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Development of an IoT-Based Smart Vehıcular Parkıng System wıth Automated Reservatıon Authentıcatıon

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ABSTRACT

In urban areas where parking spaces are often limited, innovative solutions are vital to address vehicle parking issues. This research concentrates on creating a web-based smart parking system that utilizes various technologies, including Digital Signal and Image Processing (DSIP) for access control. The main goal is to develop a model enabling users to monitor parking availability and make paid reservations via a web application, which generates unique QR codes for automated authentication. The system employs infrared (proximity) sensors installed at each parking space to detect vehicle presence, sending signals to an Atmega328p Microcontroller Unit (MCU) for processing. This data is then transmitted to a Message Queuing Telemetry Transport (MQTT) broker, which is used to publish real-time updates to the web application hosted on an HTTP server. Users can check space availability and book reservations remotely. Upon arrival, customers present their QR code to a camera module at the parking entrance, which verifies the reservation with the database server. If validated, the server instructs the MCU to open the gate for entry. This process is mirrored at the exit gate. Testing results confirmed the successful integration of remote monitoring, paid reservations, and automated access control, greatly improving parking management efficiency.

1. INTRODUCTION

The level of pollution is at an all-time high, exacerbated by the increasing number of vehicles on city roads, leading to significant traffic congestion. In response to this issue, urban centres have implemented new parking bays to alleviate the shortage of parking spaces. However, the uneven distribution of parking facilities in public areas such as schools, markets, organizations, stadiums, and universities continue to pose challenges for motorists. This often results in lost productive time, contributing to the emission of carbon soot into the environment as drivers navigate to their destinations. (Parmar, *et al.*, 2020)

Previous research has proposed various vehicle parking systems designed to enhance the management of parking lots and facilities, aiming to improve the experience for both vehicles and city infrastructures. (Pradhan, *et al.*, 2025) Introduces an automated system that combines sensors, image processing, and database management to effectively tackle parking-related challenges. A single camera is used to oversee multiple parking spaces, with each slot assigned specific coordinates and paired with IR sensors for dual-layer verification. Image processing techniques, including Optical Character Recognition (OCR), are utilized for accurate license

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plate identification. Although, the results are highly effective, the implementation is very expensive for medium scale malls. (Khosso, *et al*., 2024) Features an array of sophisticated capabilities, such as real-time detection of parking spaces and identification of unauthorized parking, enhanced by an easy-to-use mobile app that provides clear guidance. At the core of the system is an advanced camera setup at entry points, employing state-of-the-art image processing techniques to seamlessly recognize authorized vehicles.

These integrated parking management systems are intended to optimize the use of available space, thereby facilitating better traffic flow. (Kalasova, *et al*., 2021)

(Iyaka, 2025) Identified two commonly used parking management systems: The Automated Parking System (APS) and the Marshalling Parking System (MPS). The MPS relies on attendants to organise and inform drivers about available parking spaces, whereas the APS employs a combination of electrical and electronic devices, including motors, sensors, cameras, and displays, to assist drivers and parking lot managers in accessing and managing parking areas. Another study presents a solution that integrates Automatic Number Plate Recognition (ANPR) using image processing along with a sensor-driven hardware system. Vehicle number plates are automatically identified at entry, removing the need for manual registration. IoT sensors track real-time parking slot availability and relay this information to a web-based admin panel. (Ditta, *et al*., 2025)

(Agnihotri, *et al*., 2024) Utilized modern technologies such as IoT (Internet of Things) and RFID (Radio-Frequency Identification) to detect the availability of parking slots within parking lots.

Despite advancements in automated parking systems, inefficiencies persist, indicating a pressing need for innovative solutions. (Banode, *et al*., 2022) Introduced an automated car parking system utilizing inductive sensors and programmable logic controllers (PLC), but it lacks real-time and remote monitoring capabilities. Similarly, (Elechi, *et al*., 2022) developed a smart car parking system using ultrasonic sensors to detect vehicle presence; however, it does not provide integrated remote monitoring, leaving drivers unaware of parking availability until they arrive on-site. Other systems, such as those employing infrared (IR) sensors, have been studied for assigning parking slots, where vehicles communicate with an Arduino to relay parking status. (Saranya, *et al*., 2022) Recent advancements also include the use of ultrasonic sensors for distance assessment during parking manoeuvres. (Chakravarthy *et al*., 2022)

The Smart Parking System, which integrates various technologies including the Internet of Things (IoT), Arduino, Bluetooth, and RFID, has emerged as a promising alternative to traditional parking facilities. (Poonam, 2018) Some studies have explored automated billing systems (Hunusekatte, 2020), image processing for vehicle recognition (Wickramanayake *et al*., 2022), and mobile applications for real-time parking availability (AbdulMalik, 2020); they often lack comprehensive client authentication mechanisms or integrated payment systems.

