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Innovative IoT-Based Automatic Gate System with RFID and Electro-Magnetic Lock for Secure Access

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Abstract: In this study, we developed an innovative IoT-based automatic gate system aimed at enhancing security and providing flexible access control. The system incorporates an ESP32 microcontroller with integrated Wi-Fi, enabling seamless remote access via mobile devices. It also features RFID technology for reliable physical access control when an internet connection is unavailable. To ensure user safety, an HC SR-04 ultrasonic sensor is implemented to detect obstacles during gate movement, preventing potential accidents. The security of the system is further reinforced by a dual-layer mechanism utilizing an electromagnetic lock (Emlock), which activates upon gate closure to prevent unauthorized access and deactivates when the gate opens. Experimental results indicate that the system effectively addresses the shortcomings of conventional gate control methods, delivering improved security, convenience, and safety for users. Performance tests confirm the reliable operation of both RFID and mobile control functions, with minimal delays observed in sensor response times. This comprehensive solution is well-suited for residential and commercial properties, offering a modern approach to automatic gate security.

Keywords: IoT-based Automatic Gate, Remote Access Control, RFID Security, Electromagnetic Lock, Ultrasonic Safety Sensor

1. Introduction

In the digital era, the rapid advancement of technology has significantly transformed various aspects of daily life, particularly in the realm of home security and automation. The integration of smart technologies into everyday systems has reshaped how people manage their homes, offering enhanced security, convenience, and efficiency. One of the most prominent innovations is the Internet of Things (IoT), a technology that allows devices to communicate and interact in real-time over the internet [1], [2], [3]. The seamless connection between devices has made IoT a critical tool in improving the automation of numerous systems, including home security [4], [5].

Among the various applications of IoT, automatic gate systems are becoming increasingly popular for controlling access to residential, commercial, and industrial properties. Traditional manual or remote-controlled gates often present challenges such as limited security, ease of unauthorized access, and inadequate integration with other smart systems. These limitations can compromise the overall security of a property, making it essential to explore more advanced solutions that incorporate modern technologies for both improved functionality and safety.

Automatic gate systems have proven to be an effective solution for enhancing property security by allowing controlled access and reducing the need for physical interaction with the gate. These systems are especially valuable in high-traffic areas or residential zones where quick and efficient access control is crucial. However, many of the currently available automatic gate systems rely on basic remote controls, limiting the range of operation and posing security risks in the event of remote-control malfunctions or unauthorized access. Moreover, these systems often lack sufficient integration with other security measures, further weakening their effectiveness in protecting properties.

In recent years, IoT-based automatic gate systems have emerged as an ideal solution to address these challenges. These systems enable remote access control, real-time monitoring, and integration with other security features, offering more flexibility and convenience for users. By using IoT technology, automatic gates can be remotely controlled via smartphones or other connected devices, allowing users to manage gate access from virtually any location. The combination of IoT with other security technologies, such as RFID and electro-magnetic locks, provides enhanced protection and ensures that only authorized individuals can access the property.

While previous studies have explored various aspects of automatic gate systems, many of them still fall short of providing a fully integrated, secure, and reliable solution. For example, some systems use Bluetooth for communication, which offers limited range and may be susceptible to signal interference. Additionally, these systems may lack backup options in case of network failure, such as internet outages or disconnection from the remote control application [6]. Therefore, a more robust system is needed that combines multiple control mechanisms to ensure reliability and security in all circumstances.

This research aims to address these limitations by developing an innovative IoT-based automatic gate system equipped with an ESP32 microcontroller. The ESP32, with its integrated Wi-Fi capabilities, allows the gate system to be controlled remotely via mobile devices, providing users with greater flexibility and convenience. Additionally, the system integrates RFID technology for physical access control, ensuring that authorized users can operate the gate even if internet connectivity is unavailable. This dual control system enhances both security and reliability, offering users a comprehensive solution for managing gate access.

