Internet Of Things Based Car Parking Monitoring Device Integrated with WEB Server

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***Abstract*— The rapid increase in the number of vehicles has intensified the need for an efficient and well-managed parking system. Conventional parking systems, which rely heavily on human attendants, often suffer from the absence of real-time monitoring, resulting in congestion and operational inefficiencies. This research proposes an Internet of Things (IoT)-based Smart Parking System employing the HC-SR04 ultrasonic sensor to detect vehicle presence in each parking slot. The system is integrated with a web server that enables real-time monitoring and provides recommendations for parking slot based on proximity to entrance. The implementation utilizes ESP32 microcontrollers to process sensor data and communicate with the web server. All sensor readings are stored in a MySQL database and accessed through a PHP-based web application. Experimental evaluation demonstrates a 100% accuracy rate in slot detection, response time, and recommendation performance. The proposed system significantly enhances parking management efficiency and minimizes fuel consumption by reducing the time required to locate available parking spaces.**

Keywords—Smart Parking, Internet of Things, Parking Monitoring, HC-SR04, Web Server

I. Introduction

As time progresses, the number of vehicles on the road continues to increase, thereby intensifying the demand for proper and adequate parking facilities [1]-[5]. Conventional parking systems still depend heavily on manual management, where attendants supervise vehicle entry and exit without effectively monitoring the actual capacity of the parking area [6], [7]. This traditional approach frequently results in inefficiencies, congestion, and driver dissatisfaction. Many individuals continue to prefer private vehicles over public transportation due to issues such as overcrowding, inconsistent schedules, limited operational hours, and higher transportation costs [8]. Considering these challenges, the optimization of parking management has become crucial to accommodate the growing number of vehicles more efficiently.

Parking is defined as the temporary immobilization of a vehicle while the driver leaves it unattended, in contrast to stopping, which refers to a brief halt during which the driver remains inside the vehicle [9]. Properly managed parking facilities play a vital role in supporting the smooth operation of institutions and commercial establishments [10], [11]. A structured and efficient parking management system enhances user convenience, allowing visitors to access facilities seamlessly and without unnecessary delay. Conversely, poorly organized parking areas can lead to traffic congestion while searching for vacant spaces, lack of clear guidance, wasted time and fuel, and increased environmental pollution due to excessive vehicle emissions [12]. Therefore, implementing a systematic and intelligent approach to parking management is essential.

Smart Parking represents a modern solution that leverages technology to help users locate available parking spaces and even make reservations, capabilities unattainable in conventional parking systems where drivers must manually search for empty spots [13]. Moreover, the long-term operational cost of Smart Parking is considerably lower than that of traditional systems, making it a more sustainable and cost-efficient alternative. In terms of security, Smart Parking provides improved safety and monitoring features compared to manual systems [14]. From the user's perspective, this technology also offers economic and environmental benefits by reducing search time, lowering fuel consumption, and minimizing carbon emissions [15]. Given these advantages, Smart Parking is strongly recommended for large-scale implementation in urban environments [16], [17].

To overcome the limitations of conventional parking management, this study proposes an Internet of Things (IoT)-based intelligent parking monitoring system integrated with a Web Server [18]-[20]. The system is designed to address major parking-related issues, enhance parking area utilization, and provide real-time monitoring capabilities to users. The proposed system employs sensors to detect the occupancy status of each parking slot, with the collected data transmitted to a web server. The web interface then displays a dynamic, real-time visualization of the parking layout, clearly indicating available and occupied spaces.

Furthermore, the system integrates a smart recommendation feature that enhances user convenience by suggesting the nearest available parking slot to the facility's entrance, such as at a shopping mall or public building, thereby minimizing the time required to locate a suitable spot. By implementing this IoT-based Smart Parking framework, institutions and businesses can significantly improve operational efficiency, reduce maintenance and labor costs, and contribute to environmental sustainability [21]. Ultimately, the proposed system not only optimizes parking management but also elevates the overall user experience by making parking operations more seamless, efficient, and environmentally friendly.

