# A Digital Twin-Enabled Smart Car Park Management System: Architecture and Impact on Emission Reduction

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**ORIGINAL RESEARCH**

**Abstract**— Parking challenges in urban areas and educational institutions have become increasingly common due to rising vehicle numbers and rapid urbanization. The University of Lagos Engineering Car Park exemplifies these issues, experiencing inefficient space utilization, a lack of real-time monitoring, and extended search times for parking spaces. These issues mirror global parking management problems, where inadequate use of parking facilities contributes to traffic congestion and unnecessary fuel consumption. Although existing literature proposes solutions such as computer vision-based systems and sensor-based detection technologies, both approaches have their respective strengths and limitations. This work proposes a digital twin model for the smart management of the University of Lagos Engineering Car Park. The system integrates ultrasonic sensor pairs, an ESP32 microcontroller, and the Blynk IoT platform to create a real-time parking occupancy monitoring system. Ultrasonic sensor pairs are strategically positioned in each parking spot to detect vehicle presence, with data transmitted to the ESP32 microcontroller, which processes the information and sends it to the cloud via the Blynk platform. This cloud-based system provides real-time visualization of parking availability through a user-friendly interface, together with a Firebase and React-based application to display a 2D digital twin of parking spots and effectively monitor occupancy, reducing search times.
The system was tested for vehicle detection accuracy, achieving 99.3% accuracy with the ultrasonic sensors. Results demonstrated a high degree of precision in detecting vehicles, with minimal delays in transmitting data from sensors to the cloud. Additionally, the system provided continuous real-time updates on parking availability through the user interface. The digital twin model would effectively reduce parking search times, improve overall campus traffic flow, minimize environmental impacts, and thus aligns with the industry 5.0 paradigm.

**Keywords**— Car Park automation, Digital Twin, Internet of Things, Real-time monitoring, Smart cities, Industry 4.0, Industry 5.0.

## 1 INTRODUCTION

Rapid urbanisation and rising vehicle ownership have led to a critical shortage of parking spaces. The little to no parking space allocation, lack of real-time monitoring, and improper parking behaviour contribute to time wastage, increased traffic congestion, and environmental harm. The global vehicle fleet is projected to double by 2050, and the struggle to secure parking spaces has become a critical urban planning issue (Zou *et al.*, 2023). From a survey carried out by IBM, it was discovered that drivers spend an average of nearly 20 minutes in pursuit of a coveted spot globally (Galligan, 2011). Research also indicates that cars spend approximately 80% of the week parked, highlighting the complex dynamics of parking space management (Marsden, 2006). This statistic underscores the importance of efficient parking systems, especially in high-traffic areas like university campuses. The situation at University of Lagos, Engineering Car Park is particularly dire, with drivers often facing extended search times for available spots (Figure 1).

A study by the University of California, Berkeley found that drivers searching for parking space can consume up to 34% more fuel compared to those who find spots quickly. This excessive fuel consumption translates directly into increased air pollution, which is a critical public health concern.

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**Section B-** ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
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The World Health Organization has estimated that air pollution alone arising from traffic congestion and parking related problems leads to millions of deaths annually (Lindmeier, 2018). This pollution endangers both the university campus community and is inconsistent with the purpose of a university to be stewards of healthy and safe environment. The factors fundamentally responsible for parking related difficulties can, thus, be broadly categorized into two folds. In the first place, a driver may show inappropriate behaviour reflecting on failure to park within the designated lined area, which results to inefficiency in utilization of parking space (Rico *et al.*, 2013; Rosni *et al.*, 2019). Second, drivers most often do not have real time information on availability of parking lots, hence they keep moving in a circular manner thereby contributing to traffic jam and pollution (Jermsurawong *et al.*, 2012).