Furthermore, safety is a crucial consideration in automatic gate systems, especially in residential areas where children and pets may be present. To mitigate the risk of accidents during gate operation, this system incorporates an ultrasonic sensor, the HC SR-04, which detects obstacles in the gate's path and prevents it from closing when objects are detected [7]. This safety feature reduces the likelihood of injury or damage caused by the gate's movement [8] , ensuring a safer environment for users and their families.

This paper proposes a highly advanced IoT-based automatic gate system that combines cutting-edge technologies such as remote access, RFID, and safety sensors. By integrating these components into a single, cohesive system, the proposed solution provides a more secure, flexible, and efficient method of controlling access to properties. The development of such a system represents a significant step forward in the evolution of smart home technologies, offering a practical and reliable solution for modern security needs.

2. Research Methods

As a foundation for this research, the author examines relevant studies to comprehend the key concepts that are essential for developing the proposed system. Various studies have explored automatic gate systems and their integration with modern technologies, focusing on enhancing security, efficiency, and user convenience. Many of these systems, however, are limited by traditional control mechanisms, such as basic remote controls, which restrict their functionality and range of operation. To address these challenges, several studies have proposed incorporating Internet of Things (IoT) technologies to enable remote access, real-time monitoring, and integration with other security features.

The Internet of Things (IoT) has significantly influenced the development of advanced automation systems, particularly in the realm of smart home security. IoT enables devices to communicate and share data in real-time, providing enhanced control and flexibility for various applications. In the context of automatic gate systems, previous research has primarily focused on integrating IoT to enable remote access and improve user convenience [9]. For example, studies have explored the use of Bluetooth and Wi-Fi for wireless control of gate systems via mobile applications [10]. Although these systems offer an improvement over traditional remote controls, they often face challenges related to limited range, reliability, and security risks due to signal interference or unauthorized accessance the security of automatic gate systems, many researchers have integrated Radio Frequency Identification (RFID) technology as an additional access control mechanism. RFID offers a secure and contactless method of authentication, enabling authorized users to operate gates without the need for direct interaction. Research has shown that RFID-based systems can effectively prevent unauthorized access and provide a higher level of security compared to standard remote controls. However, despite its benefits, RFID alone may not be sufficient in scenarios where internet connectivity is crucial for real-time monitoring and remote access. Therefore, combining RFID with IoT technologies has been proposed as a solution to bridge these gaps, enhancing both the flexibility and security of gate control systems.

Anothaspect of automatic gate systems is ensuring user safety during operation. Previous studies have highlighted the importance of incorporating safety features, such as obstacle detection sensors, to prevent accidents. Ultrasonic sensors, like the HC SR-04, have been commonly used in various automation systems for their ability to detect objects in close proximity. These sensors provide real-time feedback to the microcontroller, enabling the system to halt or reverse the gate movement if an obstacle is detected. This approach significantly reduces the risk of injury or damage, particularly in residential settings where children and pets may be present.

The choice of miler plays a vital role in the performance and capabilities of automatic gate systems. Recent advancements have led to the adoption of the ESP32 microcontroller, known for its integrated Wi-Fi and Bluetooth modules, low power consumption [11], and dual-core processing capabilities. The ESP32's versatility makes it ideal for IoT applications [12], as it allows seamless integration of various components, such as RFID readers, ultrasonic sensors, and electromagnetic locks. Research has demonstrated the effectiveness [13] of using ESP32 in IoT-based automation systems [14], showcasing its ability to handle multiple tasks simultaneously, thereby enhancing the overall functionality and reliability of the system.

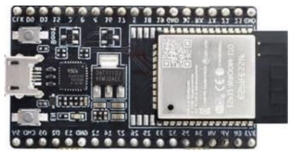

Figure 1. ESP32 WROOM- 32U

While previous studies hanificant strides in improving automatic gate systems, challenges remain in achieving a fully integrated and robust solution. Many existing systems lack comprehensive safety features, reliable remote access capabilities, and dual-layer security mechanisms. This research aims to address these limitations by developing an innovative IoT-based automatic gate system that combines the benefits of RFID technology, ESP32 microcontroller capabilities, and enhanced safety measures. By leveraging these technologies, the proposed system seeks to provide a more secure, flexible, and user-friendly solution for modern access control needs.