II. Design and Implementation

A. System Overview

In this research, the HC-SR04 ultrasonic sensor is integrated with the ESP32 microcontroller to measure distances accurately. Two ESP32 microcontrollers are utilized, functioning as Slave and Master microcontrollers. This configuration is necessary because the HC-SR04 ultrasonic sensor requires time to measure distances. After emitting ultrasonic waves, the sensor must wait for the waves to reflect off an object and return. The waiting time varies from a few microseconds to milliseconds, depending on the object's distance. If multiple HC-SR04 sensors operate sequentially, the cumulative waiting time increases, leading to significant delays in data acquisition. Additionally, the ESP32 microcontroller is tasked with intensive communication with the server, servo motor control, and other essential processes. Excessive concurrent tasks and active sensors may overload the CPU and timer, causing transmission delays or real-time measurement errors.

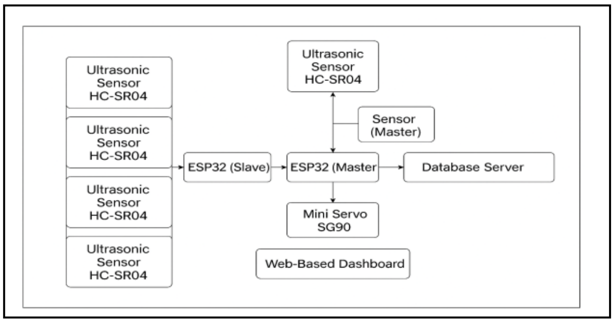

Fig. 1. Block Diagram

The Slave ESP32 microcontroller is responsible for reading data from five ultrasonic sensors and processing the information to calculate the distance. Meanwhile, the Master ESP32 microcontroller reads data from three ultrasonic sensors and controls servo actuators while simultaneously receiving processed data from the Slave ESP32 via RX-TX communication. The combined sensor data from both ESP32 units is then transmitted to a database server over a Wi-Fi network. The server stores all received data in a structured and continuous manner, ensuring reliable data management.

The data storage process is conducted through a local network, commonly referred to as Localhost. The stored data is sequentially retrieved and processed using a PHP program. The system filters the data and determines the availability of parking slots based on predefined thresholds. If the measured distance for a particular parking slot exceeds the set threshold, the system marks the slot as empty. Conversely, if the distance is below the threshold, the slot is considered occupied. This information is then displayed on a web-based interface, enabling users to monitor parking space availability in real time.

In addition to displaying parking slot availability, the website provides users with recommended parking slots closest to the mall entrance, optimizing convenience. Moreover, the web interface serves as a control system, allowing users to access or operate the parking gate remotely. By integrating IoT-based technology and a web server, this system enhances parking efficiency, reduces congestion, and improves the overall parking experience.

