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Smart Gate System Development and Automation Using Block Coding and AI Integration

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ABSTRACT

Access control systems, particularly in high-traffic environments such as residential complexes, commercial buildings, and restricted facilities have been significantly transformed due to rapid advancement in automation and artificial intelligence (AI). Traditional manual gate operations is fraught with inefficiencies, delays, and security vulnerabilities, necessitating an automated solution. This study is focused on the development and automation of a smart gate system integrating block coding and AI-driven object detection. The system employed an ultrasonic sensor for object detection, an AI module for decision-making, and an Arduino microcontroller for gate control via a servo motor. The block coding approach in the Mixly development environment enhanced accessibility, allowing users with minimal programming knowledge to implement and customize the system effectively. The AI component leverages real-time object detection algorithms, such as YOLO (You Only Look Once) or SSD (Single Shot Multibox Detector), to differentiate between objects and ensure intelligent gate control. Experimental results demonstrate an accuracy of 90% in object recognition and reliable gate operation, minimizing false triggers and unauthorized access. The proposed system enhances security, operational efficiency, and user convenience, contributing to the growing demand for intelligent automation in access control applications.

Keywords: Smart gate system, automation, artificial intelligence, block coding, object detection, Mixly development environment, ultrasonic sensor, Arduino microcontroller, YOLO, SSD, servo motor, access control, security.

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1. INTRODUCTION

Gate is an entry point to a space enclosed by walls, or an opening in a fence intended to prevent or control entry or exit, or may be merely for decoration. Gate is one of the ways to implement physical security access control (Ikpeze *et al.*, 2019). Access control devices usually, are used to authorize who gains entrance or exit in and out of a premise such as residential complexes, commercial businesses, or restricted areas that houses some critical facilities. Over the years, this has been achieved via manual approach in which, security personnel are hired to be the gate keeper. Manual gate operation in high-traffic areas is fraught with lots of inefficiencies leading to delays, inconveniences, frustrations for users and potential security risks (Kurdi *et al.*, 2023). In addition, security can be compromised if a gate is accidentally left open, particularly during peak hours, in which personnel may become overwhelmed, leading to potential errors in gate operation. Such lapses do not only expose properties to unauthorized access but can also create hazardous situations in busy environments where rapid entry and exit are essential.

In scenarios where swift and secure access is critical, such as residential complexes, commercial businesses and restricted areas, there is usually a pressing need for an automatic system that can autonomously detect objects and manage gate movement without manual control. Such systems should be capable of providing reliable and immediate responses to ensure smooth traffic flow and enhanced security. Tackling such challenge lies in building a cost-effective, user-friendly system that integrates AI for real-time object detection and decision-making. The solution must not only be efficient but also adaptable to different environments, from busy urban settings to quiet residential areas. Additionally, the system should be designed to be easily programmable using accessible tools like block coding, allowing users with limited programming knowledge to implement and customize the system effectively. By addressing these issues, an automatic gate system can significantly enhance security, improve operational efficiency, and provide a seamless experience for users, thus responding to the increasing demand for intelligent automation in everyday applications.

Automation is transforming the modern world by minimizing human effort in various tasks, and Artificial Intelligence (AI) is playing a significant role in making systems smarter and more efficient. The advancement of automation in security systems has revolutionized access control management, particularly in high-traffic areas such as residential complexes, commercial properties, and restricted zones (Luo *et al.*, 2022). With AI integration into gate automation, the system's ability to detect objects, make decisions, and operate autonomously without manual intervention is enhanced. This study explores development of an automatic gate system that integrate block coding with AI-driven algorithms to create a more efficient, secure, and user-friendly automatic gate system solution capable of real-time object detection and decision-making.

Block coding offers an accessible programming approach, especially for beginners or individuals with limited programming experience. Block coding is an element of programming where text-based computer commands are grouped together in pre-programmed blocks that can be dragged-and-dropped by converting to visual blocks (Gilbert, 2024). Tools like the Mixly (Mixly Team, 2021) environment enables developers to create complex systems using visual code blocks, simplifying the integration of AI algorithms and control mechanisms for hardware components like sensors and motors.

This kind of code automation accelerates processes and enhance reliability through the automated execution of tasks. It brings about efficiency, quality assurance, consistency, reliability, scalability and saves cost (Akash, 2024). The concept of smart gate security has gained traction as a means to enhance safety and efficiency in access control (Emerick *et al.,* 2015). Automating gate systems has evolved with the integration of different technologies. By leveraging the principles outlined in existing smart security projects, the proposed system will provide a user-friendly interface while ensuring robust security measures.