Studies by (Ali and Hamid, 2020) and (AbdulMalik, 2020) have primarily relied on manual processes for verifying and authenticating drivers entering reserved spots, often necessitating the presence of security personnel. This reliance can result in long wait times, especially during peak hours, and the payment methods used in earlier smart parking systems are typically not integrated with web applications, creating additional inconvenience for users.

The challenges associated with finding available parking spaces in traditional lots are significant, particularly given the

overwhelming number of vehicles. This search process not only wastes valuable time and fuel but also contributes to increased carbon emissions. In urgent situations, drivers may resort to parking in unauthorized areas, leading to decreased productivity, heightened traffic hazards, and further environmental degradation due to elevated greenhouse gas emissions.

This study, therefore, aims to design and implement an internet-based smart vehicular parking system with automated reservation authentication.

2. METHODOLOGY AND SYSTEM DESIGN

The research was conducted at Delta Mall, located in Effurun, Delta State, Nigeria, covering an area of 13,980 m² at the coordinates 5.5708° N, 5.7834° E. Figure 1 illustrates a Google Maps snapshot of the facility, highlighting the study area.

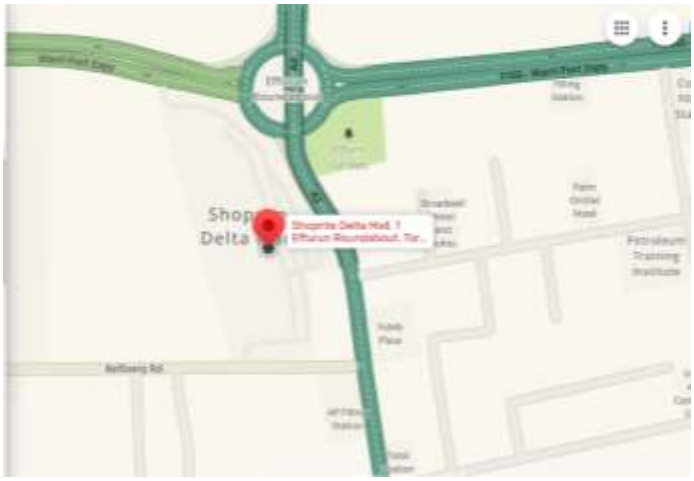


Figure 1: Geological Study Area

The conceptual framework for the proposed smart vehicle parking system, which utilized an Internet-based automatic reservation and authentication process, is depicted in Figure 2. This system consisted of several components: a power supply, a microcontroller, a QR code scanner, vehicle detection mechanisms, a gate motor driver, and display units. In this design, the parking lot was monitored using a series of infrared (proximity) sensors installed at each parking space to identify the presence or absence of vehicles. When a vehicle was detected, the sensor transmitted a signal to an Atmega328p Microcontroller Unit (MCU) for logical processing and control, which was subsequently communicated to a Message Queuing Telemetry Transport (MQTT) broker. The MQTT broker then disseminated real-time updates regarding the status of the parking spaces to the web application hosted on an HTTP server.

In this study, the web application enabled users to engage with the parking system remotely, allowing them to check the status of available spaces and make reservations. This application was divided into two main components: the front-end and the back-end. The front-end consisted of a graphical user interface (GUI), which users interacted with through their devices, such as smartphones or computers. Conversely, the back-end encompassed the logic necessary for data management, query processing, and handling general requests.

Parking spot allocation primarily followed a First Come First Serve (FCFS) approach, with an option for VIP subscriptions

allowing clients to reserve premium spaces at a higher cost as shown.