B. System Planning

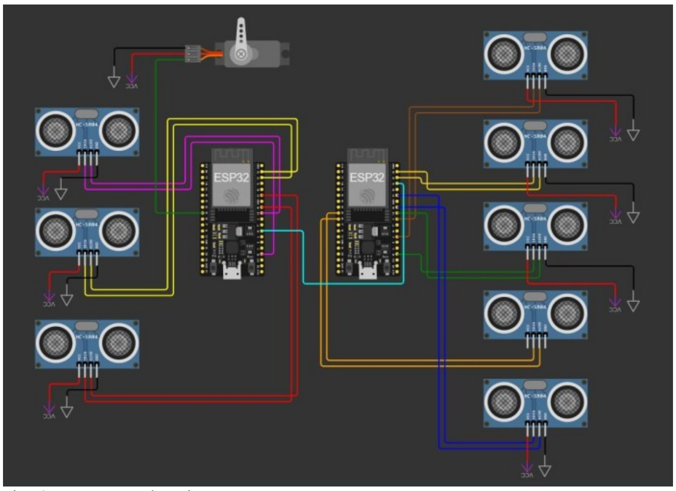

Fig. 2. System planning

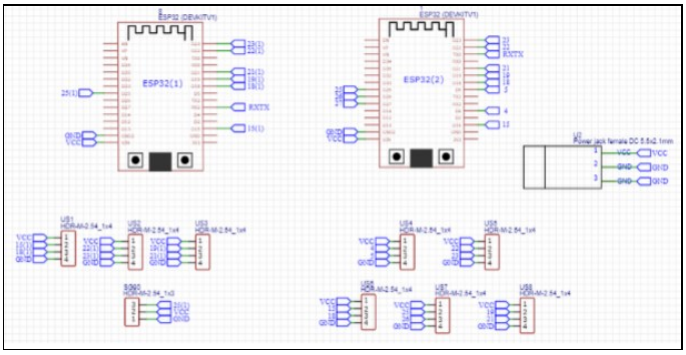

Fig. 3. System Network Schematic

In designing this system, it works using ESP32 as the main component that processes and executes the program. Starting from the process of reading data from the HC-SR04 ultrasonic sensor as a scanner for empty parking slots. Both ESP32 *Slave* nor *Master* gets a voltage supply from *adaptor* 5v which will later be passed on to other components so they can work.

