Design and Fabrication of an Android-Controlled IoT-Enabled Sliding Gate for Residential Security

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Abstract **- Residential gate systems play a vital role in ensuring security and convenience for homeowners. However, traditional manual gates are often inconvenient, time-consuming, and less secure, while existing automated solutions can be costly and complex. This research work focuses on the design and fabrication of an automated residential gate controlled via an Android smartphone, providing a cost-effective, low-cost and user-friendly alternative. The system integrates a microcontroller, motorized gate mechanism, and Wi-Fi communication to enable remote control through a dedicated Android application. The smartphone-programmed app allows seamless gate operation, including opening and closing while enhancing security through user operation. The fabricated prototype was tested and demonstrated reliable performance, smooth operation, and secure access. Experimental evaluation measured Signal Strength and control reliability over distances from 0 to 20 meters. The result showed Signal Strength tapering from ~ 120 % at 0 – 2 meters to ~ 20 % at > 15 meters, with reliable operations up to 15 m with command success above 95 % up to 12 metres. Future work will focus on enhanced security features (two-factor authentication), cloud integration and load-capacity testing for heavier gates.**

Keywords: IoT-Enabled, Residential security, Wi-Fi NodeMCU, smartphone, Android-Controlled

1.0 INTRODUCTION

The security and convenience of residential access control systems are critical in modern living environments. Traditional gate systems often require manual operation, which can be cumbersome, time-consuming, and prone to unauthorized access due to human error or lack of adequate security measures. The existing automated gate systems are frequently expensive, complex to install, and may lack user-friendly remote control options.

Although crimes like robberies and burglaries can happen practically anywhere at any time in the current period, they are more likely to happen in predictable locations and at predictable times in residential areas. In the United States, 447,403 robberies were reported to the police at a pace of one per minute, according to the 2006 FBI Uniform Crime Reports [1].

Effective methods of limiting access to high-interest locations, like communities, recreation centres, workplaces, and residences, to prevent unauthorised access are necessary due to the security issues that are present in many locations. The need to feel safe and not in danger is what gives rise to security [2]. Millions of naira worth of property and lives have been lost in Nigeria mostly due to the proliferation of armed robbers and other groups that are a nuisance to society. Unattended residences have been the scene of numerous attacks that have resulted in a substantial loss of life and property [3]. It is hypothesised that humans have attempted to regulate their built environment and the world ever since the development of early communities and residential complexes [4]. Many attacks occurred despite seemingly indestructible security gates intended to deter intruders, raising serious concerns about the gates' effectiveness.

Automatic gate systems, on the other hand, are integrated gates that use electronic components like proximity sensors and actuators to minimise the amount of human labour required to open and close gates [5]. Automation gates are becoming a major concern for end users because of the growing number of industrial and residential sectors [6]. The majority of the market's automatic gates are controlled by a radio frequency (RF) transmitter device, which uses a variety of radio frequencies to open and close the gate. Utilising a smartphone's current technology, particularly in remote applications by utilising its built-in hardware like Bluetooth and Wi-Fi, is vital given the rapid pace of technological innovation [7].

The Internet of Things (IoT) capabilities will be used to enhance the current automatic gate system in terms of smart gates. Numerous applications have been developed to design automatic gates with a variety of control devices, such as cellphones, wireless transmitters, keypads, card readers, and vehicle tag readers [8][9][10]. Numerous technologies, including radio frequency and infrared technology, are used in the development of this research. Different levels of intelligence have been embedded in the home using a variety of wireless technologies, including Bluetooth, Wi-Fi, RFID, and cellular networks, that can facilitate remote data transfer, sensing, and control [11][12]. One of the best home features designed to make gated entry simple is an automatic gate.

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Different degrees of convenience and security are provided by the use of different technologies to operate automatic gates. In particular, biometric recognition systems are more comfortable and offer superior protection compared to conventional personal recognition techniques [13]. However, there is still a vast array of technologies that can be used to operate automatic gates. [14] in their research showed that a microcontroller might be used to monitor two entries. The gates were made to automatically open, wait a predetermined amount of time, and then close when they detected a car approaching. Using a GSM connection, cell phones can also be used to operate automatic gates. One platform that provides a vast communication-based design is GSM [15]. In this study, an automated security gate is controlled over the GSM network.