2. LITERATURE REVIEW

Smart gate systems allow authorized users to operate the gate while preventing unauthorized access. Smart gate systems are automatic gates that are used to control access into a secured area such as controlling vehicular access on and off of a site or entrance to a facility. These can be achieved using remote transmitters (remotes), keypads, card readers, intercom systems, or biometric scanners. The concept of smart gate security has gained increasing attention over the years as a means to enhance safety and efficiency in gates access control (Emerick *et al.*, 2015). A detailed exploration of these systems reveals a focus on enhancing security, control, and remote access. Sunico *et al*. (2020) showed that the automated gate system when deployed in school environment facilitates the management and monitoring of students' records, employees, and visitors, who passes the gate in and out of the school premises. Thus, generating timely feedback to the administration. Different literatures have highlighted the various advantages and disadvantages of the automated gate systems (Luna, 2024).

Chethan *et al*. (2021) gave the following method for an automated gate controlled by the vehicle plate number. At First, the car will stand in front of the barrier, then the IR sensor sends a signal to the raspberry P_i and it will send a message to the python, then LCD will display a welcome message. Then, the image (license plate) acquired from the hardware components by the camera will be analyzed in data analysis part, which is mostly done in python. Then the analyzed image will be compared with the information stored in the database, if this image is matched with the information stored in the database, then python sends message to the raspberry P_i to open the barrier gate and after some time delay the barrier gate will be closed again. But if the image does not match with any of those in the database, then python will send a message to the raspberry P_i, and the raspberry P_i will turn on the alarm and LCD will display a message "you are not allowed to enter, please go back".

Several researchers have outlined the advantages of automated gate systems. Elechi *et al.* (2021) highlighted how automated gates with mobile connectivity enhance security by acting as a barrier for controlling access and allowing remote monitoring, and improving property security. Adebimpe, *et al*. (2022) noted that automated gates minimizing the need for security personnel, lowers associated insurance premiums and reduces overall operational costs for security. Emerick *et al.* (2015) and Ikpeze *et al.* (2022) discussed how these systems improve accessibility, privacy, and safety by reducing the risk of unauthorized access and accidental injuries. Ohal *et al.* (2018) and Jia *et al.* (2019) discussed how automated gates with sensors reduce the risk of accidents by halting operation if an object or person is detected in their path as well as increases a property's value due to its aesthetic appeal considered as valuable features

Despite the numerous benefits highlighted by some authors, automated gate systems are faced with some notable challenges. Ikpeze *et al.* (2019) highlighted the high initial costs of installation, while Elechi et al. (2021) pointed out the need for regular maintenance of sensors, motors, and AI components. Emerick *et al.* (2015) and Martins *et al.* (2022) discussed technical failures, power dependency, and potential cybersecurity threats that could compromise system reliability. While existing studies focus on security and automation, they lack an integrated approach that combines AI-driven real-time object detection with a user-friendly block coding interface.

Most AI-integrated gate systems require advanced programming knowledge, making them inaccessible to non-technical users. Furthermore, few studies have explored the use of block coding platforms like Mixly for system customization and rapid deployment. Additionally, existing systems often struggle with false positives in object detection, limiting their accuracy in dynamic environments. This study addresses these gaps by developing a smart gate system that integrates AI-based object detection with block coding, enabling users to program and customize gate operations efficiently. The proposed approach enhances security, reliability, and ease of implementation while reducing false triggers and operational inefficiencies.

3. MATERIALS AND METHOD

3.1 Materials

In building a typical automatic gate opening and closure system, materials such as Ultrasonic Sensor, AI Module, Arduino Microcontroller, Servo Motor, Gate Mechanism AC/DC power supply unit, and wiring cables/accessories are required. They constitute integral parts of the systems used include consist of the following components. Table 1 and 2 show the materials used to design and construct the prototype automated gate opening and closing system.

Table 1: Hardware and Software Materials

Ultrasonic Sensor
Arduino Microcontroller
Servo Motor
AC/DC power supply unit
Mixly Development Environment

3.2 Architectural Components of Automatic Gate Opening and Closure System
Figure 1, presents the architectural diagram of an intelligent gate system.

