Motion-Activated Garage Door System with Parking Detection and IOT Notification

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ABSTRACT

Traffic has been a prevalent issue since the introduction of automobiles, and many countries face it; one of its root causes is car parking. Improper parking of vehicles more often than not causes traffic congestion in urban areas, as it is usually parked on sidewalks that obstruct not only pedestrian walkways but also the road that vehicles use. Parking garages should be required for every vehicle owner, whether it be a motorcycle or, most importantly, an automobile.

This research paper discusses the process and methods used to develop a motion-activated garage door system with parking detection and IoT notification, with a focus on improving convenience, safety, and accessibility in homes. The design uses an ESP32 microcontroller, an ultrasonic sensor to enable the door to respond to motion, another ultrasonic sensor to detect whether a parked car is inside the garage, a buzzer for sound cues, and a servo motor.

Keywords: Automatic Garage Door System, Arduino Uno, ESP32, Ultrasonic Sensor, Parking Detection, IoT, Blynk, Buzzer, Motion Detection, Embedded Systems, Automation

INTRODUCTION

The use of automation is considered an integral part of current technological innovations, enabling intelligent systems to operate with minimal human input. An area where automation has shown its worth is garage control; in this regard, automated doors have enabled opening without the dangers of human error.

As highlighted by Orji et al. (2019), automated doors increase accessibility for elderly people and those with disabilities and, most importantly, reduce the effort required to operate them.

With the integration of the IoT, embedded systems have become more capable in-home automation. The use of IoT enables users to monitor home systems remotely and receive real-time updates, thereby improving convenience and situational awareness (Gupta et al., 2020). There are software platforms like Blynk that enable easy interfacing between microcontrollers and mobile apps, improving the user experience with embedded systems.

Building on previous work with door automation using ultrasonic sensors, the research presented here introduces new functions that go beyond simple door opening through motion sensing. In particular, the research presents a prototype system with an additional ultrasonic sensor to detect when a car has been successfully parked in the garage, a buzzer for audio feedback, and an ESP32 microcontroller for establishing IoT connections.

Theoretical Framework

This study is grounded in four established theoretical frameworks that collectively explain the operational behavior of the Motion-Activated Garage Door System with Parking Detection and IoT Notification.