An infrared remote with a password security function was used by some researchers to create an autonomous gate control [16]. The microcontroller that operated the gate was programmed using a logic circuit and assembly language. An 8-bit microcontroller is utilised by the processor to decode the infrared signal from the remote control's IR sensor transmitter, turn on the relay that regulates the DC motor, and receive the signal. The DC motor controls the gate's forward or backward motion with gears. The gate will not open and the security alarm will ring if the incorrect password is entered. The alarm system was included in the design to raise awareness if someone tries to enter the secured area without authorisation.

Using a password to unlock the gate caused some delay and time waste, which is the problem with the design by [16].

An RFID gate automation system based on the Internet of Things was created by certain researchers [17]. The IoT-based RFID design has the advantage of enabling owner access from any location in the world. However, this gate's qualities limited its affordability by making it expensive. [18] created an automated railway gate control system based on sensors. Although the automated controlled system can open and close gates, it is unable to regulate vehicle crossings. The system was inappropriate for usage since load sensors were not used. [19] utilised Arduino to design a home automation system that could be connected to phones using Bluetooth or Wi-Fi.

In recent years, the widespread adoption of smartphones has introduced new possibilities for affordable and efficient automation. However, the integration of Android phones as remote controls for residential gate systems remains underutilized. This gap limits the potential to leverage smartphones' ubiquity and connectivity features to improve home security and ease of access. Therefore, there is a need to design and fabricate an affordable, reliable, and user-friendly automated residential gate system that utilizes an Android phone as the remote control. This solution aims to address the challenges of manual gate operations, enhance residential security, and provide an accessible, cost-effective automation alternative for homeowners.

2.0 MATERIAL AND METHOD

The designed and fabricated system consists of two stages: the hardware (mechanical) part involves designing and implementing an automated residential gate prototype using an iron, and the software part involves designing the graphical user interface (GUI) to automate the gate. The steps involved in this research include gathering the equipment and materials, configuring the micro-controller using Arduino software (a program that utilises the Python programming language) on a computer, enabling the micro-controller to control the stepper motor, fabricating the sliding gate, installing the stepper motors on the side of the gate, testing and evaluating the micro-controller works on the electric motors, and developing an Android application that connects to the micro-controller. An electrical system is being developed using Proteus ISIS circuit simulation (CAD) software, and the Arduino IDE is used to test the system using an Arduino microcontroller. Figure 1 shows the flowchart for the proposed system

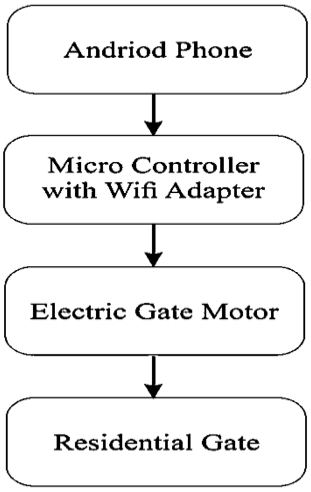

Figure 1: The flowchart for the system

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2.1 Designing the Automated Residential Gate

The mechanical draughting of the automated residential gate prototype is shown in Figure 2. The sliding gate was selected for this research due to its motion, which can be matched with a stepper motor. According to equation (1–5), the rotational motion of the stepper motor is converted to linear motion through the combination of rack and pinion gear.