Solving these challenges demands innovations that enhances on existing parking structures yet delivers information to the users in real-time; an approach that converges with the industry 4.0 & 5.0 paradigm. Industry 5.0 suggests a transition from the narrowly defined industrial revolution based solely on technology advancements to technological transformation with focus on human values, quality lives, resilient industrial system, and sustainable environment (Cotta *et al.*, 2021). Thus, unlike industry 4.0 that focuses only on automation and efficiency, industry 5.0 is about to enhance human - machine interaction and make manufacturing solutions more flexible and inclusive. Industry 5.0 technologies consist of artificial intelligence, technologies derived from nature; Internet of Things (IoT), Digital Twins, advanced data analysis; and energy-efficient systems, all working together making the industrial environment more

sustainable and adaptive (Cotta *et al.*, 2021).
Grieves (2017) provides a definition of the Digital Twin as a fully defined digital model of a physical or potential product on the atomic, molecular, component, subsystem, system, service, and macro geometrical scale. That is, a digital twin is the digital representation of a tangible object. This model is then at any particular time, synchronized with real-time data so that it gives a true picture of the physical entity, whether it be objects, systems or processes. It is a model generated by computer that mirrors the physical objects, and regularly updated in real-time with data from sensors, alongside IoT edges, cloud services with advanced modelling and simulation techniques to reflect the condition of the physical entity. Digital twin concept is a promising framework to solve complex urban issues including parking management (Deren *et al.*, 2021; Ali *et al.*, 2023). It is possible to monitor, analyse, and optimize parking utilization in real-time, by creating a digital replica of the University of Lagos, Engineering Car Park thereby, potentially transforming the parking experience for the university community. Consequently, this work seeks to create a digital twin model for the automation of University of Lagos, Engineering Car Park (Figure 1), using low-cost sensors, cloud technology and data analytical tools to enhance the parking utilization. In so doing, it attempts to eliminate the current problem of congestion, pollution and inefficiency that presently affect the parking system and consequently make the campus environment more ecological and user friendly. The rest of the manuscript is organized as follows: Section 2 presents some of the related work in addition to some of the recent ideas in digital twin and smart parking, section 3 gives the overview of the methodology used, section 4 describes the findings while section 5 gives the conclusion.

Fig. 1. Engineering Car Park at University of Lagos

## 2 Related Work

In a recent study, Zou *et al.* (2023) presented a smart parking system integrating Computer Vision (CV) and Building Information Modeling (BIM) to provide live information regarding parking lots status to enhance parking space utilization and overall parking lot management. The identification of the objects was achieved using a real-time object detection system called the YOLO – You Only Look Once combined with a laser scanning and BIM-generated 3D digital model. The process begins with setting up of cameras to be used to take pictures of parking zones. This is followed by applying YOLO model to identify vehicles and computing the distance between vehicles and the parking bays with a programmed excel sheet. Finally, the detected data is visualized in a digital twin model to monitor the system in real-time. The result achieved shows that the proposed approach works well in detecting vehicles with a mean confidence level of 70 % thereby concluding that accuracy is majorly affected by environmental constraint such as poor lighting condition, reflected window, or existence of barriers like trees and other vehicles (Zou *et al.*, 2023).

Morsin *et al.* (2010) developed a smart parking guidance system that is aimed to assist drivers find vacant spaces efficiently resulting to reduced search time for vacant spaces, reduced fuel consumption and reduced traffic congestion. The system comprises three key components including Very High-Speed Integrated Circuit Hardware Description Language (VHDL) coding, display units and sensing elements. The system employs a Light Dependent Resistor (LDR) to detect the occupancy of a vehicle by sensing variations in the amount of light falling on the sensor when a car is parked over it. The VHDL code counts, updates display, and processes the sensor data all of which are done on the ALTERA DE II board. One of the main drawbacks of the system is the LDR sensor sensitivity to ambient light and shadows which can cause false activation. To address this, it was observed that the LDR needs to be carefully calibrated, hence another 100-ohm resistor was added in series with the LDR to reduce its sensitivity and improve detection accuracy. Arowolo and Adekunle (2019) proposed the design and simulation of an automated car parking system using Programmable Logic Controllers (PLCs) and the LADSIM software. The system manages a six-car parking space and utilizes light dependent resistors (LDRs) to detect the presence of car in the parking spots while Infrared (IR) sensors were used to monitor cars entering the parking zone. The PLC takes data from these sensors and use it to control the gates: opening the gates where lot is available or restricts entry where lot is full. The study replicated real-world conditions by automating the aspect of car parking while enhancing efficiency in space management (Arowolo and Adekunle, 2019). While the system could give information concerning parking availability, it has no provisions for remote monitoring. A smart parking management system using IoT was proposed in Alsafar *et al.* (2024). The system provides a display of the parking area map while the nearest available parking spot is displayed by pressing a button beside the screen. Furthermore, infrared sensors were used to determine the presence or absence of vehicles. A real time database was subsequently created using the Firebase platform to store information about the availability of parking lots (Alsafar *et al.*, 2024). An IoT-based smart parking reservation system was designed to avoid common parking problems, such as long queues, inefficient space utilization, and manual payment delays in public spaces like malls and hospitals (Panpatil *et al.*, 2020). The system allows the users to pre-book parking spots by means of a web or mobile application with an embedded payment interface. A camera and Raspberry Pi module capture the vehicle's number plate at the entrance, and an optical character recognition (OCR) algorithm verifies the vehicle details before allowing entry. The system manages the available parking space and provides real time payment information. Although the parking efficiency and security of the system is improved by only allowing pre-registered vehicles, it entirely relies on camera and OCR performance, thus the accuracy could be affected by poor