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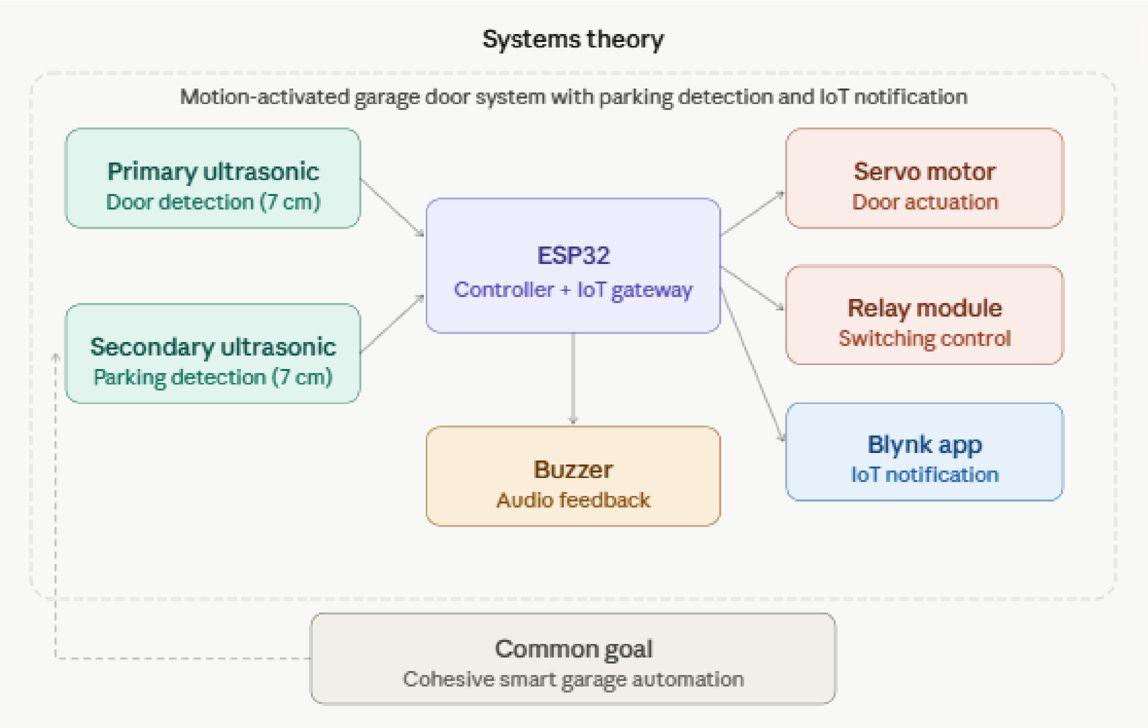
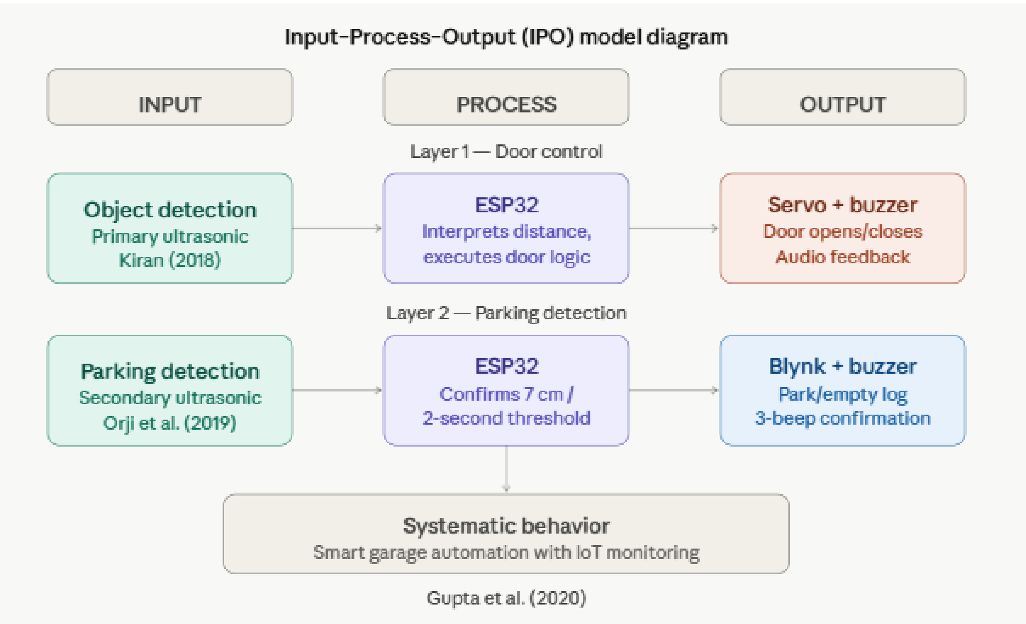
Figure 1. Systems Theory



This functional system involves parts that are connected and act together to achieve a specific purpose. In the current case, all the parts used, which are the HC-SR04 ultrasonic sensors, ESP32 microcontroller, servo motor, relay module, and buzzer, perform different functions but operate in harmony to automate the process of parking in a garage.

Figure 2. Input–Process–Output (IPO) Model



The IPO process describes the flow of the functions within the system at two operational levels. The first operational level involves door operation. In this case, the process input is object detection from the primary ultrasonic sensor, while the output involves actuating the servo motor via a relay and activating a buzzer. The second operational level involves parking detection, where the input is proximity detection using the secondary ultrasonic sensor, and the output is IoT Blynk logging and the activation of the buzzer for confirmation.