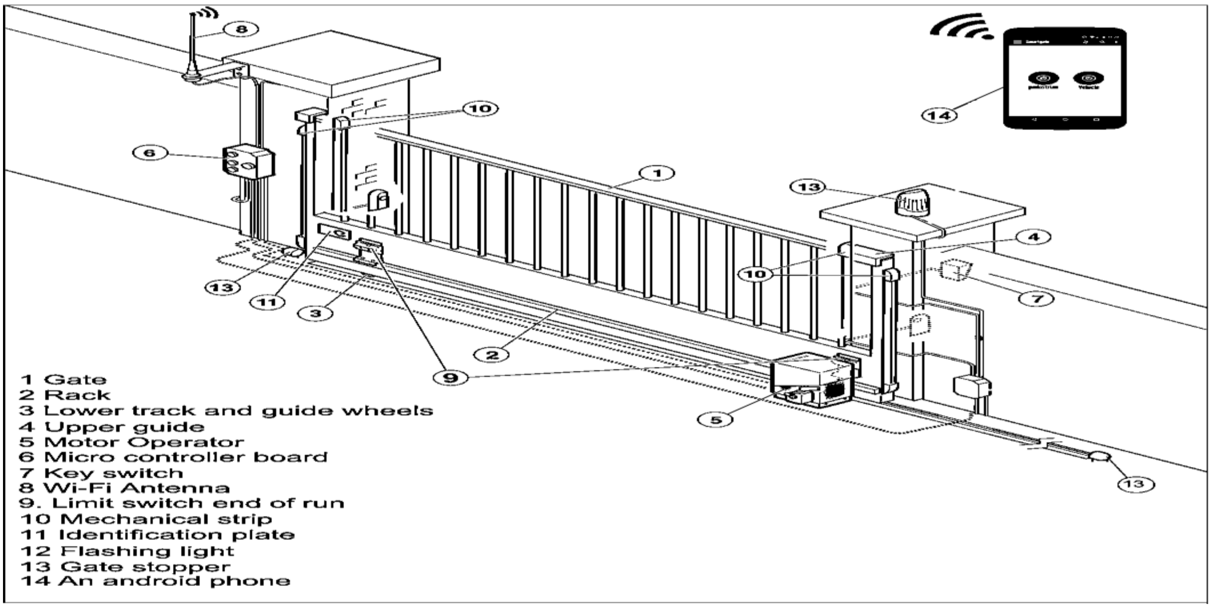

Figure 2: mechanical drafting of the automated residential gate prototype.

The Torque needed to be produced by the stepper motor to move the gate along its roller track is as follows:

$$Ʈ_1 = F \times L \qquad [1]$$

$$Ʈ_1 = mg \times L \qquad [2]$$

But $\quad g = \alpha \times r$

$$Ʈ_2 = m\alpha r \times r \qquad [3]$$

$$Ʈ_2 = m\alpha r^2$$

$$Ʈ_1 = mr^2\alpha \qquad [4]$$

But $\quad mr^2 = I$

$$Ʈ_2 = I\alpha \qquad [5]$$

Effective actuating Torque for the sliding gate

$$Ʈ_3 = Ʈ_2 - Ʈ_1 \qquad [6]$$

Where $Ʈ_1$ is Torque induced by the gliding gate on the stepper motor, $Ʈ_2$ is Torque produced by the stepper motor to move the gate, $Ʈ_3$ is Effective Torque produced, F is the weight of the sliding gate, g is the acceleration due to gravity, L is Lever's arm, m is mass of the sliding gate, a is linear acceleration of the gate, r is pinion gear radius, α is angular acceleration of the stepper motor and *I* is moment of inertia of the sliding gate.

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From Equations (1)-(5), the gate's peak effective torque requirement (Ţ_3) was calculated at approximately 0.45 N. munder full-load, dynamic conditions. Nema 17 stepper motor was selected due to the Holding torque of 0.59 N. m, Rated current of 2.0 A/phase, Rated voltage of 3.6 V and Step angle of 1.8° ± 5%. This motor thus provides a design margin of approximately 31 % ($0.59\ N.m\ \div 0.45\ N.m^{-1}$), ensuring reliable operation despite friction, tracking irregularities, and environmental variations. Its current rating (2 A) also matches the driver's capability, simplifying the electrical design while avoiding over-stress or overheating.

2.2 Fabricated Prototype of the Automated Residential Gate

Following the design, the automated residential gate prototype is constructed using a 1:2 scale, meaning all dimensions were reduced to half the size of the intended full-scale gate. This scaling was done to conserve materials, simplify handling and allow for easier testing in a laboratory setting. Iron was selected as the primary construction material due to its strength, durability and ease of welding. As shown in Plate 1, the frame, guide rail and gate structure were fabricated using mild steel square tubing and flat bars, accurately replicating the mechanical layout of the full-scale system.

Plate 1: Fabricated Residential Gate prototype with installed Nema 14 Electric motor

2.3 Electric Circuit of the Automated Residential Gate Controller

This research employs the use of an electric stepper motor actuated by signals from an Arduino UNO microcontroller with a Wi-Fi NodeMCU Microcontroller. This facilitates the gate to be remotely controlled by an Android phone to control a residential gate. The circuit diagram of the gate control system is shown in Figure 3. The circuit majorly uses a NEMA 14 Electric motor, Arduino UNO with Wi-Fi NodeMCU Microcontroller, Arduino power pack, Motor driver (Relay), and Stepper motor. Plate 2 shows the developed gate controller unit.