 

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lighting or by images of damaged number plates (Panpatil *et al.*, 2020).

In a related work, Sudhakar *et al.* (2023) proposed a smart parking system that identifies the vehicle license number using image processing and automatically open the gate based on vehicle detection at the entrance. A mobile application was incorporated as part of the system to provide detail about available spaces for parking and other safety features such as fire alarms and gas leakage alerts. The control was done by Raspberry Pi in which all operation processes are performed. A liquid crystal display was placed at the gate of the parking lot to display the available space with infrared proximity sensors installed to detect the vehicles at the gate. Upon identification of the license plate from the image recognition, the Raspberry Pi will open the gate with the help of the servo motor for some time for the driver to enter the parking lot. The date/time stamp is taken for the billing as soon as the driver goes out of the parking area (Sudhakar *et al.*, 2023). Liu *et al.* (2023) explores the Freight Parking Management Problem (FPMP) in last-mile delivery in Smart Cities, with particular attention to Cognitive Digital Twins (CDTs), which are digital models of physical objects with improved semantic functionalities, to monitor and control the parking availability for delivery vehicles. The authors introduce a four-layer architectural framework using Property Graph, Web Ontology Language, and the Web of Things to integrate logistics objects into smart urban environments. A case study in Paris demonstrates the framework's application, showing how CDTs can optimize parking selection and resource allocation. Results indicate improved delivery efficiency, reduced environmental impact, and cost savings. In Syahla and Ogi (2021), the authors proposed a secure parking system using Cyber-Physical System (CPS) that incorporated a one-time password (OTP) authentication for addressing replay attacks which is a prominent security threat. They noted that CPS are vulnerable to network attacks resulting to compromise in data confidentiality and data integrity. To minimize these risks, the paper recommended the use of OTP mutual authentication scheme within the one-way hash function and random permutations to avoid the replay attacks. A System Development Life Cycle (SDLC) approach was employed, wherein a secure parking prototype was developed using a Raspberry Pi 3 Model B+ to implement and test the effectiveness of the OTP scheme.

Most of the reviewed papers show that smart parking systems are primarily sensor-based (Morsin *et al.*, 2010; Arowolo & Adekunle, 2019; Alsafar *et al.*, 2024) or image-based (Abu-Alsaad, 2023; Panpatil *et al.*, 2020; Zou *et al.*, 2023). Sensor-based systems include the use of ultrasonic, magnetic, or infrared sensors, which accurately provide real-time data of vehicles but also may have high installation cost and interference with some environmental factors. For example, light-based sensors may be interfered with by ambient light conditions while a single proximity or ultrasonic sensor will occasionally not be able to distinguish between cars and other objects. On the other hand, image-based systems require computer vision with complex artificial intelligence algorithm together with the use of cameras to detect cars and provide real time information on parking space availability. Generally, image-based systems provide scalability and cost-effectiveness, though often faced with challenges such as complex algorithm training, privacy concerns, and sensitivity to other interference like background lighting and image quality degradation due to damaged or obstructed images. Overall, digital twin technology therefore holds significant potential, for smart car park management systems through provision of real-time updates to users in a meaningful and interactive way. Emerging paradigm such as application of cognitive digital twin (CDT) in logistics systems offer immense benefit in supporting urban sustainability and improvements of operations in smart cities (Lie *et al.*, 2023).