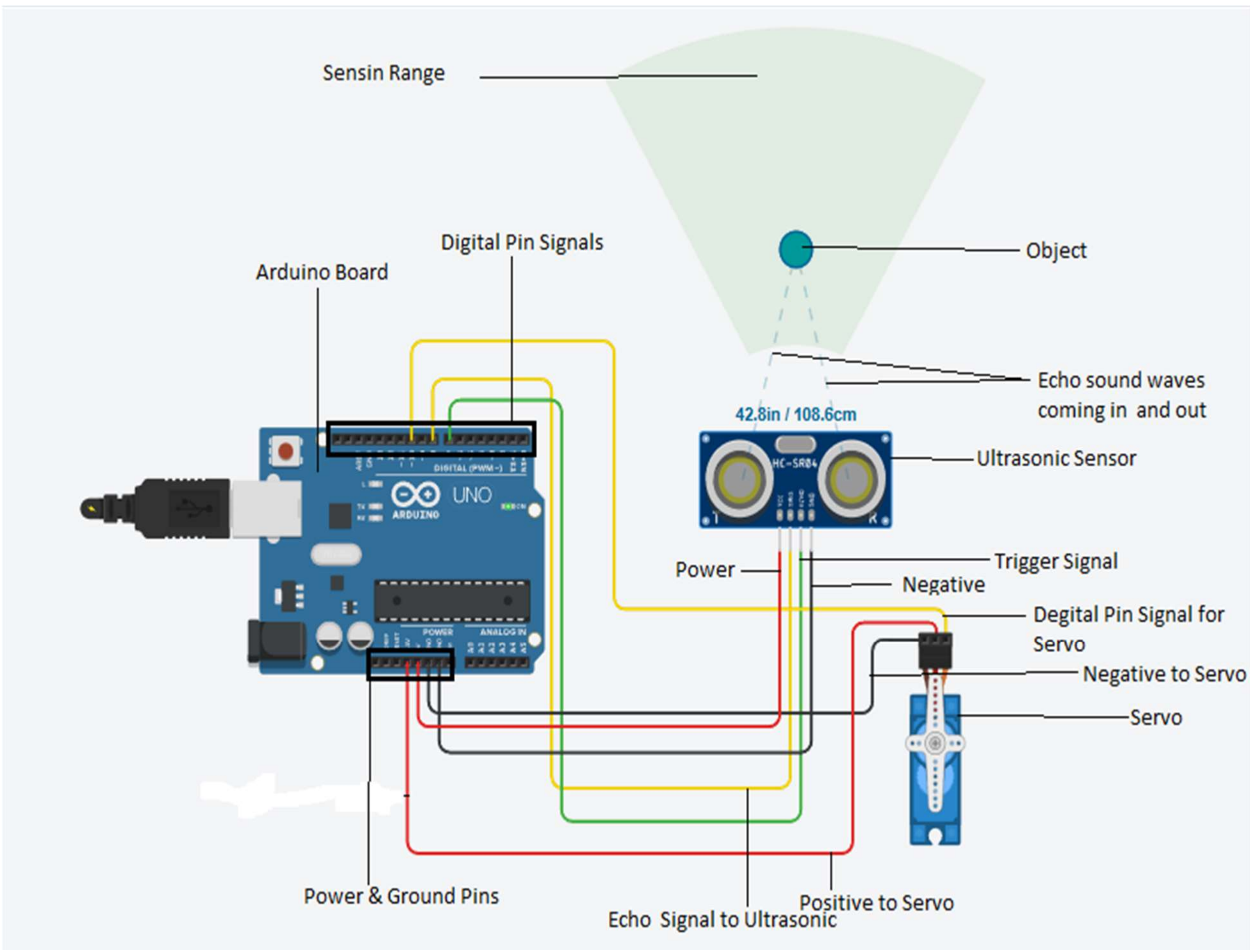

Figure 1: Architecture of a smart gate design and automation using block coding and AI integration

Typically, the system consists of components that performs the following functions

i. Object detection by the ultrasonic sensor, which triggers the servo motor to rotate to open the gate, allowing entry (Object Detection Response).
ii. Physical opening and closing of the gate are controlled by the servo motor which positions the gate according to commands from the Arduino (controlled movement).
iii. Returning the gate to closed state once no object is detected by the sensor, the servo motor moves to close the gate (Closure Upon Passage). This ensures that the gate remains closed when no object is present, maintaining security.

These components and its functions are further explained in the section that follows.