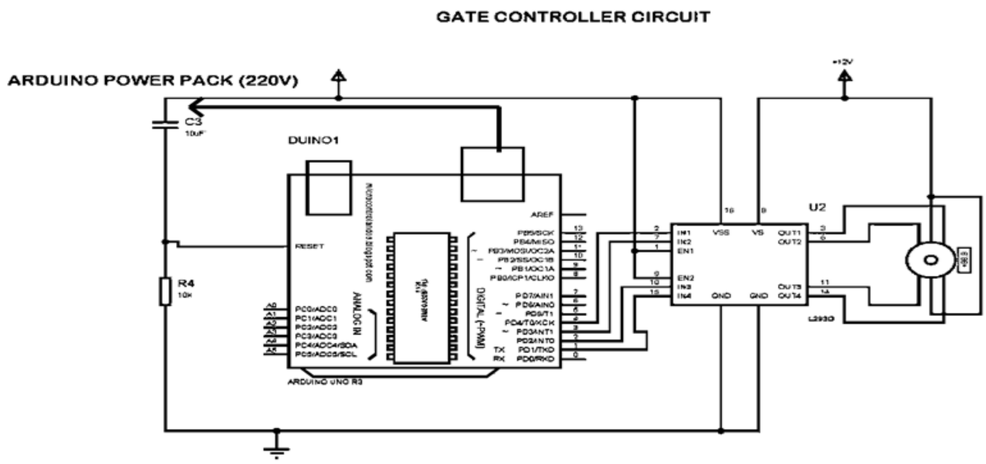

Figure 3: Circuit diagram for the automated residential gate controller developed on ISIS Proteus