In this work, a digital twin model is developed for the automation of the University of Lagos Engineering Car Park. A key contribution is the use of ultrasonic sensor pair, strategically placed at specific distances, to detect the presence or absence of cars in each parking spot. This method minimizes false detection since it is predicated on the idea that, in most situations, both sensors would not simultaneously deliver an incorrect detection. In addition, the system provides real-time updates by displaying a two-dimensional digital twin of parking space availability via a mobile platform.

## 3 Methodology

The conceptualized system architecture for the automation of the University of Lagos Engineering Car Park is shown in Figure 2. The system components consist of multiple Ultrasonic Sensors, ESP32 Microcontroller and Blynk Cloud. The sensors were strategically placed to monitor the parking spaces, the entrance and the exit. Each sensor is responsible for detecting the presence of vehicles by measuring the distance to the nearest object. The sensors send digital signals to the ESP32 microcontroller, indicating whether a parking space is occupied or free, or whether a car is at the entrance or exit.

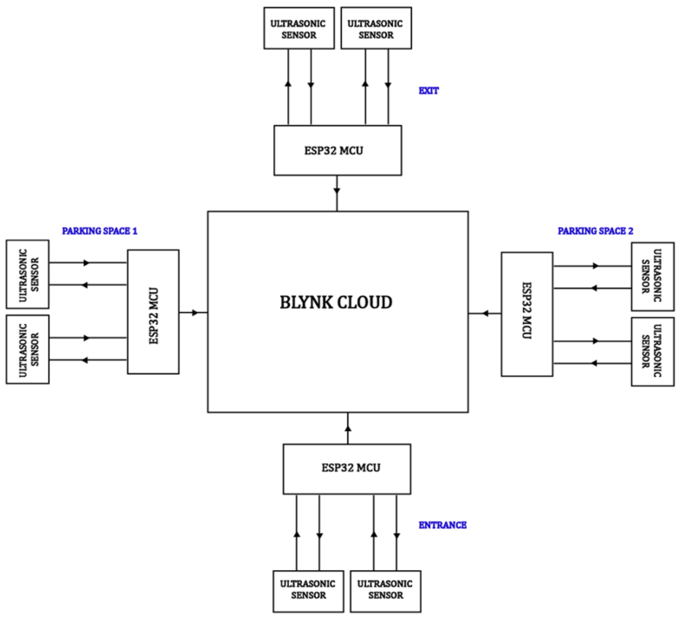


Fig. 2. Conceptualized System Architecture for the Automation of the University of Lagos Engineering Car Park

The ESP32 Microcontroller serves as the central processing unit which collects data from the ultrasonic sensors, processes the signals received and determines the occupancy status of each parking space, subsequently communicates this information to the Blynk Cloud via Wi-Fi.

The Blynk Cloud acts as the data management platform, where the occupancy data is collected, stored, and processed. The cloud platform enables real-time data visualization, allowing users to access the status of parking spaces from anywhere. This is followed by creation of 2D digital twin model of the car park using Firebase for the backend and React for the frontend. The procedure and roadmap for the processes and techniques employed to achieve the system concept are as follows:

i. Design of sensor network
ii. System simulation using Wokwi platform
iii. Implementation of the sensor network
iv. Development of cloud-based data management system
v. Development of 2D digital twin display
vi. Performance evaluation of the system