Ultrasonic Sensor: This ultrasonic sensor component is responsible for detecting objects near the gate and it is depicted in Figure 2.

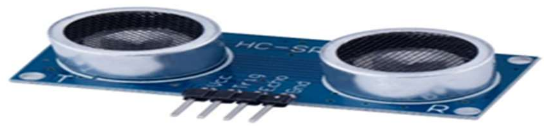

Figure 2: Ultrasonic Sensor

The operational methodology of the ultrasonic sensor makes it efficient for real-time distance measurement and ideal for automating systems like the gate project. It involves continuous measurement of distance to detect nearby objects. The sensor emits ultrasonic waves, which travel until an object is encountered. Upon hitting the object, the waves bounce back, and the sensor measures the time it takes for the waves to bounce back after hitting an object. Using the speed of sound, it calculates the object's distance based on the data obtained by the sensor.

Arduino Microcontroller: The Arduino microcontroller serves as an intermediary, executing control tasks efficiently based on processed sensor data The Arduino serves as the system’s brain, receiving signals from the AI module and controls the servo motor based on the AI's instructions to determine when to trigger the gate’s movement. Arduino microcontroller component is depicted in Figure 3.

Figure 3: Arduino Microcontroller

The Arduino microcontroller in the gate system operates as follows;

i. The Arduino receives data from the AI module (Signal Reception) which processes the object’s distance and context (such as speed and size).
ii. Based on the AI module's decision, the Arduino determines the appropriate control signal (command processing) for the servo motor.
iii. The Arduino microcontroller then sends an output signal to the servo motor to open or close the gate (motor control). If the AI indicates the object has passed, it commands the motor to close the gate, completing the interaction.

Servo Motor
The servo motor is responsible for the actual physical movement of the gate. Once the microcontroller sends the command, the servo motor rotates to open or close the gate. The servo motor component is depicted in Figure

Figure 4: Servo Motor

The servo motor components used for the automatic gate system function as follows:

i. The servo motor receives electrical signals from the Arduino microcontroller (command reception), which has been instructed by the AI module to open or close the gate based on detected object data.
ii. According to the command, the servo motor rotates to a specified angle (rotation and positioning), by physically moving the gate to either the open or closed position.
iii. The motor holds its position until a new command is received (maintaining position), ensuring the gate remains in the desired state (open or closed) for safety and security.

3.2 The Block Diagram of an Intelligent Gate Controller System with AI-Integration
Figure 5 depicts a block diagram showing the workflow of an automatic gate controller system with AI-integration. The ultrasonic sensor detects object proximity and sends data to the Arduino microcontroller that processes the basic sensor data and forwards it to the AI module. The AI module analyzes the object data, potentially using machine learning (ML) models to recognize patterns in the signal data and then decides on gate actions (like distinguishing between people and other objects). The decision signal is then sent to the Arduino microcontroller which then sends a signal to the servo motor for activation of the gate mechanism to carry out the physical action of opening or closing the gate based on the servo's movement. This setup allows intelligent decision-making and efficient gate control through AI-integration.

This AI-based approach leverages real-time object detection algorithms, allowing the gate to open or close based on vehicle or human presence. It combines the simplicity of block coding with the complexity of AI, offering an efficient and scalable solution that minimizes the need for human oversight while ensuring improved security and operational efficiency.