3. Material and Methods

This study presents the design and implementation of an automatic gate control system using the Internet of Things (IoT) approach, which will focus on controlling automatic gates with door lock security and implementing a safety system for users by applying sensors to detect any movement or obstacles.

1.1. Research Stage

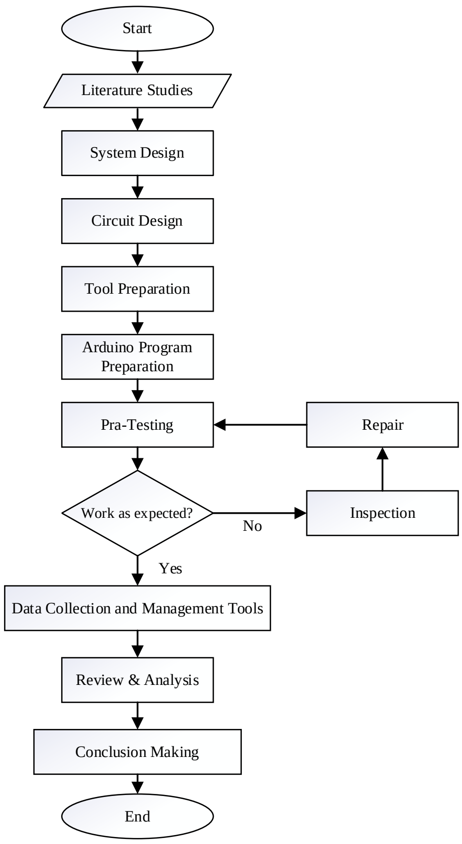

Figure 2. Research Flowchart

Developing a design through literature study, namely by reviewing references related to the topic being discussed. The goal is to gain a deep understanding, ensure the feasibility of this research, and provide guidance in minimizing the risk of errors that may occur during the research process.

After the literature study is continued with the system design followed by the selection of the right technology, as well as designing the communication flow between components to ensure smooth integration. The system must also be tested to ensure that each part functions according to plan and can operate efficiently. The goal of the design system is to create an optimal, functional, and reliable solution, while considering factors such as cost, time, and operational needs. After the literature study, the system design is developed, including selecting suitable technology and designing communication between components for seamless integration. Testing ensures each part functions efficiently. The goal is to create an optimal, functional, and reliable system, considering cost, time, and operational needs.