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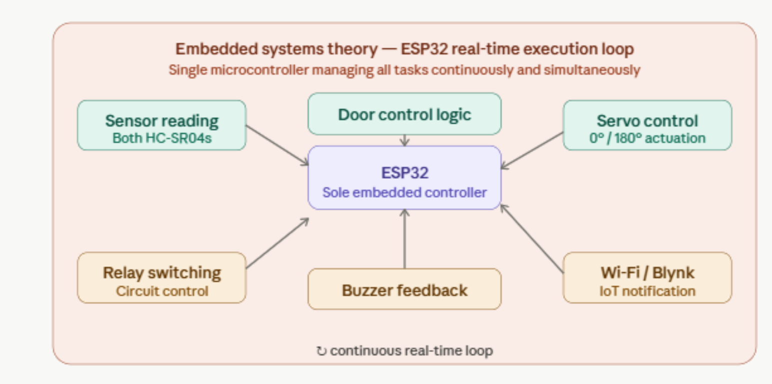
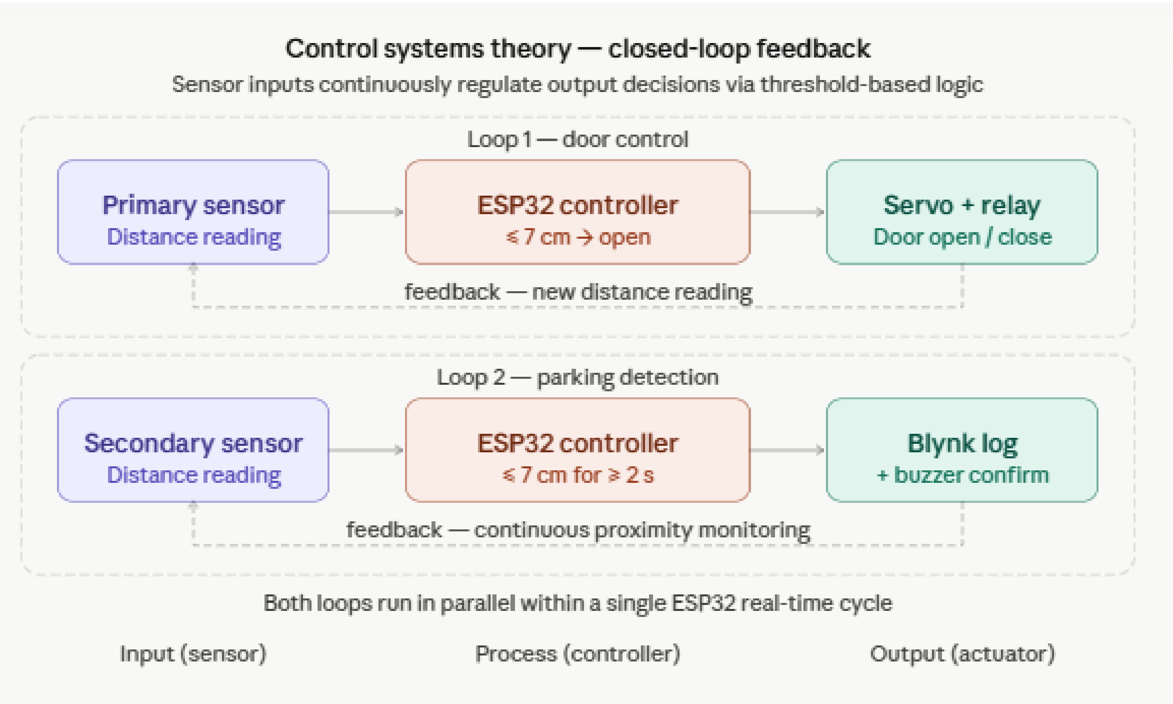
Figure 3. Embedded Systems Theory



Embedded systems theory concerns the process by which microcontroller-based systems perform their allocated tasks. Here, the task allocation is such that the ESP32 functions solely as an embedded controller, performing the processes involved, including acquiring sensor data, controlling the door, controlling the buzzer, triggering the relay, and controlling the servo.

Figure 4. Control Systems Theory



Control System Theory provides an insight into how the system output is controlled using continuous feedback of inputs. The ultrasonic sensors provide the distance information required for motor control and determining if the car has been parked. Using logic that sets a threshold at 7 cm to trigger door opening and 7 cm sustained for 2 seconds to ensure parking has taken place ensures precise system performance.