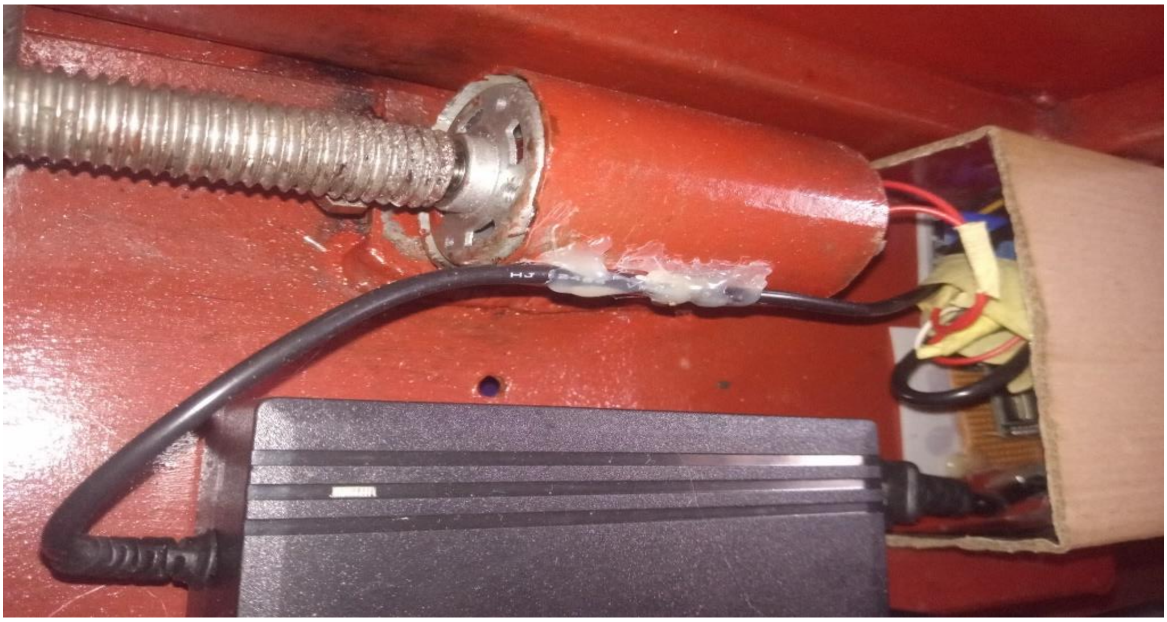

Plate 2: Developed gate controller unit

2.4 Graphical User Interface (GUI) of the automated residential gate

The Android app SmartGate was used to construct the system's software component. MIT application inventor software was used to create the SmartGate. This is the remote control for the sliding gate mechanism, which opens and closes the gate. The Android Studio development software was used to create the application's Graphic User Interface (GUI). The drag-and-drop visual programming tool in MIT App Inventor makes it simple to use for creating and designing mobile apps for iOS and Android. Without the need for coding or programming knowledge, it may turn a concept into a functional application. The C programming language is used by the app Inventor software to make it easier to program the SmartGate mobile application. Plates 3 and 4 below display a screenshot of the Graphic User Interface (GUI). The gate's opening and closing times are determined by the pedestrian and vehicle options.

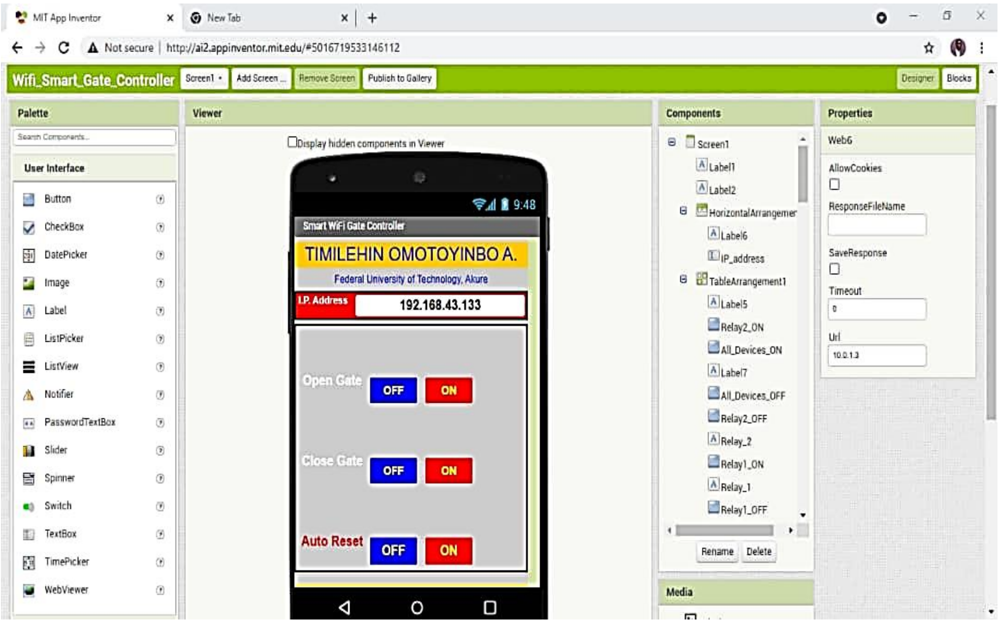

Plate 3: The GUI App development process on SmartGate Mobile App.

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Plate 4: Screenshot images of the SmartGate application on an Android phone

3.0 RESULT AND DISCUSSION

The developed system was tested to determine the intensity of the wireless signal and the efficiency of the stepper motor. The prototype and the GUI system were tested to determine the effectiveness of the stepper motor. The goal is to demonstrate that the Arduino microcontroller can be used to develop an Android application. The FUTA central mechanical workshop was used to test the residential gate prototype, which was set up as seen in plate 5. The Wi-Fi NodeMCU microcontroller and the SmartGate app on the Android phone were connected by Wi-Fi, and the setup was powered by 220V mains. When the OPEN button on the mobile app was clicked, the gate was seen as open, and when the CLOSE button was clicked on the mobile app, the gate was seen as closed. As a potential solution, a driver board was used in conjunction with 12 V two-channel relay switches to help alternate the drive of the electric motor in the two opposing directions after it was discovered during research execution that the Nema 14 stepper motor, which had been used initially, was not operating efficiently due to its driver incompatibility with the Wireless Module NodeMCU. When used during operation, the smartphone app worked well with the new electric motor.

The wireless strength between the smartphone and the Wi-Fi NodeMCU is tested further. The Wi-Fi Analytics Android app was used to measure the signal strength. The Wi-Fi NodeMCU was placed one meter away, and the signal intensity was monitored at 1-meter intervals. The results were plotted on the graph in Figure 4.