### 3.1 Design of Sensor Network

The sensor network was used to capture and process near real-time data on parking space occupancy. The purpose is to ensure accurate detection of available spots, process the data, and transmit it to a cloud-based system for storage and visualization. Ultrasonic sensor was selected because of its simplicity, efficiency, low power consumption, and ability to detect objects within a 400 cm range. Ultrasonic sensors can as well be easily integrated with the ESP32 microcontroller. Infrared sensors were not used because of its limited range, while cameras were avoided because of its high processing power and large data storage requirements. The ESP32 microcontroller was selected for its cost-effectiveness, Wi-Fi capabilities, adequate processing power, and low energy consumption, which makes it suitable for real-time transmission of data to the cloud. It has a dual-core processor which can efficiently handle tasks such as processing sensor data and maintaining network connectivity. For implementation, HY-SRF05 ultrasonic sensors are used for accurate distance measurement. A total of 8 sensors were required: 2 for each parking space, 2 for the entrance, and 2 for the exit. The sensors detect vehicle presence and send signals to the ESP32 microcontroller, which processes and transmits this data to the cloud. The power supply consists of two 3.7 V Li-ion batteries connected in series, together with a battery management system, buck converter, and 12V charger, providing stable 5V power for the sensors and microcontroller while ensuring battery health and efficient operation.

### 3.2 System Simulation Using Wokwi Platform

The Wokwi platform (Figure 3a) is an online simulation platform designed for prototyping and testing electronics projects, particularly those involving microcontrollers like Arduino, ESP32 (from Espressif Systems), Raspberry Pi Pico and other similar devices. To begin, an account was created on wokwi.com, and a new project was initiated. The ESP32 microcontroller was chosen as the primary device, with two HC-SR04 ultrasonic sensors added to monitor the parking spaces. A 5V power supply was included to power the ESP32 and sensors (Figure 3b).

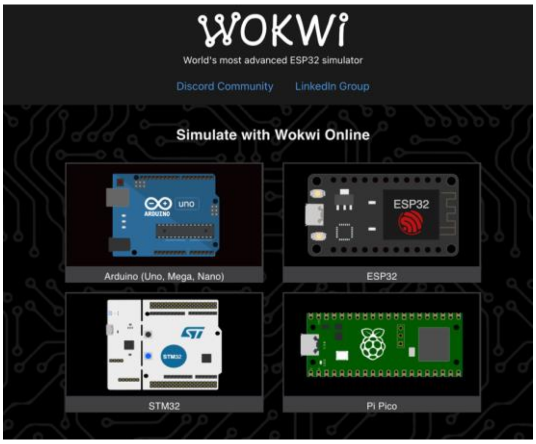


Fig. 3a. Wokwi Web Based Simulation Platform

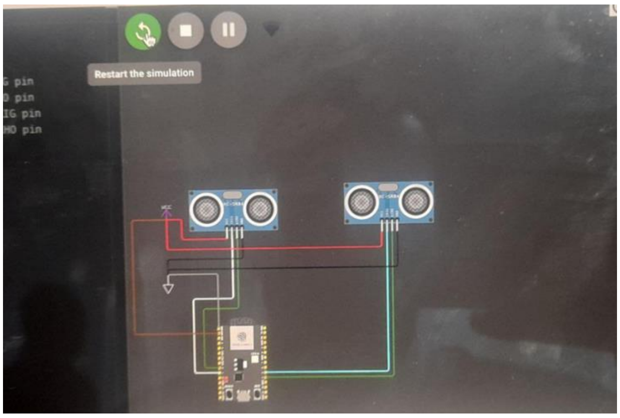


Fig. 3b. Sensor Network Connection to ESP32 controller on Wokwi platform

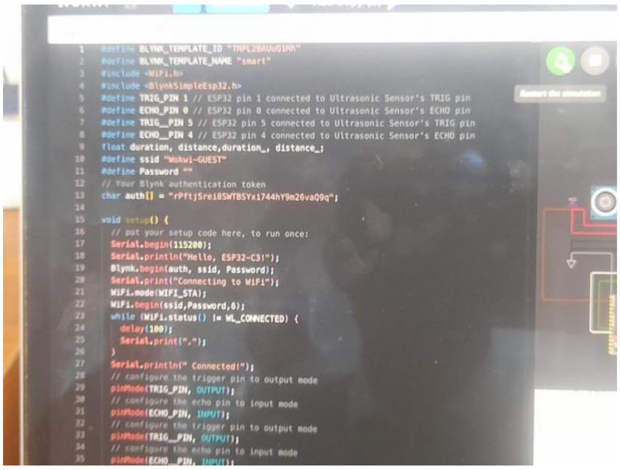

Fig. 3c. ESP32 Microcontroller Programming on Wokwi platform

In the simulation (Figures 3b and 3c), the Vcc pins of the ultrasonic sensors were connected to the ESP32's 5V pin, and their GND pins were linked to the ESP32's GND pin. The Trigger and Echo pins of each sensor were connected to specific GPIO pins on the ESP32. The ESP32 was programmed in the Wokwi environment using the Arduino IDE (Figure 3c). The code initialized the sensors, measured distances, and simulated occupancy detection by comparing the measured distance to a 100 cm threshold. The results were displayed in real-time on the Serial Monitor, providing a simulation of the

 

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parking space status.