REVIEW OF RELATED LITERATURE

The use of ultrasonic sensors for object detection and motor control using Arduino in automated doors has proven effective. The research by Orji et al. (2019) demonstrates accurate object detection using ultrasonic sensors and reliable door control via servo motor control and Arduino technology. According to Gupta et al. (2020), implementing door control with an Arduino board is both cost-effective and versatile.

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Kiran (2018) explained the concept of motion-activated door control, in which sensors help avoid unnecessary door activation and energy waste. Faroqi et al. (2018) further expanded this idea by incorporating SMS notifications into Arduino-based door control technology.

The introduction of the ESP32 chip as a microcontroller has significantly increased the opportunities to embed IoT capabilities in inexpensive devices. Unlike the Arduino Uno, which has no built-in Wi-Fi or Bluetooth, the ESP32 makes it highly suitable for wireless connections to cloud platforms, such as Blynk. Sahu et al. (2024) have observed that automatic door control using microcontrollers highly benefits from remote monitoring capabilities.

The use of the Blynk IoT development framework in various prototypes has been successful because of its ease of integration, dashboarding on mobile devices, and event logging and notifications. Together with the ESP32, it enables low-code development for IoT notifications and can be used in learning institutions and home settings.

The inclusion of a buzzer to generate audio alerts adds an element of usability to the proposed system that other scholars have not adequately addressed. The audio alerts generated for door opening and closing, and for parking confirmations, make the user aware of any activity in the system.

METHODOLOGY

In this study, the research method used a descriptive, experimental approach to design and test the proposed motion-activated garage door system with parking detection and IoT notification. This project involved the use of an ESP32 (ESPRESSIF ESP-WROOM-32) microcontroller, which would act as the main

brain and the Internet of Things communication interface of the system; an ultrasonic sensor HC-SR04 for object and distance detection purposes; a servo motor to mimic the action of opening and closing a garage door; a relay module (JQC-3FF-S-Z, 5VDC); and a buzzer.

We used a developmental-experimental research design method for this experiment; in descriptive section, we design the system's architecture, its component and control logic, and in experimental part we perform repeatedly functional tests to make sure if system work correctly at different input scenarios (Object distance, dwells time and power stability, Wi-Fi signal strength).

For the experiment, we built a single car garage model at a scaled size [specify the model dimension/materials used, e.g. Plywood/acrylic framework] using toy car to demonstrate a parked vehicle as in table 2 summary of scenarios. Independent variables are the distances between sensor and object (7cm is the distance to trigger the door) and the time for which the object stayed in this threshold (2 seconds to make sure it parked and 3 seconds to close automatic). Dependent variables were the system outcomes including servo angle position (70 closed/160 open), buzzer pattern and Relay actuation to control. Also, latency of Blynk notification and accuracy were measured.

Using pass/fail criterion, each of scenario mentioned in table 2 would be graded. When the output matches the expected output according to previously mentioned thresholds, the trial will be marked as pass and otherwise as fail when the failure reason is clear for any reason of hardware or network failure.

System Architecture

The system implementation is based on a single ESP32 microcontroller capable of performing sensing, actuation, audio, and IoT communication simultaneously. This arrangement allows combining the above two arrangements on a single microcontroller by leveraging the integrated Wi-Fi functionality and sufficient GPIOs.

For door control, a constant-distance measurement is performed using the HC-SR04 ultrasonic sensor. If an object is less than 7 cm, the ESP32 controls the relay circuit to actuate the door opener mechanism and rotate the servo motor to 160° (opening the door), while the buzzer sounds during actuation. When the object moves outside this distance range, the door shuts down, and the buzzer sounds, indicating the process.

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For parking detection, you can use a single sensor or another sensor that detects the presence of an object inside the garage. Upon the car object remaining within 7 cm for more than 3 seconds, the ESP32 activates the buzzer twice and sends the "Park Successfully" message to the Blynk IoT app via Wi-Fi. If there is no detected object at the threshold, the message "Garage Empty" is logged onto the Blynk dashboard.