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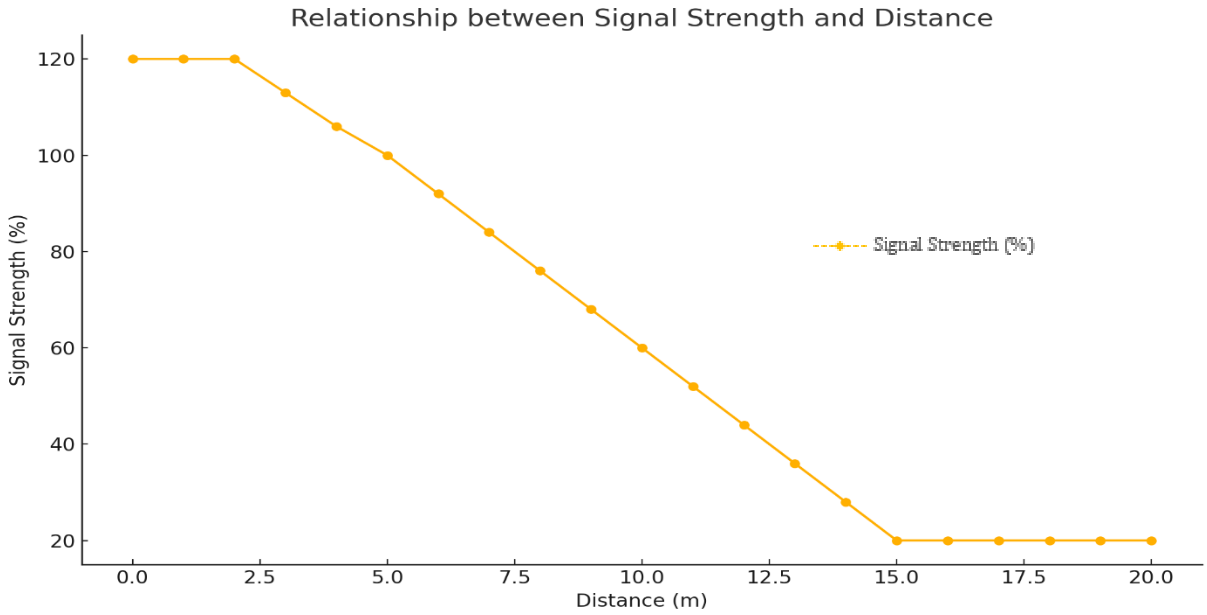

Figure 4: The relationship between the signal strength and the range of distance

The graph illustrates the relationship between the Wi-Fi NodeMCU microcontroller signal strength of an automated residential gate and the operator's distance. It showed a clear inverse relationship, where the signal strength decreases as the distance increases. At very close distances (0–2 meters), the signal strength is at its maximum, approximately 120%, indicating optimal communication between the operator and the gate. However, as the distance increases beyond 2 meters, the signal strength gradually diminishes, dropping to around 100% by 5 meters. Beyond this point, the decline becomes more pronounced, with the signal strength falling sharply between 5 and 15 meters. At distances greater than 15 meters, the signal strength stabilizes at a much lower level, nearing 20%. This decline in signal strength can be attributed to signal attenuation, environmental interference, or physical obstructions between the operator and the gate. The graph highlights the importance of maintaining proximity to the gate for efficient operation and reliable communication. It's observed that the effective distance to operate the residential gate is between the ranges of 2 meters.

4.0 CONCLUSION

It is impossible to overstate the importance of offering a practical method of safeguarding limited locations. Mobile phone-controlled automated gates provide a special, safe, and practical method of managing facility access. The accomplishment of this research was made possible by contributions from the literature, which provided an insight into knowledge that served as the theoretical foundation for the study. Materials chosen are manufactured locally in the design, development, and testing of the automatic gate. The technology worked with different kinds of gates. The research's goal of employing Android applications to operate the smart gate was accomplished, and the system could be controlled wirelessly. By employing a remote control device, it will be easier and faster to access the gate, which will benefit a lot of people. Increasing the number of characters in the secret word and also adding two-factor validations will result in a higher level of security. The control framework depicted can still be used to create a larger entryway. Further studies, the driver hardware embedded with components that withstand the higher force will be required to drive the gate.

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