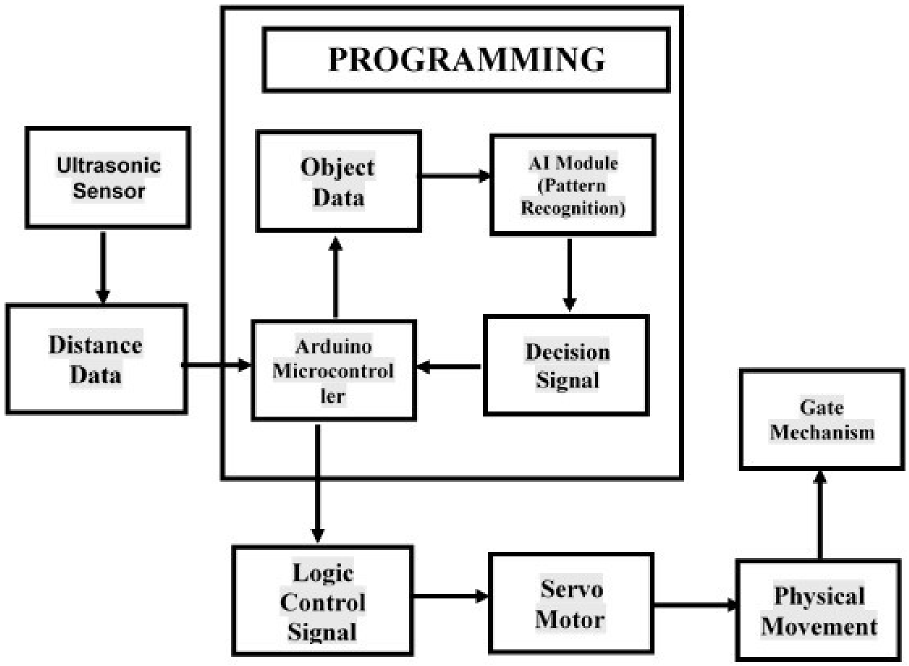

Figure 5: The Block Diagram of an Automatic Gate Controller System with AI-Integration

3.3 Steps for Object Detection, Gate Opening and Closure

Here is a framework that describes the approach:

Step 1: Signal Emission and Return

Emit Signal: Ultrasonic pulse is emitted from the sensor.

Capture Echo: Echo is received, and the time delay is recorded.

Step 2: Data Filtering

Noise Reduction: Average multiple signals to remove inconsistent readings.

Distance Filtering: Filter out echoes outside a specified distance range.

Step 3: Threshold-Based Object Confirmation

Threshold Check: If the echo distance falls within an expected object range, it proceeds to the next step.

Reconfirm Consistency: Verify consistent distances across multiple pulses.

Step 4: Object Classification

AI/Pattern Recognition: The AI module assesses reflection patterns to distinguish the object type or movement.

Step 5: Trigger Response

Decision Making: If an object is confirmed, the system decides to open/close the gate based on proximity.

3.4 Description of the Setup, Implementation and Working of the System

The automatic gate system was developed using block-coding in the Mixly development environment, integrated with AI for object detection and servo motor control. The following diagram (Figure 5) shows the working of the proposed smart gate system with AI-integration

The AI component is integrated to enhance decision-making by processing the data obtained with sensors (such as the ultrasonic sensor). The AI module processes the data from the ultrasonic sensor using some algorithms. Instead of merely opening or closing the gate based on object proximity, the AI processes object information to determine whether to activate the gate mechanism or not. It uses pattern recognition or other algorithms to identify objects or situations accurately and efficiently, ensuring the gate only responds to appropriate triggers. Here an efficient object detection algorithm such as YOLO (You only look once) or SSD (Single shot multibox detector) that can detect and recognize objects in real-time based on sensor data that was used. The model identifies and classifies objects by analyzing features like distance, size, direction and speed, and makes decisions on when to trigger the gate mechanism to open or close the gate. This approach improves system reliability and performance, making the gate "intelligent" in recognizing valid open/close conditions.

The AI module continuously receives data from the ultrasonic sensor, once the AI has made its decision, it sends a command to the servo motor to open or close the gate accordingly. This approach allows the gate to operate based on the context, such as the speed and size of approaching objects, making it efficient and responsive in real-time.

4. IMPLEMENTATION, RESULTS AND DISCUSSION

In this study a smart gate system that automatically opens and closes the gates using ultrasonic sensors and a servo motor with AI integration was implemented successfully. The ultrasonic sensor accurately detects objects with the aid of some algorithms such as Single Short Detector (SSD) or YOLO`, and triggers the servo motor to open or close the gate. The AI integration significantly enhanced the system's ability to detect and categorize objects by distance, speed, and size, minimizing errors and enabling more accurate gate operation. The AI-supported detection reduced false triggers, creating a more responsive and secure system, especially useful in differentiating between various types of moving objects.

The system consistently responds within a set detection range, achieving high reliability in object detection for controlled gate access. This automated process meets the goal of hands-free operation, improving convenience and security in gate management. The Block coding in Mixly environment facilitates in-built programming, making it easier to develop, test, and modify the system without complex code. This simplified coding environment enables a faster setup, contributing to efficient project progress and allowing for clear, user-friendly adjustments.

To determine the reliability and accuracy of the gate system, 20 trials was conducted in the experiment. Eighteen (18) outcomes were found to be correctly predicted, while two were wrongly predicted that is with TP = 15, TN = 3, FP = 1 and FN = 1.