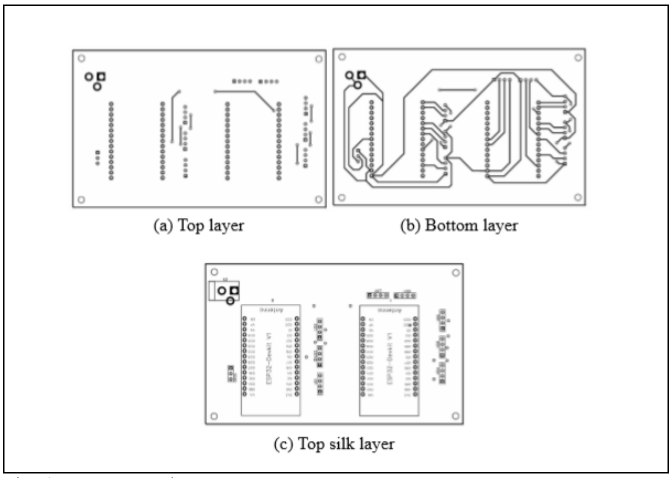

Fig. 4. System Pathway

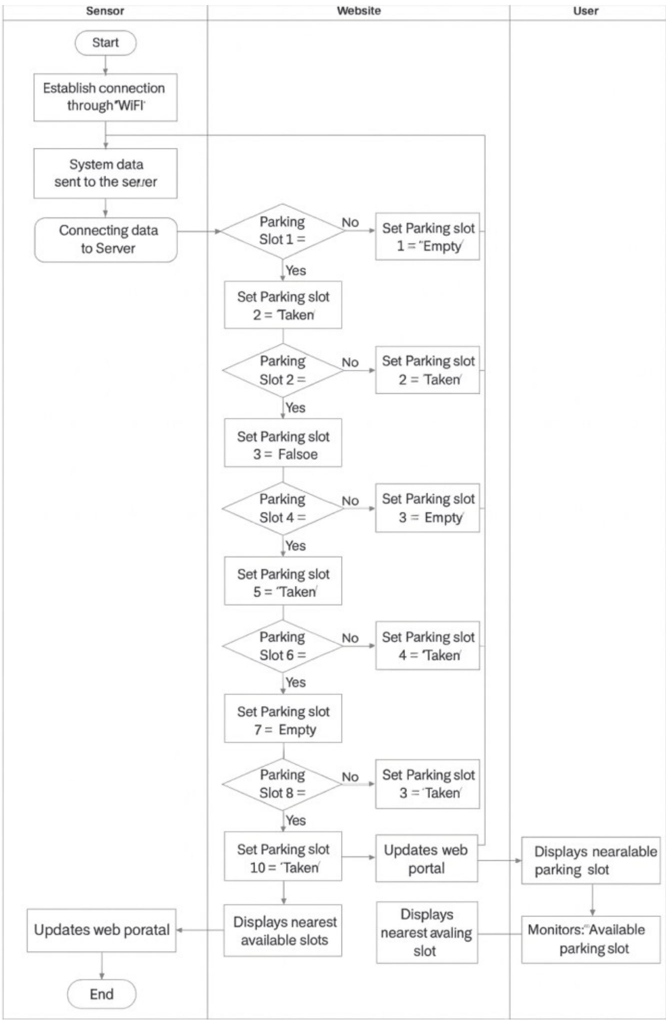

Fig. 5. Flowchart

The diagram presented above illustrates a swimlane flowchart, which is divided into three main sections: the processing performed by the ESP32, the processing conducted by the website, and user interactions. At the system's initialization, the ESP32 immediately activates the sensor, Wi-Fi, servo motor, and server. The HC-SR04 ultrasonic sensor transmits measurement data, which is then received by the ESP32. The ESP32 converts this data into distance units, measured in centimeters. If the ESP32 successfully connects to the local Wi-Fi network, it automatically transmits the processed data to the server, where it is stored in a database. The stored data is then retrieved by a PHP program for further processing. If the retrieved data exceeds a predefined threshold, the corresponding parking slot is marked as empty. Conversely, if the data is below the threshold, the parking slot is identified as occupied. This process is continuously executed for each parking slot.

In the subsequent stage, the PHP program analyzes the availability of parking slots and provides recommendations to the user. The system determines recommendations based on the nearest available parking slot to the mall entrance, ensuring optimal convenience. This feature allows users to monitor parking space availability in real time and receive guidance on the most strategic parking spots. At the final stage, users can access the parking gate by selecting the "Action" button on the website. Once activated, users can enter the parking area and occupy the recommended parking slot.

This research involves the development of three interconnected software components. The first component is the ESP32 programming module, which is responsible for operating the hardware and facilitating communication between the website and hardware components. The second component is the database system, which serves as the repository for all input data collected from sensors and servo motors. The third component is the website programming module, which functions as the user interface. Through this website, users can monitor parking availability and control access to the parking gate.