### 3.3 Implementation of the Sensor Network

The sensor network's hardware components were connected using a combination of connectors and soldering. The ultrasonic sensors' Vcc pins and the ESP32's 3V3 pin were connected in parallel to the buck converter's positive terminal, while their ground pins were connected to the battery's negative terminal (Figure 4). The trigger and echo pins of the ultrasonic sensors were connected to specific pins on the ESP32 microcontroller (Figure 4). To ensure stability, these connections were soldered onto a Veroboard. The Li-ion battery was linked to a protection board and then to the buck converter, which supplied regulated voltage to the microcontroller and sensors.

The ESP32 microcontroller was programmed using Arduino IDE to interface with two ultrasonic sensors per parking space, detect vehicle presence, and communicate with the Blynk IoT platform. The program initializes the sensors, measures the distance to objects, and uses this data to determine if a parking space is occupied based on a threshold of 120 cm. If both sensors detect an object within this range, the space is marked as occupied; if not, it's marked available. Similar functions are used for detecting vehicles entering or exiting the car park. The ESP32 connects to Wi-Fi and updates the parking status on the Blynk platform in real-time. The microcontroller measures distances, determines parking availability, and reports the status to the Blynk Cloud for user access.

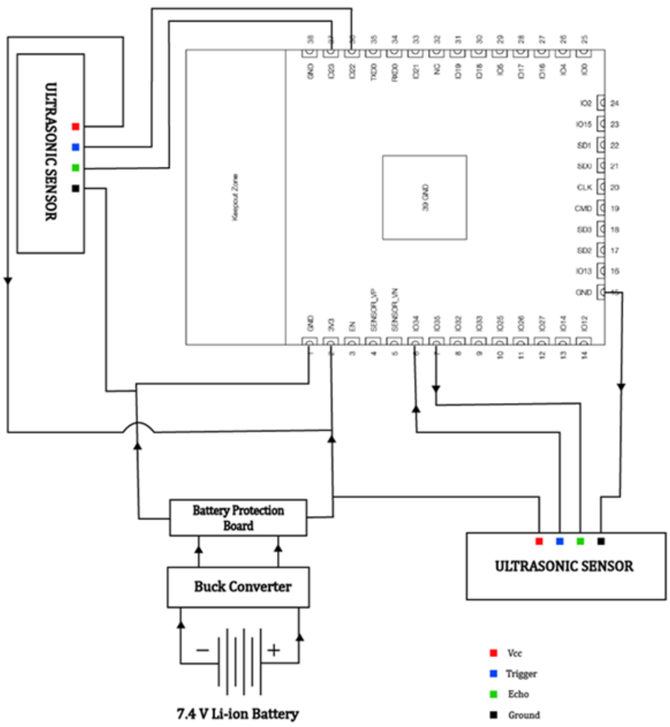


Fig. 4. Wiring Diagram of the Sensor Network

### 3.4 Development of Cloud-Based Data Management System

The cloud data storage was provided by the Blynk IoT platform supporting data visualization, mobile access and seamless integration with the ESP32 microcontroller. The Blynk IoT platform was selected because of its specific application to IoT devices, making it ideal for monitoring of parking space occupancy. To setup the system, a Blynk user account is first created. This is followed by starting a project to integrate the ESP32 device and configuration of dashboard to visualize the data. The ESP32 was added to the platform and linked to the Blynk Cloud through secure authentication tokens, enabling it to send parking status data. Widgets were then created on the dashboard to display the real-time occupancy status. The ESP32 microcontroller was programmed to communicate with the Blynk platform, sending data from the ultrasonic sensors, which is then reflected on the dashboard.