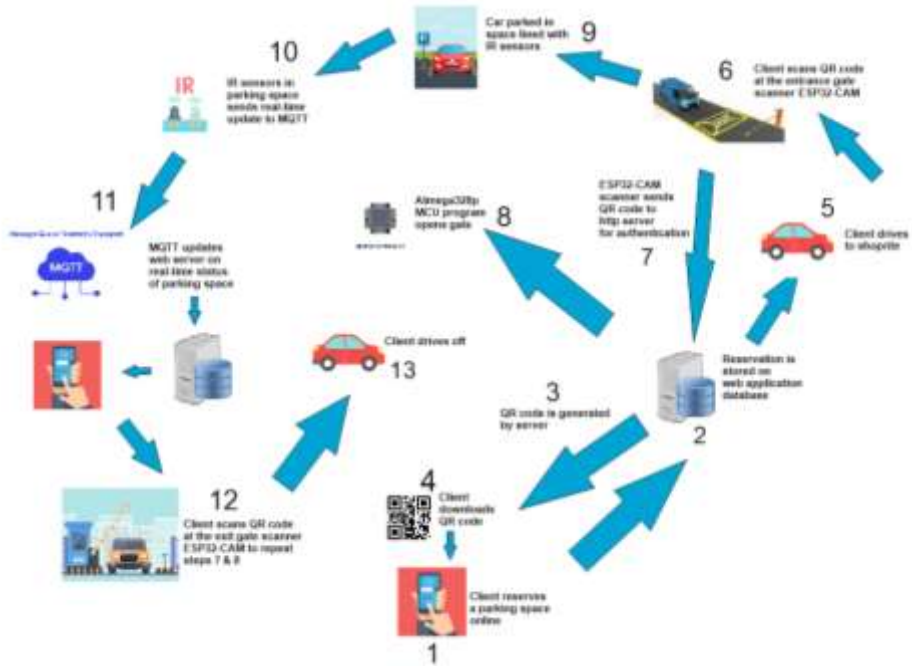


Figure 2: Conceptual Design of an Online Smart Vehicle Parking System with Automated Reservation Verification

QR code scanning technology facilitated driver authentication for entry and exit. Clients generated and downloaded a QR code during the reservation process in the web application. Upon arrival, they presented the QR code to the camera module at the parking gate, which transmitted it to the database server for verification. If successful, the server signalled the Atmega328p microcontroller (MCU) to activate the gate actuator, granting access to the designated parking space. The design models for both software and hardware were illustrated in Figures 3 and 4.

2.1 Design Analysis

The hardware system consists of several interconnected units that receive specific inputs to perform their functions effectively. The power supply converts a 12V DC input into a stable 5V output, powering sensors, the microcontroller, Wi-Fi modules, gates, and displays. The microcontroller, based on the Atmega328p, receives digital signals from infrared sensors indicating parking space occupancy, serial data from the ESP32-CAM QR scanner modules that transmit decoded QR codes, and server responses via Wi-Fi for access permission. It manages gate operations through signals sent to the motor driver (L293D) and updates status

messages on LCD displays via I2C communication lines.

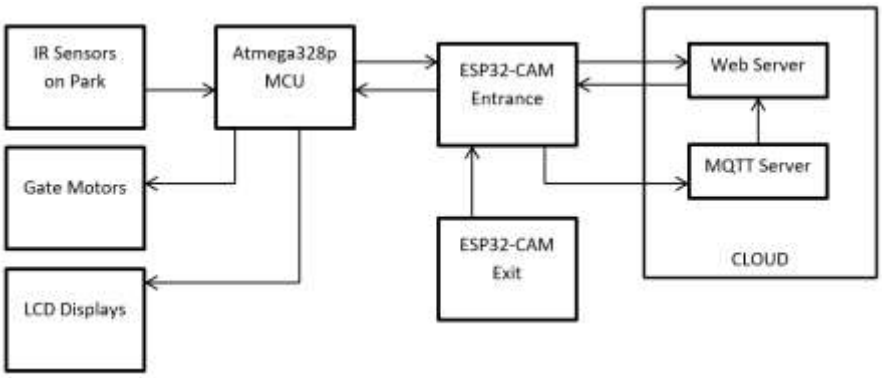


Figure 3: Software System Design Model

The QR scanner units capture images of QR codes using their cameras; these images are processed to decode user reservations, and Wi-Fi is used for server verification, with the results sent back as serial signals to the microcontroller to approve or deny gate access. Infrared sensors continuously provide occupancy status by sending digital signals about vehicle presence, which is then transmitted to the server through the ESP32-CAM acting as an access point. The gate motors receive control signals from the microcontroller via the motor driver, enabling opening and closing actions based on verification outcomes. The LCD display units receive data from the microcontroller via I2C, providing real-time feedback to motorists regarding their access status. This integrated setup ensures precise parking management, vehicle authentication, and efficient gate operation, driven by a combination of input data and responsive control signals.