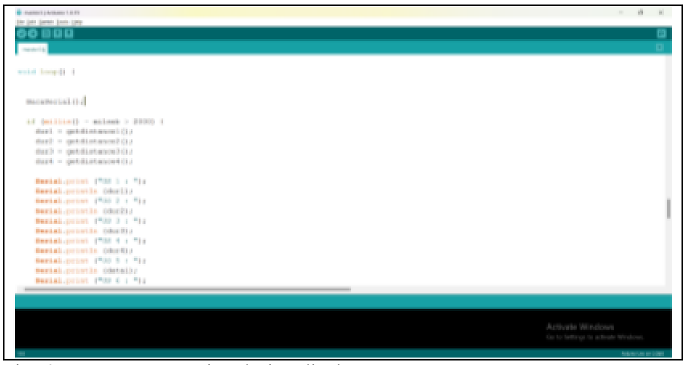
Fig. 6. C++ programming design display

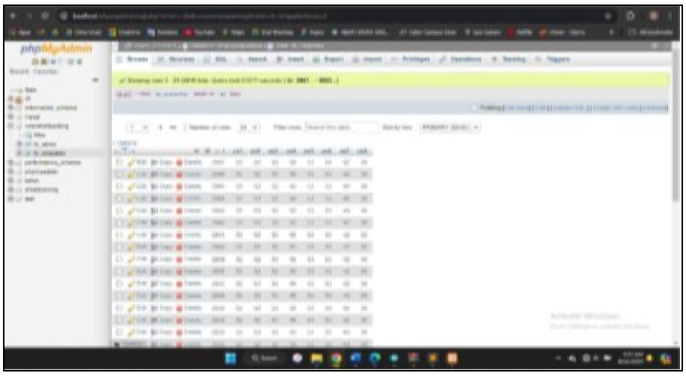

Fig. 7. Display Design Database MySQL

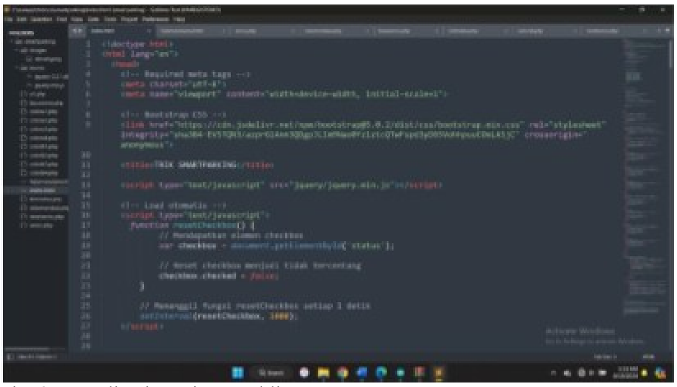

Fig. 8. Application Views Sublime Text

C. System Implementation

The hardware design consists of several key components. In this study, two ESP32 microcontrollers are utilized, functioning as Slave and Master units. The ESP32 Slave is responsible for reading data from five HC-SR04 ultrasonic sensors, while the ESP32 Master handles data acquisition from three HC-SR04 ultrasonic sensors, controls one SG90 servo motor, and communicates with the server. To facilitate component integration, a PCB board is designed, ensuring seamless connections between hardware elements.

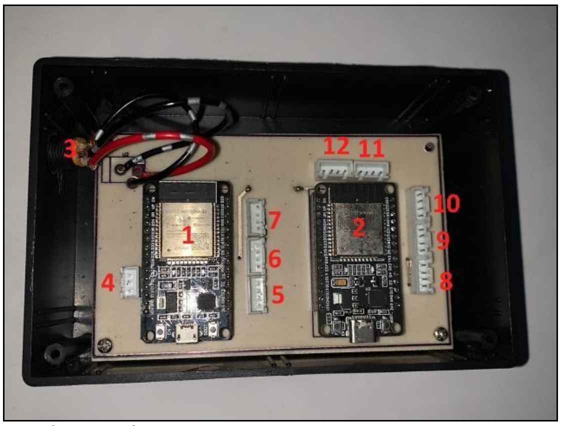

Fig. 9. Hardware Series System

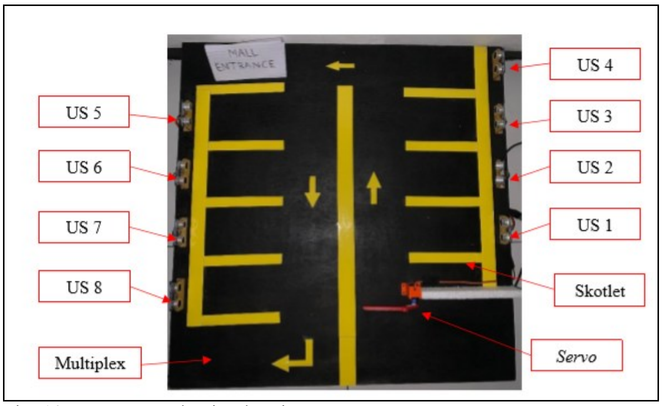

Fig. 10. System Mechanic Planning

For mechanical design, this study employs a multiplex wooden board with dimensions of 60 cm × 60 cm and a thickness of 0.5 cm as the primary structural medium. The board is painted black and enhanced with yellow scotlet strips to represent parking slot markings. Ultrasonic sensor brackets are constructed from acrylic and positioned along the rear boundary of each parking slot to ensure accurate distance measurements.

Additionally, an SG90 servo motor is installed on a 3D-printed bracket, serving as a visual representation of the parking gate. This design ensures that the hardware components are arranged efficiently, enabling smooth operation and reliable parking space detection.