The reliability of the system is determined by the percentage of successful operations over the total trials conducted. From experimental testing:

Successful Operations were 18 out of 20 trials, therefore the reliability can be computed as follows;

$$\text{Reliability (\%)} = \left(\frac{\text{Successful Trials}}{\text{Total Trials}}\right) \times 100$$

Substituting values:

$$\text{Reliability (\%)} = \left(\frac{18}{20}\right) \times 100 = 90\%$$

Percentage Accuracy is given as Accuracy (%) = $\frac{TP+TN}{TP+FP+TN+F}$, = (18 / 20)

= (18 / 20) × 100 = 90%

- Criteria for Successful Operation:
  - The gate responded correctly to objects (e.g., vehicles or humans) detected within the specified range of the ultrasonic sensor (Figure 6).
  - No false openings for irrelevant objects (e.g., leaves or small animals).
  - The servo motor responded within the expected time without delay.
- Failures:
  - Missed Detections: The ultrasonic sensor occasionally failed to detect objects due to environmental noise.
  - False Positives: The system responded to objects it was not intended to, such as birds.
  - Servo Malfunctions: Infrequent delays caused by power interruptions.
    - Excessive noise in the sensor's surroundings may cause disruptions in accurate readings.
    - Ambient light interference may have contributed to inconsistencies.
    - The range limitations of the ultrasonic sensor led to false negatives for objects outside its reliable detection radius.
    - Small delays in servo motor responsiveness increased the average gate operation time.

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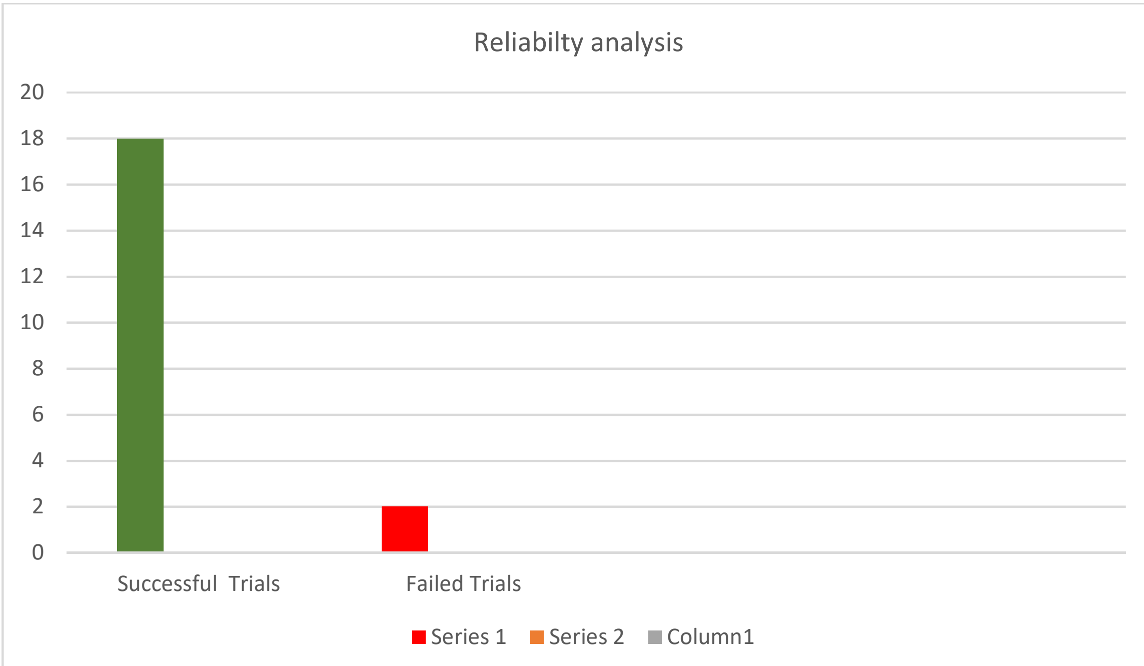

Figure 6: Graphical Representation of the Reliability Data

Response time analysis was also performed to determine whether the gate has performed efficiently. To achieve this the average response time for the gate to open and close was analyzed as follows:

- the time taken from the moment the ultrasonic sensor detects an object to when the servo motor operates measured.
- multiple trials (e.g., 20 trials, shown on the Y-axis) was performed in order to determine the average response time.