2.2 Software Design Analysis

The software design integrates microcontroller programming with web application development to form a unified control system. The microcontroller program, running on three units (the Atmega328P and two ESP32-CAM modules), handles real-time operations and communicates with external servers. The Atmega328P acts as the central controller, executing an algorithm that coordinates the entire hardware system based on inputs from sensors, QR code scanners, and server responses.

The entrance ESP32-CAM is programmed to scan reservation QR codes and transmit the encrypted data via Wi-Fi to the server for validation, following its specific flowchart. Similarly, the exit ESP32-CAM validates exit requests by following an identical algorithm, ensuring only authorised vehicles can leave. The web application plays a vital role by managing requests related to authentication, reservations, and administrative tasks, guided by a predefined flowchart. It processes data received over the internet, verifies reservations, updates user profiles, and sends responses back to the microcontrollers, which then control the gates based on the validation results. This integrated software architecture ensures a smooth data flow from user reservations to physical gate operations, maintaining system integrity and security.

2.3 Security Considerations

The MQTT server uses Transport Layer Protocol also referred to as SSL (Secure Sockets Layer) to encrypt the communication between itself and the proximity IR sensors, ESP32 CAM scanners and web server. This security measure ensures protection of information by unauthorized third parties from reading

or alteration. It works in the following steps:

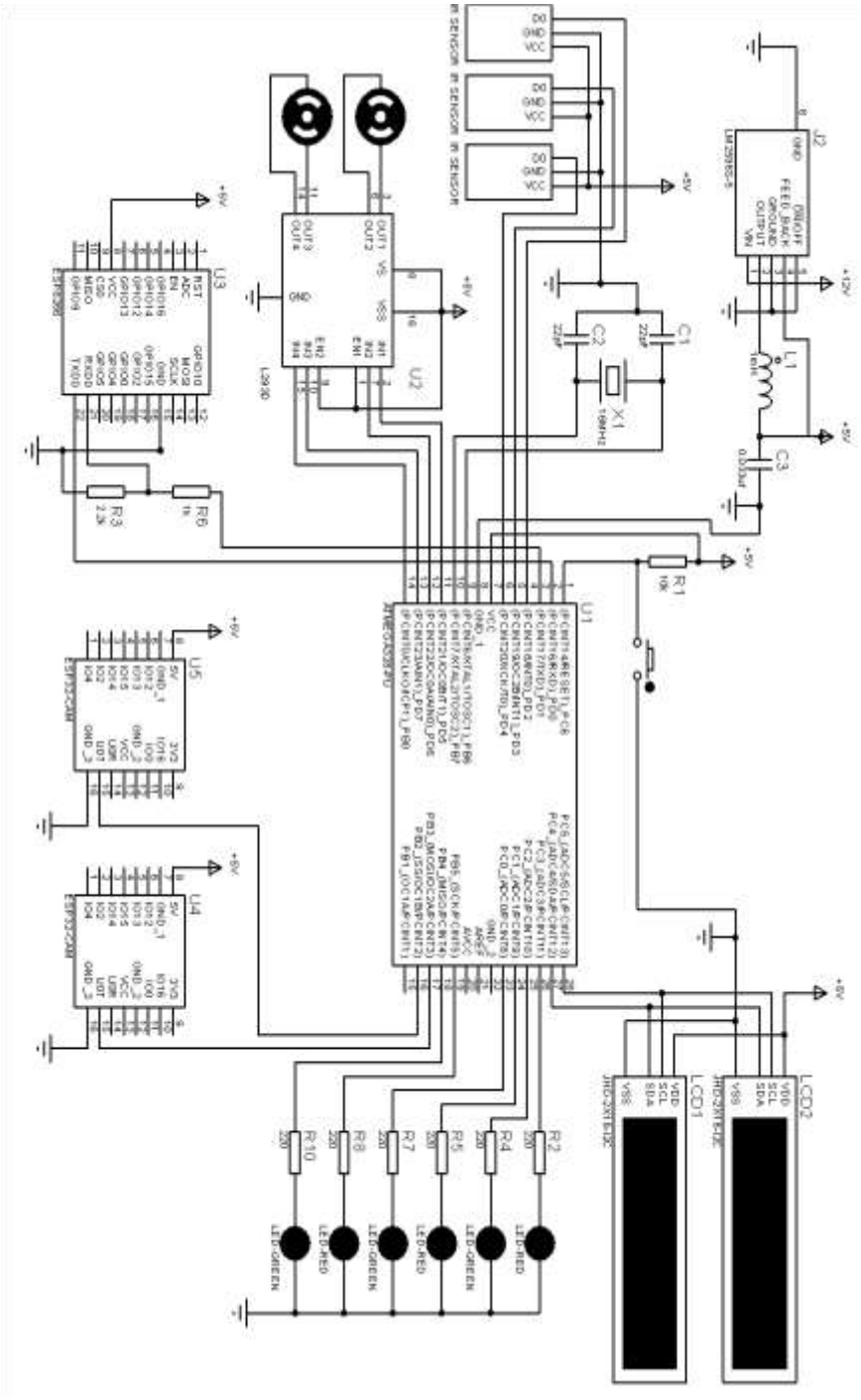


Figure 5: Illustrates the complete circuit diagram for the internet-based smart vehicular parking system, which incorporates automatic reservation authentication.

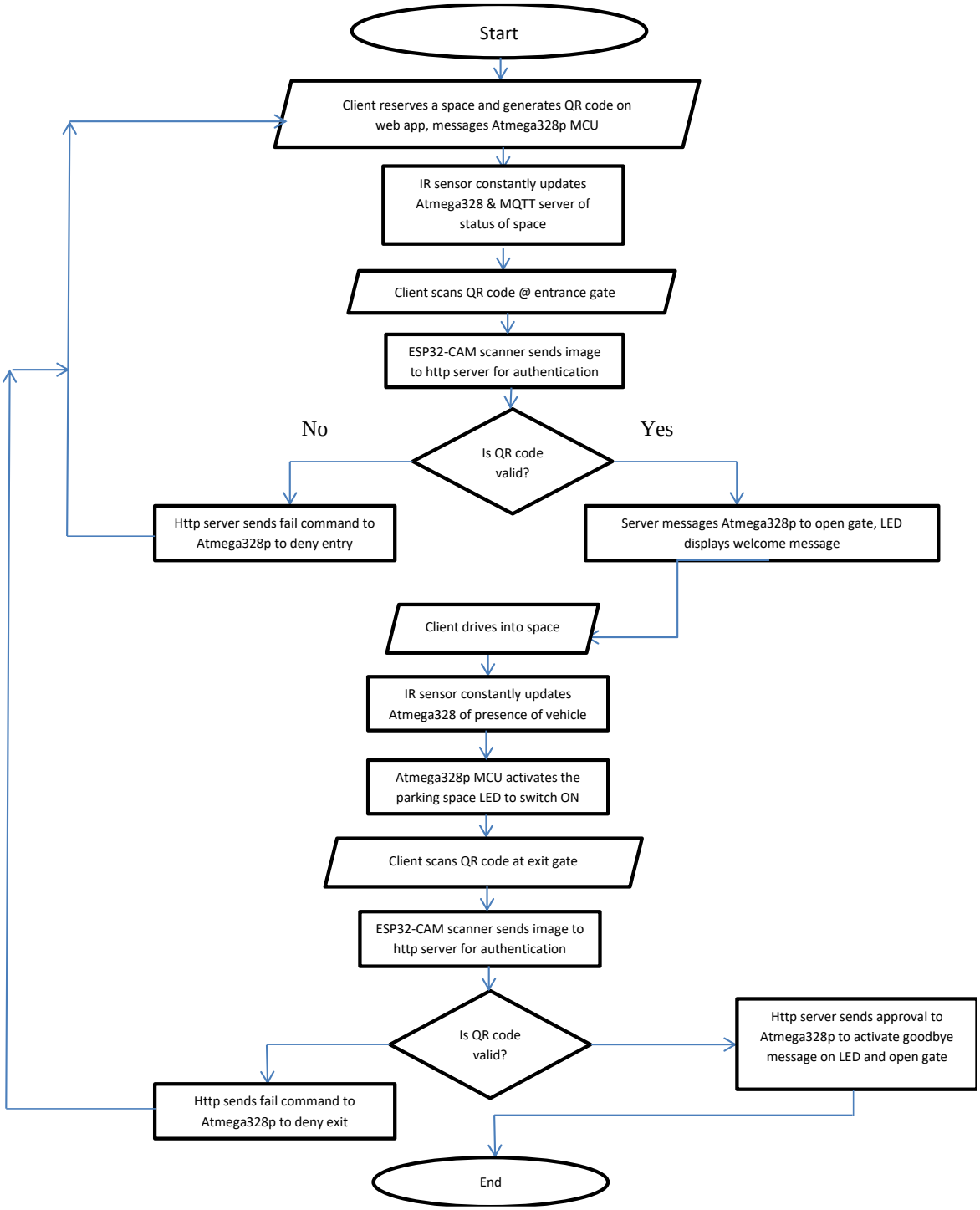


Figure 6: System Flowchart

i. The proximity IR sensor or HTTP server (MQTT clients) – as the case may be – establishes a standard connection with the MQTT server using the TCP protocol

ii. Certificates and cryptographic information are exchanged between the MQTT server and the MQTT client through a TLS handshake in order to establish a secure channel of communication.