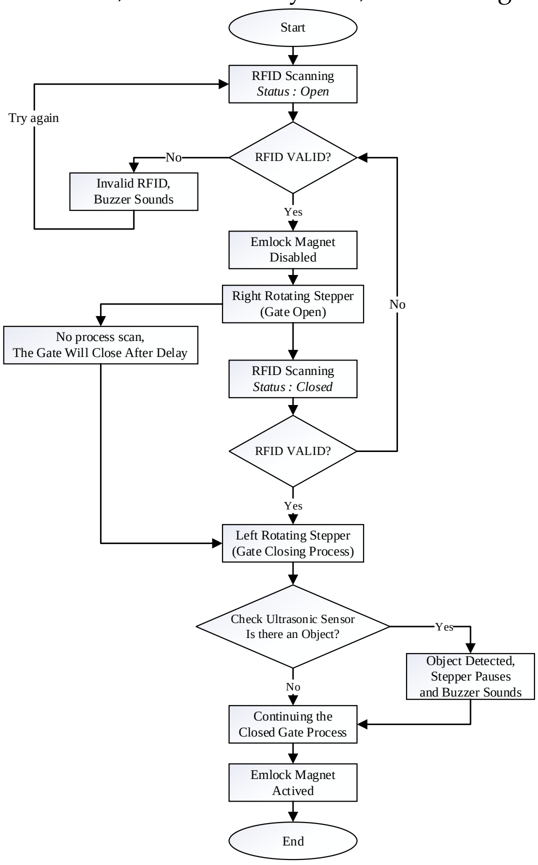

Figure 3. Design System of RFID Control

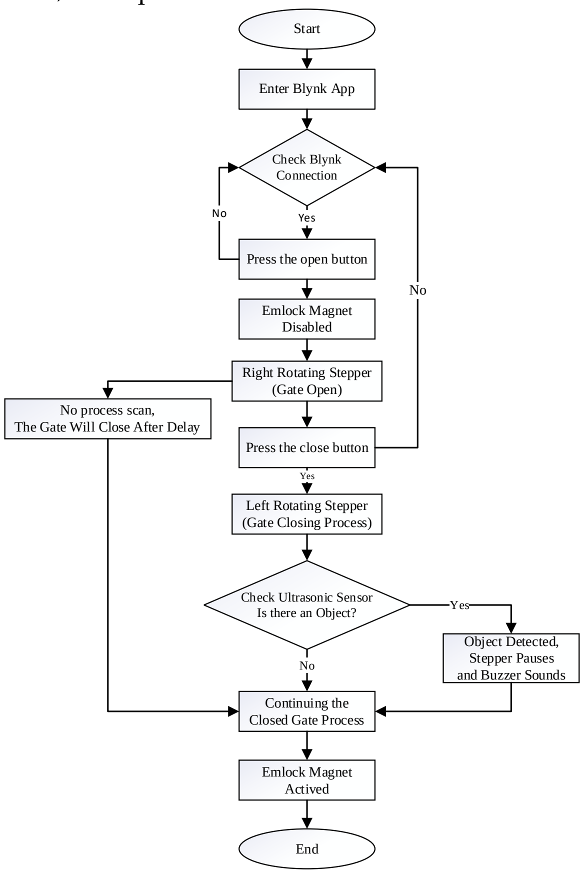

Figure 4. Design System of Mobile Control

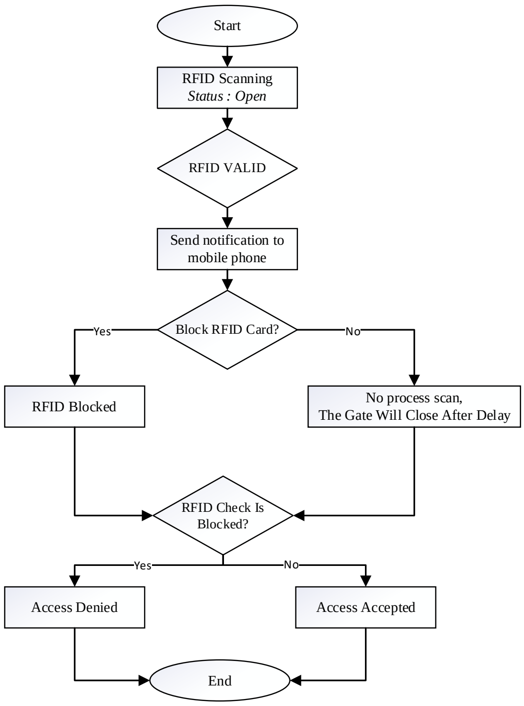

Figure 5. RFID Control Security Integration

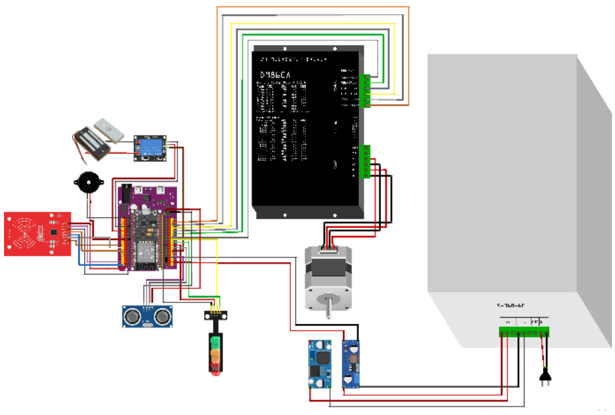

Figure 6. Circuit Design

The circuit design involves selecting suitable components and creating a wooden miniature gate structure. A Nema 17 Stepper Motor powers the gate, with all components connected using jumper cables while ensuring proper power supply. Accurate movement is achieved by matching the gate's teeth with the Stepper Motor's gear. The design also includes an Emlock Magnetic locking system, along with sensors and other components.