Table 2: Respond Time

Trial	Detection Time in millisecond (ms)	Gate Operation Time in millisecond (ms)	Total Response Time in millisecond (ms)
1	120	300	420
2	110	290	400
...	...	...	...
Average	115 ms	295 ms	410 ms

From the experimental setup average response Time Metrics obtained were; Average detection time = 15 ms, Average gate operation time = 295 ms, Total average response time = 410 ms. Figure 7 depicts the graphical analysis for average response times as shown in Figure 7.

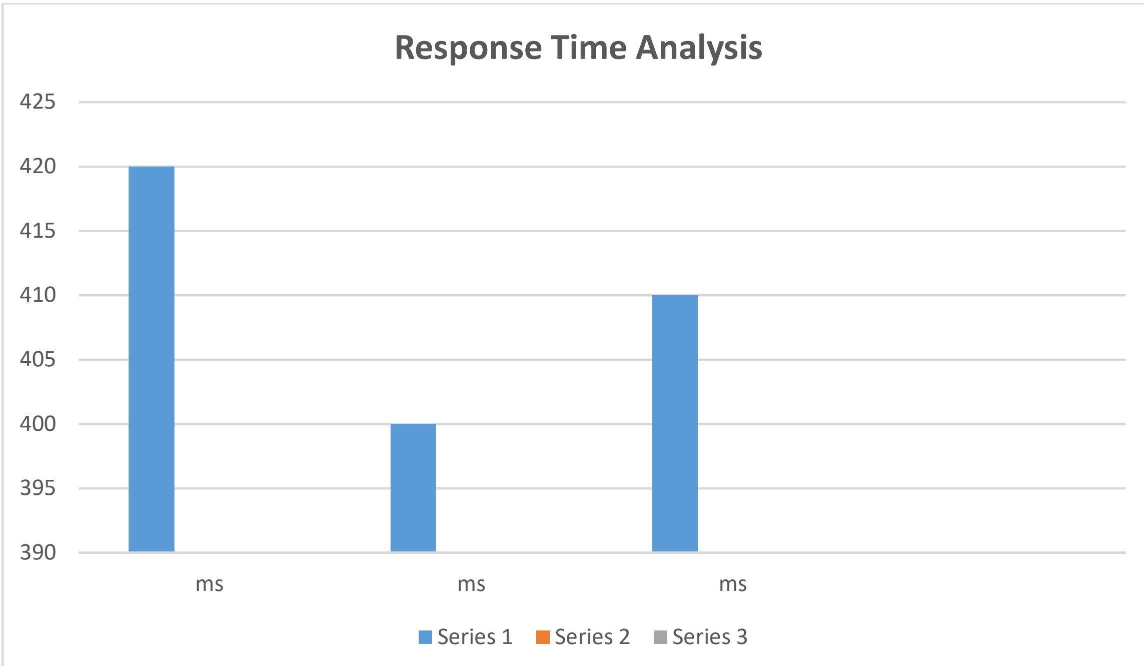

Figure 7: Depicts Graphical Analysis of Average Response Time.

The closeness of human to the gate that prompts the opening of the gate, was evaluated to ascertain the efficiency of the gate.

5. CONCLUSION

This research focused on the development and automation of a smart gate system using block coding and AI integration. The motivation behind this study was to tackle inefficiencies associated with manually operated gates, particularly in high-traffic areas where delays and security risks are prevalent. By leveraging AI-driven object detection and decision-making, the system enhances both security and operational efficiency. This study used an ultrasonic sensor for real-time object detection, an Arduino microcontroller for processing, and a servo motor for automated gate movement. The Mixly development environment facilitated block coding, enabling an accessible programming approach for system implementation. The AI module, integrated with object detection algorithms such as SSD and YOLO, ensured precise object classification and improved response accuracy.

The results demonstrated a high level of system reliability, with an accuracy of 90% across 20 experimental trials. The system successfully identified and responded to authorized objects while minimizing false triggers. Additionally, response time analysis indicated an average total operation time of 410 ms, ensuring quick and efficient gate control. The smart gate's ability to differentiate between various object types contributed to reducing unnecessary activations, thus optimizing performance. This research contributes to the body of knowledge by demonstrating the practical application of AI in access control systems, offering a cost-effective and adaptable solution for automated security infrastructure.

The integration of block coding in Mixly enhances accessibility for users with minimal programming experience, promoting broader adoption of smart automation. Future work can explore the incorporation of advanced AI models and cloud-based monitoring to further refine security and operational efficiency in automated gate systems.

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