### 3.5 Development of 2D Digital Twin Display

The 2D representation for displaying real-time parking occupancy status was developed using Firebase for the backend and React for the frontend. The backend setup requires creation of a Firebase project followed by Firestore setup as the live database. A collection named "Parking" was created in Firestore, where each document represents a parking spot with its occupancy status. The required Software Development Kit (SDK) was used to integrate with the Firebase project to manage and synchronize data. The frontend was developed using a React application with Vite, which allows a blazing-fast development server experience for React. The Firebase SDK was configured such that the React application communicates with the backend. To provide a 2D visualization of parking availability, a React component was developed to represent a 2D layout which is updated in real-time reflecting changes in Firestore.

### 3.6 Performance Evaluation of the System

The performance of the system was evaluated through detailed testing of its components and the overall system functionality. The ultrasonic sensors were tested individually to evaluate their accuracy for distance measurement. This required preparation of a test environment with a drawing board and ruler, together with initialization of the serial monitor from the Arduino IDE to observe sensor readings. The sensors were placed at one end of the board with distances marked from 0 cm to 100 cm. Then the measured output from the serial monitor for each sensor were compared to these distance markings for proper calibration to ensure consistent results for all eight sensors. Furthermore, all the subcomponents (ESP32 microcontroller, Blynk Cloud, and the web-based visualization) were integrated in a complete system for testing. The objective of this test is to check whether the occupancy status of parking spaces was accurately detected and captured by the Blynk Cloud or not. During the process, any discrepancies observed were corrected, for optimal design, to ensure that the digital twin system reliably reflects the actual parking lot occupancy.

## 4 Results and Discussion

The integrated sensor pair is shown in Figure 5 for a parking spot. The sensors are spaced at a minimum distance of 1 meter to ensure accuracy and minimize false positives.




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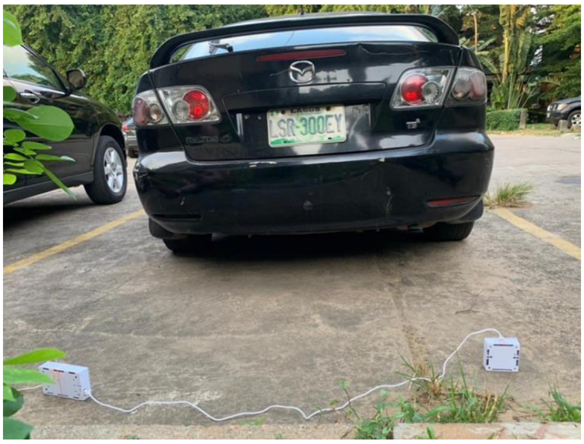


Fig. 5. The integrated sensor setup for a parking spot

### 4.1 ULTRASONIC SENSOR ACCURACY TEST

Table 1. Comparison of actual distance against sensor reading

| $i$ | Actual distance (cm) | Sensor reading (cm) | Absolute error ($\epsilon$) |
|---|---|---|---|
| 1 | 10.00 | 10.00 | 0.00 |
| 2 | 20.00 | 20.00 | 0.00 |
| 3 | 30.00 | 30.00 | 0.00 |
| 4 | 40.00 | 40.00 | 0.00 |
| 5 | 50.00 | 51.00 | 1.00 |
| 6 | 60.00 | 61.00 | 1.00 |
| 7 | 70.00 | 70.00 | 0.00 |
| 8 | 80.00 | 80.00 | 0.00 |
| 9 | 90.00 | 90.00 | 0.00 |
| 10 | 100.00 | 100.00 | 0.00 |

The mean absolute error is defined as (Xu *et al.*, 2024):

$$MAE = \frac{1}{N}\sum_{i=1}^{N} \epsilon_i \qquad (i)$$

The mean absolute percentage error is defined as (Xu *et al.*, 2024):

$$MAPE = \frac{100\ \%}{N}\sum_{i=1}^{N} \frac{\epsilon_i}{y_i} \qquad (ii)$$

Hence, $MAE = 0.2$, while $MAPE = 0.367\ \%$,
Prediction accuracy ($PA$) is: $PA = 1 - MAPE = 99.63\ \%$

The above results depict a very high accuracy for the tested ultrasonic sensor. All ultrasonic sensors used in the project displayed similar levels of accuracy. The most likely source of variability in sensor readings in this case is due to environmental factors such as temperature, humidity, wind flow and vibration noise. Other sources of error could be from the angle of placement of the sensor itself as well as from limitation of the sensor signal processing algorithms.