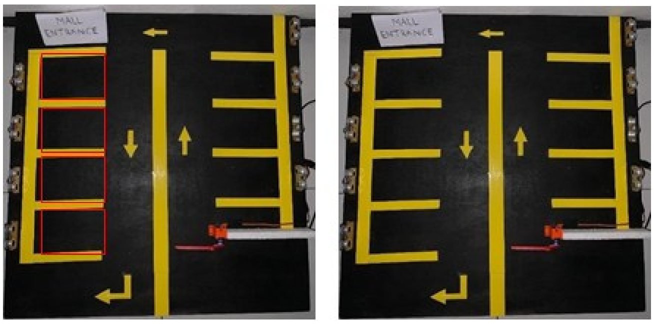

Fig. 11. Internal System

Manufacturing website in this research using an application Sublime Text. Website This will later be used by users as an interface for monitoring a parking lot. On the main page website Several options will appear mall which can be monitored. Users can view and monitor each one one by one mall by pressing the "buttonVisit". On the monitoring page display, you can see that if the slot is green, it means the slot is empty and has the status "Available". On the other hand, if the slot is red, it means the slot is filled with a car and has the status "Filled". On the menu "Action" there is a button to access the portal from website. On the menu "Recommendation". There are recommendations for parking slots closest to the entrance mall. These recommendations will provide recommendations in a timely manner realtime. If the parking lot is full, the parking recommendation status will show that the parking lot is full or full.

Fig. 12. Menu Display Main Website

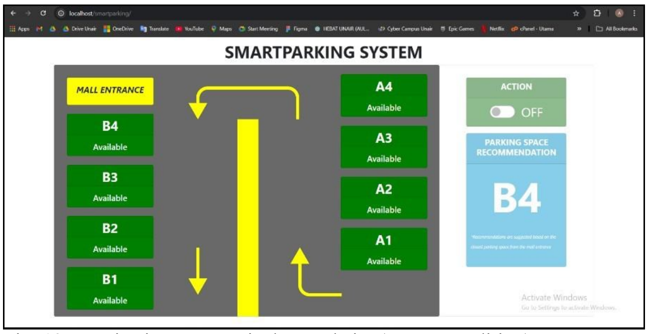

Fig. 13. Monitoring Menu Display Website (empty condition)

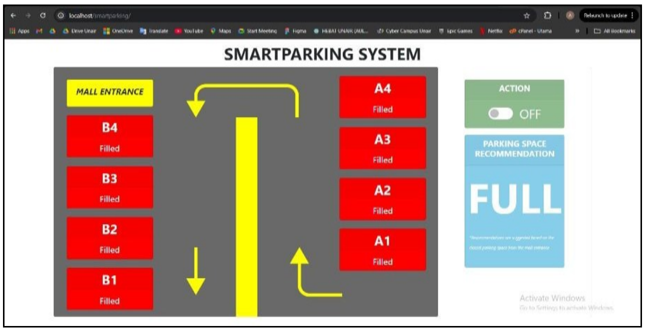

Fig. 14. Monitoring Menu Display Website (full condition)

III. TESTING

A. *Sensor Testing*

Testing of the HC-SR04 ultrasonic sensor was carried out to determine how the sensor works and how accurate it is in capturing and processing data. This test is carried out by testing ultrasonic sensor readings. This test tests the accuracy of the sensor and makes a comparison with a predetermined distance. In this case, the distance has been determined using a measuring ruler as a comparison for the HC-SR04 ultrasonic sensor readings.

TABLE I. *ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 1)*

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	17	1	0.055556	94.4
10	20	20	0	0	100.0
Average			**0,1**	**0.005556**	**99.4**

TABLE II. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 2)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	3	1	0.055556	94.4
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	18	0	0	100.0
10	20	20	0	0	100.0
Average			**0,1**	**0.005556**	**99.4**

TABLE III. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 3)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	18	0	0	100.0
10	20	20	0	0	100.0
Average			0	0	100.0

TABLE IV. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 4)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	9	1	0.055556	94.4
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	13	1	0.055556	94.4
8	16	16	0	0	100.0
9	18	18	0	0	100.0
10	20	20	0	0	100.0
Average			**0.2**	**0.011111**	**98.88**

TABLE V. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 5)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	18	0	0	100.0
10	20	20	0	0	100.0
Average			**0**	**0**	**100.0**

TABLE VI. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 6)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	17	1	0.055556	94.4
10	20	20	0	0	100.0
Average			**0,1**	**0.005556**	**99.4**

TABLE VII. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 7)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	18	0	0	100.0
10	20	20	0	0	100.0
Average			**0**	**0**	**100.0**

TABLE VIII. ACCURACY TESTS OF HC-SR04 ULTRASONIC SENSOR (US 8)