Figure 6. Motor Gear Rack

Figure 7. EmLock Magnet

After the entire circuit is designed, the next step is to compile a program using the Arduino IDE software to be programmed into the ESP32 microcontroller. In addition to writing code for circuit operation, this step also includes developing a program for access control using RFID scanning and a mobile application, which will be tested through the Blynk cloud platform. After completing the design and programming, the device is tested to ensure proper performance. If issues arise, further inspection and program adjustments are made. Once functional, the system is reviewed to analyze the microcontroller's performance with all components, ensuring optimal operation and coordination. The analysis stage collects data on performance, flexibility, and safety aspects of the automatic gate control system. This ensures accurate and reliable results, serving as a basis for decision-making and conclusions.

1.2. Related Hardware

The system uses the ESP32 microcontroller as the main control unit. It integrates multiple components, including the Nema 17 Stepper Motor with the TB6600 module, which drives the sliding gate to open and close automatically. Figures 8 and 9 show the Stepper Motor and Microstep Driver.

Figure 8. Motor Stepper Nema 17

Figure 9. Microstep TB6600

The system features a mini magnetic emlock that uses magnets powered by electricity to attract an iron piece on the fence, securing it. When activated, the magnets hold the iron piece, preventing manual opening. A relay controls the activation and deactivation of the lock as needed. Figures 10 and 11 show the magnetic emlock and relay in operation.

Figure 10. Magnetic Emlock

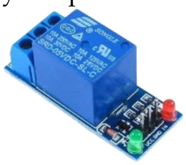

Figure 11. Relay

Meanwhile, the function of the RFID component as access control opens or closes the gate physically by attaching the card to be scanned into the module section. This function will later work carefully by giving signals to several main components to open and close the gate. The RFID component can be seen in the following figure 12:

Figure 12. RC-522 RFID

The safety sensor used for user safety is the HC-SR04 ultrasonic sensor, this sensor is considered capable of detecting the movement of every object or human in its coverage area, where in this case the sensor is used to detect the presence of every object, human, and animal so that they are not trapped when the door closes. For the ultrasonic sensor, this can be seen in the following figure 13:

Figure 13. Sensor HC-SR04

For other sensors, a Reed Switch sensor is used which is equipped with a magnet and a sensor module to realize limiting the range of the fence when closing and opening the gate when the motor is working. For the magnet and reed switch sensor, this can be seen in figures 14 and 15:

Figure 14. Magnetic Reed Switch

Figure 15. Reed Switch Sensor

The resources used by this system use a 12V 5A Power Supply. To see the total voltage and ampere consumption, an Ammeter display is used to measure the exact power consumption. For the power supply and voltmeter, can see Figures 16 and 17 below:

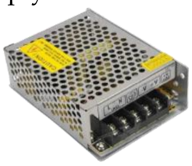

Figure 16. Power Supply

Figure 17. Volt&Amp Meter

Because the system of each component uses 12V, 5V and 3.3V, an LM2596 step down module is needed which is converted down to 3.3V, and an XL7015 step down module which is converted to 5V. Both step downs can be seen in the differences in figures 18 and 19 below.

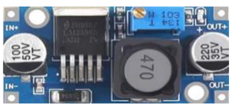

Figure 18. Step Down LM2596

Figure 19. Step Down XL7015

Other supporting components such as LED Traffic Light and Buzzer are only used as a form of visualization of each performance or process of each gate control. For LED Traffic light can be seen in figure 20 and buzzer in figure 21:

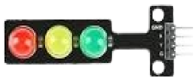

Figure 20. LED Traffic Light

Figure 21. Buzzer

1.3. Related Software

In this research, software integration is needed to support the control system on the automatic gate fence. The software will be designed to support every process needed in the operation of the system efficiently and effectively.

1.3.1. Arduino IDE

Arduino IDE supports ESP32 programming, enabling users to write, upload, and manage code in C/C++. It provides access to features like Wi-Fi, Bluetooth, and GPIO. Known for its simplicity and large community support, it offers examples and libraries for IoT projects, including multi-controller automatic gate systems.[13], [14].