Hardware Components and Wiring

- HC-SR04 Ultrasonic Sensor—Connected with the ESP32 board using VCC (5V), GND, TRIG (digital output), and ECHO (digital input) pins. The sensor emits ultrasonic waves and detects the returning echoes to determine the real-time distance to the object.
- Servo Motor – Connected to one of the digital pins on the ESP32 board that has PWM capabilities, sharing common voltage connections (VCC and ground) with the ESP32. The servo will rotate the motor shaft from 70 degrees (closed state) to 160 degrees (open state) based on sensor input data.
- Relay Module (JQC-3FF-S-Z, 5VDC/10A 250VAC) – Connected to the ESP32 board via a digital pin for controlling the relay module. The relay acts as an electric switch that controls larger circuit elements in the system controlled via the digital signal output by the ESP32.
- Buzzer – Connected to one of the digital pins on the ESP32 board with a common ground terminal. The buzzer is activated when the door opens, producing three beeps for parking validation.
- ESP32 (ESPRESSIF ESP-WROOM-32) – Used as the main microcontroller and IoT hub in the system. It handles sensor operations, relay actions, servo operations, buzzer sound control, and communication with the Blynk app.

This system's IoT architecture is a three-layered structure as described. There is a perception layer, which consists of the two HC-SR04 ultrasonic sensors continuously taking distance readings. There is a processing/communication layer, consisting of the ESP32, running control logic for the relay, servo, and buzzer. State changes are sent out from this layer to the Blynk Cloud server via the ESP32's native 802.11 b/g/n Wi-Fi, utilizing the Blynk library. The application layer is the Blynk mobile dashboard application, which renders state changes to a log of events ("Successfully Parked," "Auto Close," "Garage Empty"), in addition to providing manual control buttons. The system is event-driven rather than constantly polling the inputs, to reduce unnecessary traffic on the Wi-Fi but also has event latency dependent on the Wi-Fi link at the time of the event. The HC-SR04 sensor is specified by the manufacturer to have an effective range of approximately 2 to 400 cm, a resolution of 0.3 cm and a typical error margin of 3 mm under standard environmental conditions within a 15-degree detection cone. This study's threshold for activation of 7 cm is well within this accuracy range, with plenty of margin from noise. The relay module (JQC-3FF-S-Z) is rated to operate on a 5V DC coil with 10A/250VAC switching capacity, well beyond the required current for the servo, providing ample headroom on the switching side.

Development Phases

The functional needs were identified during the requirement analysis as follows: an ultrasonic sensor for object detection and door triggering, secondary proximity sensing for parking confirmation, relay switching assistance, servo action to move the door, buzzer feedback, and notification to the Blynk app via the ESP32.

During the system design process, component functions were described, and hardware connections were planned based on the circuit schematic. A flowchart depicting the system control was designed to specify how the ultrasonic sensor would regulate the relay, servo, and buzzer outputs, as well as the Blynk communication managed by the ESP32.

Implementation included writing firmware and running it on ESP32, putting together the components and connecting them following the circuit schematic, and configuring the Blynk dashboard for two event logging widgets with "Successfully Parked" and "Auto Close" labels, respectively.

The testing and validation procedure ensured that ultrasonic sensor detection is precise, relay and servo actuations are reliable, the buzzer sounds correctly, parking-sensing operation within 2 seconds works as intended, and Blynk notifications arrive while the Wi-Fi connection is stable.

Schematic Diagram

The schematic diagram shows the entire wiring layout of the motion-activated garage door with parking detection and an IoT notifications system. The core of this project is the ESP32 microcontroller, which serves as the main controller to which all other components are connected. The HC-SR04 ultrasonic sensor is connected to its trig and echo terminals, enabling distance measurements for both door opening and parking applications. The servo motor is connected to the general-purpose input/output terminal, which provides pulse-width modulation functionality. It moves the simulated door from 70° to 160°. The relay is connected to a digital pin and enables switching control of the circuits. The buzzer is connected to another digital output pin and emits audio notifications when the door opens or when a parking spot is detected.

RESULTS & DISCUSSION

Observations, Analysis & Interpretation

In general, the developed system performed all necessary functions. First, the primary ultrasonic sensor successfully detected objects closer than 7 cm, triggering the servo motor to open the garage door and the buzzer to emit audible signals during the process. Next, once the object was moved away, the door returned to its original state, and the buzzer signaled its closing. Moreover, the secondary ultrasonic sensor accurately registered a vehicle as parked once it remained within 7 cm of the sensor for 2 seconds, producing 3 beeps and sending a "Successful Park" notification to the Blynk application. System logs were recorded with date and time stamps via Network Time Protocol (NTP) synchronization and displayed in the Blynk application for monitoring.