iii. Thereafter, all MQTT messages are exchanged within this encrypted TLS tunnel providing security at the transport layer

3. RESULTS AND DISCUSSIONS

The hardware components include the Exit ESP32-CAM, Entrance ESP32-CAM, Atmega328P microcontroller, power supply unit, exit and entrance gate displays, motor/gate driving units, and parking space indicators.

The power supply employed a buck converter based on the LM2576 IC, converting 12V DC to 5V to power all components. The Atmega328P acted as the central controller, connecting the two ESP32-CAMs via serial interfaces for data transfer. Infrared sensors were used to detect vehicle presence, connected to digital I/O pins on the microcontroller, while the LCDs at the gates are linked through I2C pins (27 and 28).

Gate operations were managed by a dual-channel motor driver with an LD309 IC, configured as an H-bridge, allowing independent opening and closing controlled by signals from the microcontroller. LED indicators for each parking space are connected to I/O pins, displaying occupancy status. Data exchange between the microcontroller and ESP32-CAMs occurs via hardware serial interfaces, enabling real-time communication with remote servers for reservation validation and parking status updates.

To validate the system's functionality and efficiency, a prototype shown in Figure 7 was constructed and tested to generate billed reservations with varying QR code durations for verification, enabling controlled vehicle access.



Figure 7: System Prototype Diagram (Central view, Entrance view and Exit view)

3.1 Test Results

To assess the functionality and effectiveness of the prototype, various tests were conducted to evaluate its ability to generate billed reservations with QR codes for verification and controlled access for vehicle owners. Physical tests were performed on the prototype using toy cars as parking clients, while the web application was used to reserve spaces, with responses recorded.

3.1.1 Parking Status Test

The Smart Car Parking System prototype includes three parking spots: SPC1 (VIP), SPC2, and SPC3, each equipped with IR sensors to detect vehicle presence. The parking status of each space was evaluated by placing miniature test cars in it. The status was monitored both on the client web application and through the LED indicators at each parking space. The results are summarized in Table 1 below and shown in Figures 8 and 9:

Table 1: Parking Status Test

PARKING SPACE	STATUS ON WEB APPLICATION (WITHOUT CAR)	STATUS ON WEB APPLICATION (WITH CAR)	LED STATUS (WITHOUT CAR)	LED STATUS (WITH CAR)
SPC1 (VIP)	Reserve now	Reserved	Off	On
SPC2	Reserve now	Reserved	Off	On
SPC3	Reserve now	Reserved	Off	On

Where SPC represents Spaces, VIP (Very Important Person)

The different parking scenarios are shown below



Figure 8: Plan View of Car Parked in SPC1 (VIP), SPC2 & SPC3



Figure 9: Screenshot of client application showing Spc1 & Spc2 reserved

The screenshot of the parking space reservation on the web application is shown Figure 8.

3.1.2 Parking Space Reservation Test

Tests for parking space reservations were conducted for each space, with results summarized in Table 2 and screenshots of the payment process for the parking space reservation in Figure 10a and b below:

3.1.3 Entry and Exit Authentication Test

Upon successful reservation of a parking space, the HTTP server generated a QR code, which was stored in a database for authentication purposes and displayed to the user. The generated QR codes were tested by scanning them at the entry and exit gates to determine if the gates would open within the validity periods. The results are presented in Table 3.

Table 2: Parking Space Reservation Test

PARKING SPACE	PAYMENT	SUBMISSION	RESERVATION	LED BEFORE	LED AFTER
SPC1 (VIP)	Success	Success	Success	Off	On
SPC2	Success	Success	Success	Off	On
SPC3	Success	Success	Success	Off	On

Where SPC represents Spaces, VIP (Very Important Person)

The following images show screenshots of the parking space reservation payment process for SPC 1 and 2.