### 4.2 INTEGRATED SYSTEM TEST

The integration of the ESP32 microcontroller, Blynk Cloud, and the Blynk mobile app for visualization demonstrated highly satisfactory performance in accurately creating a digital twin of the car park. Key findings include:

1. **Occupancy Detection Accuracy**: The system consistently and accurately detected both occupied and available parking spaces, accurately reflecting the real-time status of the car park.
2. **Vehicle Movement Tracking**: The sensors at the entrance and exit gates successfully registered vehicles entering and leaving the car park, providing real-time updates on traffic flow.
3. **Blynk IoT Application Visualization:** As shown in Figure 6, the Blynk IoT web application effectively displayed the car park status with clear, easy-to-read information:
   a) "CAR AT GATE" indicator shows when a vehicle is present at the entrance.
   b) "SPACE FREE" and "SLOT 2 FREE" accurately reflect available parking spaces.
   c) "CAR AT EXIT GATE" notifies when a vehicle is leaving the premises.


Fig. 6. Visualization Through Blynk IoT Mobile App

4. **Real-time Updates and visualization on the digital twin:** The system demonstrated rapid response times, with the Blynk application updating almost instantaneously to reflect changes in the physical car park. Figure 7 shows the results of the digital twin interface for the car park, created using Firebase and React. The clean, intuitive design of this interface ensures that users can quickly assess the parking situation immediately.

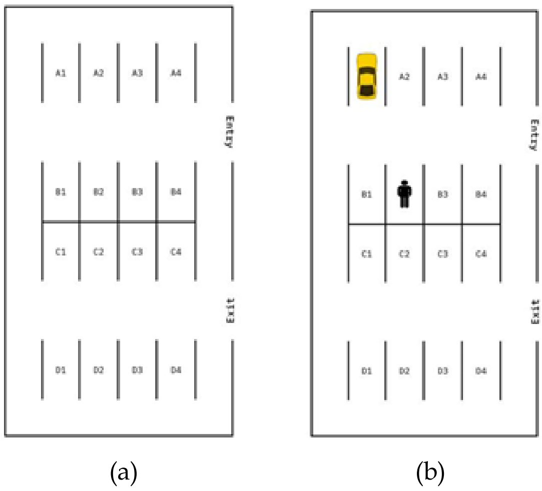


Fig. 7. 2D Model showing (a) empty car park slots alongside (b) occupied and obstructed slots



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A parking spot is considered occupied only when both sensors detect the presence of a car. If only one sensor detects the car, the spot is marked as obstructed but not necessarily occupied.

## 5 Conclusion and Recommendation

A digital twin model for the UNILAG Engineering Car Park was implemented through a combination of IoT and digital twin technologies. The IoT system employs ultrasonic sensors, an ESP32 microcontroller, and the Blynk platform to detect parking occupancy, process the data, and transmit it to the cloud. The digital twin model integrates Firebase for backend database management and React for frontend visualization. This system enables real-time detection of parking space occupancy, with data being collected, processed, and stored via a cloud-based management system. Simulations using Wokwi validated the performance of the ultrasonic sensors before physical deployment on the system. In addition, the digital twin provides an accurate virtual representation of the car park for real-time monitoring of the park occupancy. The system accurately updates parking spot occupancy, achieving up to 99.63% accuracy with ultrasonic sensors. Thus, the system effectively addresses congestion and parking inefficiency by enhancing driver experience and providing real-time parking availability leveraging on IoT and digital twin. This study highlights how smart parking solutions can enhance campus infrastructural development and places the university in the frontier of smart campuses. The future recommendations are increasing the number of sensors in the whole car park area, installing the entrance panel that will display the real-time parking lot information, and forecasting parking demand using historical data and machine learning. This would enable the campus authorities to forecast parking demand using historical data and apply dynamic strategies to optimize parking during peak times.

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