The Blynk application also allowed manual remote opening and closing of the garage door through virtual buttons, providing users with additional control and convenience. Finally, when no object was detected within the specified range, the system registered "Garage Empty" in Blynk. When the garage became empty, the system waited for 3 seconds before automatically closing the garage door to prevent premature closure caused by temporary sensor fluctuations, thereby improving the system's reliability and automation.

Overall, the servo motor consistently operated at the specified angles, the relay module effectively controlled the power supplied to the servo motor, and the buzzer functioned properly as an audible notification device. In addition, notifications and status updates were successfully transmitted to the Blynk application via Wi-Fi with no significant delay under normal network conditions. The 2-second parking verification period and the three-second automatic door-closing delay helped prevent erroneous actions caused by temporary sensor readings and environmental disturbances, resulting in more stable system performance.

Nonetheless, the tests however did also reveal a number of constraints to do with the conditions of operating it in the real world, not to the system's logic. Servo glitching was observed under low input voltages of below the rated motor values, it was observed that it was being operated off a single unregulated 9V source and under load the voltage would sag when the servo demanded more current, it was solved with the addition of the buck converter in Table 1.

Significant 2-second delays in Blynk notifications were only observed under poor Wi-Fi strength, the system behavior in this regard being indistinguishable to any cloud dependent system in IoT reliant on a robust connection to the internet to enable real time relay. No false detections or misses occurred after correct wiring and power supply setup therefore the only apparent deployment risk is associated with the peripheral power supply and network resources and not the sensors themselves or the microcontrollers logic. This constraint did not inhibit the system from achieving its stated objectives, showing the feasibility of combining the above aspects into a single "smart garage door".

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Table 1. System Components, Variables, and Conditions

Variable / Component	Type	Parameter	Condition / Range	System Response
Primary Ultrasonic Sensor (HC-SR04)	Input	Distance to approaching object:	0–7 cm / > 7 cm	Triggers the door to open or close
Secondary Ultrasonic Sensor (HC-SR04)	Input	Distance to parked vehicle	≤ 7 cm for ≥ 2 s / > 7 cm	Triggers-park confirmation or empty log
Servo Motor	Output	Angular position	70° (Closed) / 160° (Open)	Opens/closes garage door
Relay Module (JQC-3FF-S-Z, 5VDC)	Output	Power switching	Activate during door movement/ deactivate when the door reaches the target position	Controls power supply to the servo motor, disconnecting power when idle to reduce unnecessary consumption.
Buzzer	Output	Audio alert	Door open/close, successful park detection	Produces an audible notification pattern to indicate system status
ESP32	Controller + IoT Gateway	IoT transmission	Continuous real-time operation	Process all sensor inputs and outputs and send logs to the Blynk application
9V Li-ion battery and Buck Converter	Input	Power Regulation	9V DC input, 5V DV output	Provides regulated power for the ESP32, servo motor, relay module, ultrasonic sensor, and buzzer

Table 2. Test Results

Test #	Input Condition	Observed Output	Expected Output	Pass / Fail	Remarks
1	No object within 7 cm	Servo at 70°, no buzzer	The door remains closed	Pass	Correct idle state
2	Object placed within 7 cm	Buzzer sounds, servo → 160°	The door opens with audio feedback	Pass	Proper detection and actuation