1.3.2. Blynk Application in IoT Systems

This research aims to advance knowledge in remote control automation by integrating the Blynk application into an automatic gate control system. The system enables users to open and close the gate as needed while also offering real-time door status monitoring whether open or closed via mobile devices[15]. The Blynk application features advanced security. If a user's RFID card is lost and misused, the system will automatically send a notification to the user's phone. Users can block the lost card via the app, rendering it unusable for door access. This feature ensures optimal protection for home security.

4. Conclusions

The automatic gate control prototype uses a Nema 17 Stepper Motor system combined with a 12V TB6600 driver. The motor is installed on the gate with a gear mechanism featuring a 32 mm diameter gear, enabling smooth opening and closing of the gate. The system also integrates a security feature using a 12V magnetic emlock, ensuring the gate remains securely locked when closed. Additionally, other components are designed using an ESP32 as a multicontroller to seamlessly coordinate the entire system. The following are the prototype results, as shown in Figures 23,24,25 and 26:

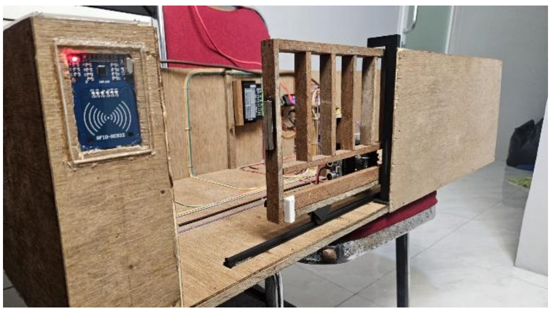

Figure 23. Design Architecture

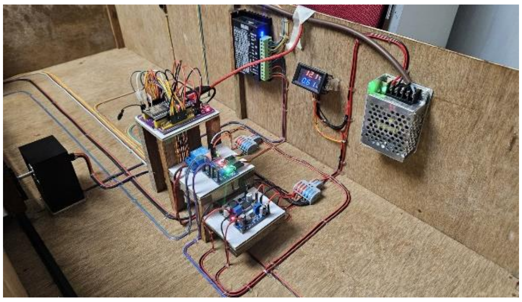

Figure 24. Microcontroller Placement

1.4. RFID Scanning Distance Test

The RFID scanning test was carried out in a simple way. This study tested the distance between the RFID card and the scanning module in centimetres, ranging from 1 to 5 cm. The results showed that the RFID scan worked well at distances of 1 to 4 cm. However, at a distance of 5 cm, the RFID could no longer function.

Table 1. RFID Card Scan Distance Test

No	Distance (Cm)	Status
1	5	Not Working
2	4	Working
3	3	Working
4	2	Working
5	1	Working

1.5. Mobile Control Testing with Blynk

The testing using mobile access control with the Blynk system showed excellent results. The prototype works well for opening and closing the gate, similar to the RFID scanning system. However, the mobile access control using Blynk has the advantage of being operable anytime and anywhere without the need for physical interaction. This testing can be seen in Figures 27 and 28 below.

Figure 25. Open Control Test

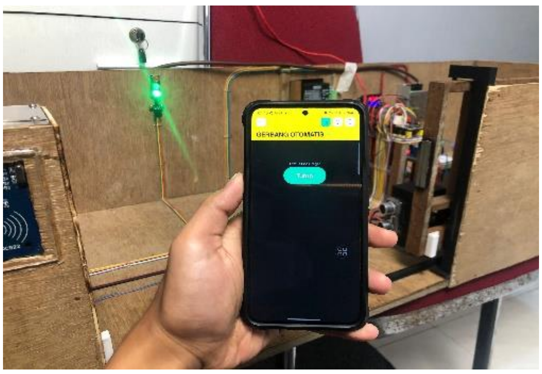

Figure 26. Close Control Test

1.6. Sensor Ultrasonic Reading Analysis

The sensor works by detecting objects within its detection range. For testing the HC-SR04 ultrasonic sensor, the study conducted three rounds of testing, with each round consisting of six trials. The detection distance was predetermined in centimeters for each trial. From the results of the three tests, there were some detection times that took longer than others, such as in the first test during the first trial (5.16 seconds) and in the second test during the sixth trial (4.20 seconds). Overall, the average time required by the sensor to detect objects at each specified distance was approximately 3 seconds.

