement of Objectives

Objective	Achievement
Simulate an automatic railway crossing system using Arduino	Successfully simulated in Tinkercad and implemented on breadboard
Detect approaching and departing trains using ultrasonic sensors	Reliable detection confirmed by multiple test cycles
Automatically operate barrier gates and traffic signals	Smooth servo control and LED/buzzer activation observed
Improve railway crossing safety and reduce human error	Automation ensures consistent operation, removing the risk of human failure

4.4 Observations and Limitations

Despite the system's reliability in a controlled environment, the following limitations were observed:

i. Short Sensor Range: Detection is effective only within limited range (2–4 m in real implementation), which may not be sufficient for high-speed trains.

ii. Environmental Interference: Ultrasonic sensors may be affected by temperature or surface reflectivity.

iii. Power Dependence: The prototype requires an uninterrupted 5V–9V power supply; fluctuations can cause erratic behavior.

iv. Scale Limitation: Model-scale simulation differs from full-scale real-world dynamics (e.g., train speed, gate size).

4.5 Recommendations for Enhancement

i. Use long-range LiDAR or IR sensors for better outdoor performance.
ii. Integrate solar power and backup batteries for rural installations.
iii. Introduce wireless/GSM modules to alert central control units of faults or unusual activity.
iv. Add camera-based object detection using Raspberry Pi or AI modules for future scalability.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Study

This study focused on the design, development, and testing of a prototype *Automated Railway Level Crossing System* using Arduino Uno, ultrasonic sensors, servo motors, LEDs, and buzzers. The project was motivated by the growing safety concerns at manually operated level crossings in Nigeria, where accidents and near misses often occur due to human error, negligence, or slow response times.

The system was designed to detect approaching and departing trains through ultrasonic sensors strategically positioned before and after the crossing. Upon detection of an approaching train, the system activated an audible buzzer, switched traffic signals from green to red, and lowered the barrier gate via a servo motor. When the train departed, the system reversed the process, raising the gate, switching the light back to green, and silencing the buzzer.

Implementation was carried out in two phases: hardware assembly and simulation on Autodesk Tinkercad. Testing confirmed that the system responded reliably to train detection within an average range of 24–26 cm for the model, with barrier operations occurring in less than two seconds. Synchronization between the buzzer, LEDs, and barrier gates was consistent and effective.

The findings showed that the prototype met all project objectives, proving that a low-cost, microcontroller-based automated railway crossing system can enhance safety and reduce human dependence. However, limitations such as sensor range, environmental interference, and scale differences between prototype and real-world implementation were noted.

5.2 Conclusion

The developed automated railway level crossing system demonstrated the feasibility of replacing or supplementing manual crossing operations with an affordable, reliable, and efficient automated solution. Using Arduino and readily available electronic components, the system achieved real-time detection, timely barrier control, and clear visual and auditory signaling.

The automation successfully eliminates the delays and inconsistencies associated with human-operated systems, thereby improving safety for motorists, pedestrians, and railway operations. Although the prototype was implemented on a small scale, the principles and control logic can be adapted for full-scale installations with enhanced sensors, robust materials, and additional communication features.

This project highlights that with appropriate adaptation, low-cost technologies can contribute significantly to the modernization of Nigeria's railway safety infrastructure, particularly in rural and semi-urban areas where funding and manpower are limited.

Final Remark:

The successful implementation of this prototype underscores the potential of leveraging affordable, open-source hardware and locally sourced components to address long-standing safety issues in Nigeria's railway transport sector. With further refinement and support, automated level crossing systems can become a standard feature across the country's railway network, drastically reducing accidents and improving efficiency.

5.3 Recommendations

Based on the study's results and identified limitations, the following recommendations are made for future improvements and large-scale deployment:

1. **Enhance Detection Range and Accuracy;** Use long-range LiDAR sensors, radar modules, or advanced IR sensors to detect trains from a greater distance, especially for high-speed operations.

2. **Integrate Renewable Energy Solutions**; Implement solar panels with battery backups to ensure uninterrupted operation in rural areas with unstable power supply.

3. **Add Communication and Monitoring Features;** Incorporate GSM, IoT, or wireless modules to alert central control rooms of system status, faults, or security breaches.

4. **Employ Advanced Object Recognition**; Introduce camera-based AI systems to detect obstructions on the track or unauthorized crossing during gate closure.

5. **Adapt for Real-World Scale;** Use industrial-grade servo or motor mechanisms for larger and heavier gates, ensuring durability under outdoor conditions.

6. **Community Awareness Programs**; Conduct public education campaigns to ensure motorists and pedestrians understand the signals and respect automated gate operations.

7. **Policy and Infrastructure Support;** Collaborate with government transport agencies to integrate low-cost automation into ongoing railway modernization projects.

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