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3	Object removed from range	Buzzer sounds, servo → 70°	The door closes with audio feedback	Pass	Correct closing behavior
4	Toy car within 7 cm for 3 s	The buzzer sounds twice, and Blynk logs "Successful Park."	Park confirmation and IoT log	Pass	Parking detection confirmed
5	No car inside the garage	Blynk logs "Auto Close."	Empty state notification	Pass	Correct empty state logging
6	Object briefly within 7 cm (< 3 s)	No park confirmation triggered	No false positive	Pass	The 2-second window prevents a false trigger
7	Continuous object presence at the door	The door remains open; no repeated servo commands	Stable open state	Pass	Logic prevents repeated commands
8	Loose wiring on the servo line	Erratic servo movement	Stable movement	Fail	Resolved by securing the wiring
9	Fluctuating power supply	Servo stops early, glitches	Full 180° rotation	Fail	Resolved by stabilizing power
10	Weak Wi-Fi signal	Delayed Blynk notification	Immediate notification	Fail	Stable Wi-Fi required for consistent delivery
11	Stable wiring and power, good Wi-Fi	All functions perform correctly	Full system operation	Pass	All issues resolved; system meets objectives

Over the eleven scenarios of Table 2, the system achieved an initial pass rate of 72.7% (8/11) with all three failure scenarios attributed to unreliable servo wiring, unstable power delivery, and poor Wi-Fi signal, and not due to incorrect control logic. Once the issues were addressed – by splitting the servo's power source using a buck converter (refer to Table 1), the system passed all eleven scenarios upon retest without either spurious parking detection or the failure to detect the door open state. Thus, the hardware sensing and control logic appear to be effective, and the potential pitfalls of field deployment are not the sensor itself or the microcontroller, but rather power delivery and network conditions.

Direct hardware benchmarking against commercial systems or published approaches was beyond the scope of this work. Instead, the feature-based comparison which follows uses systems which were discussed in the literature:

From the experiments above, it is evident that the proposed design can easily incorporate various functionalities, such as motion-activated door controls, audio alerts, parking sensors, and IoT notifications, into an embedded system. The consistent performance of the ESP32 microcontroller, ultrasonic sensors, servo motor, relay module, and Blynk IoT platform confirms the effectiveness of the proposed motion-activated garage door system. These observations align with the literature on automation and embedded designs incorporating ultrasonic sensors and IoT technologies.

CONCLUSION

This research explores the design and development of the motion-activated garage door system that incorporates parking detection and IoT notifications. The system uses a single ESP32 microcontroller that serves as both an embedded controller and an IoT gateway. Hardware components used in this design include an HC-SR04 ultrasonic sensor to detect object proximity for activation, another ultrasonic sensor to sense parking in the garage, a servo motor to open the door, a relay to perform switch operations, and a buzzer for audio notifications. In terms of operation, the system provides reliable automatic door opening based on object detection and contextual audio notifications during the process and upon parking. The system provides reliable parking detection using a 7 cm threshold maintained for 2 seconds, and with a short delay to prevent premature closure due to sensor fluctuations, it automatically closes the garage door when the parking area is detected as empty, enhancing operational efficiency, convenience, and system automation.

Testing conducted in a controlled environment demonstrated that the design met all functional requirements. Small problems such as servo glitches, power instabilities, and Wi-Fi signal dependency were addressed by implementing better wiring techniques, improved ground connections, and a better network setup. Integrating all functionalities into a single ESP32 device demonstrated the design's efficiency in meeting the prototype's functional requirements, despite simplifying the entire hardware design.

In addition to fulfilling its intended functionalities, the system has potential academic applications for exploring various technical skills. In particular, the project can serve as a learning tool in studying sensors, communication between microcontrollers, IoT connectivity, and embedded system design.

RECOMMENDATIONS

Directions for future research may involve the following improvements. For instance, an external regulated power source should be used instead of the battery to power the servo motor, to prevent glitches caused by voltage drops when the motor moves. The parking detection algorithm may be upgraded by adding PIR and infrared detectors, in addition to the existing ultrasonic sensor, to increase reliability regardless of a vehicle's size or the surface it stands on. Testing with the actual garage door operation system, rather than a model, will provide a more accurate evaluation of the results.

The security aspect may be enhanced by incorporating additional modules, such as unauthorized user entry detection, PIN verification, access control, or a camera module available on the ESP32-CAM variant. Blynk app integration could be further improved by allowing push notifications with timestamps, keeping logs of cars in the garage, and remotely operating the garage door via the smartphone application. Lastly, future research may explore implementing a two-sensor detection method, divided into approaching and parked areas, and possibly optimization of the ESP32 code for faster response.

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