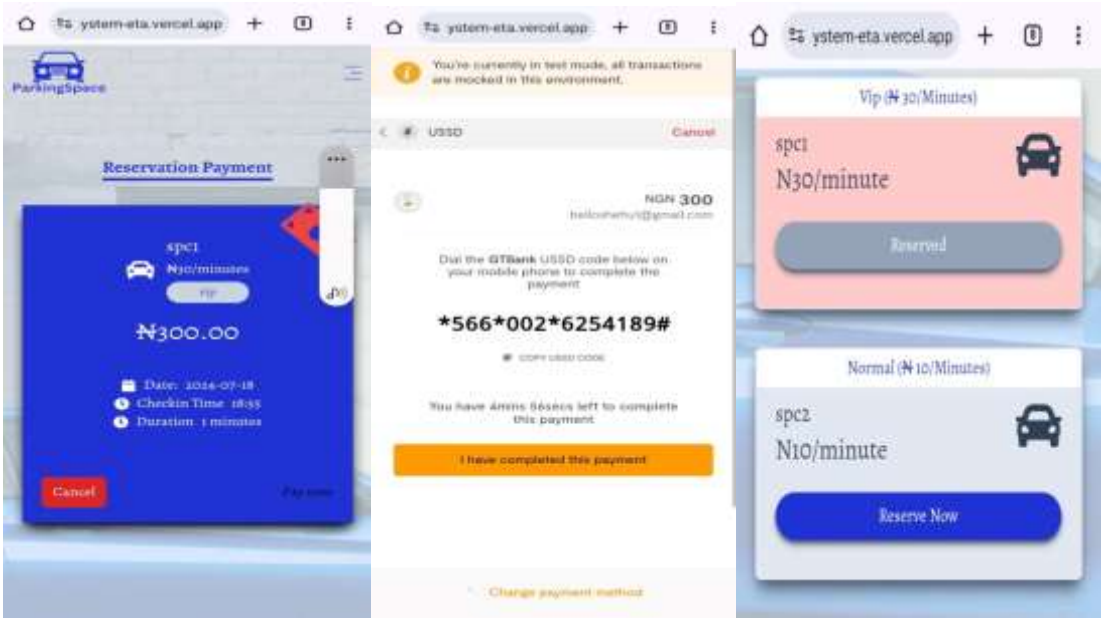


Figure 10a: Screenshot of client application showing SPC1 payment

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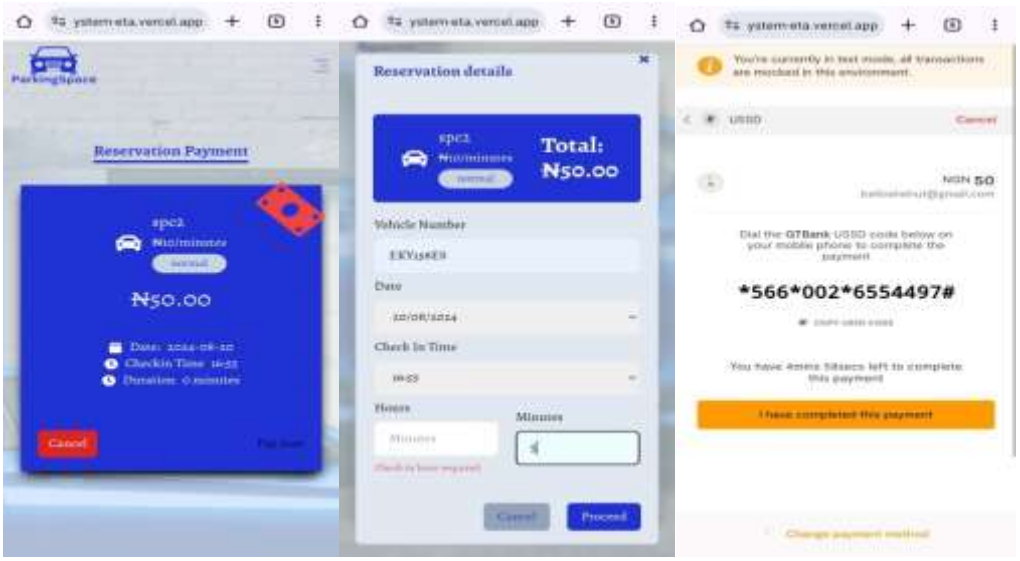


Figure 10b: Screenshot of client application showing SPC2 payment

Table 3: Entry and Exit Authentication Test Results

PARKING SPACE	ENTRY ACCESS	EXIT ACCESS
SPC1 (VIP)	"Welcome, drive in…"	"bye, thank you"
SPC2	"Welcome, drive in…"	"bye, thank you"
SPC3	"Welcome, drive in…"	"bye, thank you"

Where SPC represents Spaces, VIP (Very Important Person)

The figures below show the entry and exit authentication test outcomes, with QR code, for parking spaces 1 & 2



Figure 11a: Entry and Exit Authentication with QR Code for Spc1



Figure 11b: Entry and Exit Authentication with QR Code for Spc2

3.1.4 QR Code Validity Period

A validity test for QR codes was conducted for each reservation before the start of the parking duration at the entry and exit gates to determine if they would open. The results are presented in the table below.