Table 2. Object Detection Sensor Testing

No	Distance to (Cm)	Sensor Reading Delay (Sec)		
		Testing 1	Testing 2	Testing 2
1	33	5,16	3,09	2,84
2	27,5	2,99	2,51	2,99
3	22	2,77	2,59	2,93
4	16,5	3,06	3,05	3,02
5	11	3,05	3,05	3,15
6	5,5	2,35	4,20	2,43

1.7. Gate Opening and Closing Time Analysis

The analysis of the gate's opening and closing time involves calculating the wheel's circumference, determining the number of revolutions needed, and measuring the time taken for one revolution. These calculations are used to estimate the total time required for the gate to complete its opening and closing operations efficiently. Using theoretical calculations, the estimated time is as follows, while the measured time using a stopwatch is shown in Figure 29 below:

- Calculate Wheel Circumference:
  $C = \pi \times D$
  $C = 3{,}14 \times 0{,}032 = 0{,}10053\ m\ (10{,}052\ cm)$
  Each wheel rotation covers a distance of **10,053 cm**

- Determine the Number of Revolutions (*N*)
  $$N = \frac{Distance}{Wheel\ Rotation} = \frac{33}{10{,}053} \approx \mathbf{3{,}28\ rotation}$$

- Calculate the Time for One Revolution
  $$T_{rev} = \frac{60}{RPM} = \frac{60}{7{,}7} = 7{,}79\ sec/rev$$

- Calculate Total Time
  $$T_{total} = N \times T_{rev} = 3{,}28 \times 7{,}79 = \mathbf{25{,}5\ seconds}$$

Figure 17. Fence Rate Measurement

1.8. RFID Block Based Security

The RFID blocking system ensures the security of users if the RFID is lost or stolen and used by an unauthorized person to open the door. With this additional security feature, users will receive notifications on their mobile devices when the door is opened or closed using RFID. The system not only provides notifications but also allows users to block RFID access if the action is not made by them or someone they know. If the action is legitimate, the user can simply ignore the alert.

Figure 28. RFID Blocking Access

1.9. Total Power Consumption

A 12V 5A power supply is used as the power source for this prototype. Power consumption is measured using a digital multimeter, comparing the theoretical calculations of each component's power usage with the actual measurement results. Comparison data between RFID scan control and Mobile Blynk control is presented in tables 1 and 2 below.

Table 3. Total Power Consumption RFID Control

RFID SCAN	Close Door Mode	Open/Close Process Mode	Open Door Mode
Calculation	300 mA	930 mA	60 mA
Actual Result	**340 mA**	**880 mA**	**40 mA**

Table 4. Total Power Consumption Mobile Control

MOBILE BLYNK	Close Door Mode	Open/Close Process Mode	Open Door Mode
Calculation	0.38 A	1.30 A	0.36 A
Actual Result	**0.34 A**	**1.18 A**	**0.34 A**

5. Conclusions

This research presents an innovative IoT-based automatic gate system that integrates multiple advanced features, including RFID technology, an ESP32 multicontroller, an HC SR-04 ultrasonic sensor, and an electromagnetic lock (Emlock). The experimental evaluation demonstrates that the proposed system effectively addresses the limitations of traditional gate control mechanisms by offering enhanced security, flexible access control, and improved user safety.

The system's dual-layer security approach, combining RFID access control with an electromagnetic lock, successfully prevents unauthorized entry and ensures that the gate remains secure when closed. The use of the ESP32 microcontroller allows for efficient integration and coordination of various components, providing seamless remote access via mobile devices and stable performance in diverse operating conditions. The ultrasonic sensor's integration further enhances safety by detecting obstacles during gate movement, reducing the risk of accidents

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