Table 4a: Showing Status before Start of Reservation Period

PARKING SPACE	ENTRY ACCESS BEFORE START OF RESERVATION PERIOD	EXIT ACCESS BEFORE START OF RESERVATION PERIOD	RESERVATION STATUS BEFORE START OF RESERVATION PERIOD
Spc1 (VIP)	"invalid reservation"	"exit denied, pay overtime"	"reserved"
Spc2	"invalid reservation"	"exit denied, pay overtime"	"reserved"
Spc3	"invalid reservation"	"exit denied, pay overtime"	"reserved"

Where Spc represents Spaces, VIP (Very Important Person)

Screenshots of QR code validity period test outcomes showing the access of entry and exit gates before and after the validity period are presented Figure 12.

Upon expiration of the parking duration for each reservation, the validity of the respective QR codes was tested at the entry and exit gates. The results are summarized in Table 4b.



Figure 12: SPC 1 QR code validity before start and after expiration of the reservation period

Table 4b: Showing Status after Expiration of Reservation Duration

PARKING SPACE	ENTRY ACCESS AFTER RESERVATION EXPIRATION	EXIT ACCESS AFTER RESERVATION EXPIRATION	RESERVATION STATUS AFTER RESERVATION EXPIRATION
Spc1 (VIP)	"invalid reservation"	"Exit denied, Pay overtime"	"reserve now"
Spc2	"invalid reservation"	"Exit denied, Pay overtime"	"reserve now"
Spc3	"invalid reservation"	"Exit denied, Pay overtime"	"reserve now"

Where Spc represents Spaces, VIP (Very Important Person)

The Screenshots of QR code validity period test outcomes showing the access of entry and exit gates after the start of the validity period are presented below,

3.1.5 Discussion

Table 1 indicates that all parking spaces accurately reflected the presence and absence of test vehicles, displaying "Reserved" and "Reserve Now" accordingly. However, during testing, SPC3 occasionally remained stuck on "Reserved," regardless of vehicle presence. This issue stemmed from a technical glitch in the programming algorithm of the Atmega328P microcontroller, which was subsequently debugged. The problem was akin to a processing bottleneck encountered by the microcontroller. In this case, the Atmega328 MCU was inundated with too many simultenous MQTT updates from the IR sensor in SPC3, causing the LED and web application label for SPC3 to remain in a single status. Debugging modifications were made by implementing a message queue in the program algorithm. Table 2

confirms that the reservation processes for SPC1, SPC2, and SPC3 were all successful.



Figure 4.8: SPC2 QR code validity after start and before expiration of the reservation period

Also, during testing, SPC3 initially faced repeated failures due to the same problem as stated above, leading to its status being stuck on "Reserved" with the parking LED consistently illuminated. In Table 3, QR code entry and exit authentications for SPC1, SPC2, and SPC3 were successful. However, SPC3's reservations failed during initial testing, as reservations cannot be processed for a space already marked as "Reserved." Same debugging measure of messages queuing was used to solved the problem. Tables 4a and 4.4b show that QR code entry and exit authentications failed for SPC1, SPC2, and SPC3. In the first case, this was due to the QR codes not being valid before the reservation period commenced, and in the second case, it was due to the expiration of QR code validity time which is a security consideration to avoid cases of QR code replay attack.

4. CONCLUSION

Over the years, automated parking systems have evolved into sophisticated solutions that integrate various technologies such as IoT, Arduino, RFID, and Bluetooth for effective vehicle park management. The smart car parking system developed in this study significantly alleviates the challenges associated with traditional parking systems. By creating a fully automated parking solution that interlinks IR sensors, microcontrollers, and a web application (coupled with billed QR code generation and scanning), this project enhances convenience from the reservation stage through to exiting the parking facility. This system saves time and effort for users, generates revenue for parking lot owners and reduces carbon emissions released into the atmosphere.

A system of distributed microcontroller networks can be employed to scale up this system in future works. By linking multiple microcontrollers through a secure wi-fi network, a host or master microcontroller can manage and direct a number of slave microcontrollers in performing specific tasks.

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