No	Specified distance (cm)	Reading Sensor (cm)	Difference(cm)	*Error* (%)	Accuracy (%)
1	2	2	0	0	100.0
2	4	4	0	0	100.0
3	6	6	0	0	100.0
4	8	8	0	0	100.0
5	10	10	0	0	100.0
6	12	12	0	0	100.0
7	14	14	0	0	100.0
8	16	16	0	0	100.0
9	18	17	0	0	100.0
10	20	20	0	0	100.0
Average			**0**	**0**	

In the table above it can be seen that the sensor readings have an average error rate of 0.1% with a difference of 0.2 cm which occurred in the US 4 experiment and produced an accuracy level of 98.88%. From the results of experiments US 1, US 2, and US 6 it was found that Level *error* from the sensor is 0,005556% And the sensor accuracy level reaches 99.4%. Meanwhile, in experiments US 3, US 5, US 7, and US 8 the error value was obtained 0% and 100% accuracy rate. In this way, all HC-SR04 ultrasonic sensors used in this research are in optimal condition and suitable for use.

B. Servo Testing

Testing *servo* done to find out that *servo* runs normally according to the specified status. This test uses *input* from the button on it *website* and stored on *Database*. The main function of *servo* itself is a visualization of the doorstop or portal that is generally found in parking lots.

TABLE IX. SERVO SG90 TESTING

PWM	Angle (°)
26	0
77	45
128	90
179	135
230	180

From the table above, test results are obtained to determine the optimal angle for opening and closing the portal. In this study, the angle used for closed portal conditions was 90°. The angle used in the open portal condition is angle 0°. Portal control will be executed at the time the ESP32 receives input from *website.* Input from this website will later be saved on *database.* ESP32 will take the value from *database* in real time until when there is a value update in the table *servo*, ESP32 will immediately respond and execute portal control. If *input* from *website* shows a value of 0 then the portal will be closed. On the other hand, when *input* from *website* is 1 then the portal will open.

TABLE X. TESTING OF DOORWAY CONTROL

Test	*Input from web*	Response *servo*	Information
1	0	*Angle* 90°	Succeed
2	1	*Angle* 0°	Succeed
3	0	*Angle* 90°	Succeed
4	1	*Angle* 0°	Succeed
5	0	*Angle* 90°	Succeed
6	1	*Angle* 0°	Succeed
7	0	*Angle* 90°	Succeed
8	1	*Angle* 0°	Succeed
9	0	*Angle* 90°	Succeed
10	1	*Angle* 0°	Succeed

From the test results above, it was found that *servo* The SG90 has been running well and has not experienced any problems. *Input* is input provided from the web which will later initiate movement from *servo*. Moment *input* value 0 then *servo* will move to *angle* 90°. When *input* is worth 1 then *servo* will move to *angle* 0°.

C. Data Delivery Speed Testing

This test is carried out to determine the suitability and speed of delivery in one data reading cycle. In this test ten data samples were taken. Data samples are taken based on the time recorded when data is sent and received. The recorded time interval will become a benchmark for the average speed of data delivery in one delivery cycle.

TABLE XI. *DATA DELIVERY TESTING*

Test	Time Update		Time Diference (Second)
	ESP32	*Website*	
1	00:13:26	00:13:27	1
2	00:13:42	00:13:43	1
3	00:13:59	00:14:00	1
4	00:14:17	00:14:18	1
5	00:14:33	00:14:35	2
6	00:14:51	00:14:52	1
7	00:15:08	00:15:09	1
8	00:15:20	00:15:21	1
9	00:15:35	00:15:36	1
10	00:15:46	00:15:47	1
Average			1.1

From ten experiments, it was found that the average obtained in one data transmission cycle had an interval of 1.1 seconds. The time difference is obtained by subtracting the time recorded when receiving data from the time recorded when sending data.

D. Testing Tool Response to Input Commands

This test is conducted to determine the suitability and speed of delivery in one data reading cycle. In this test, ten data samples were taken. Data samples were taken based on the time recorded when the data was sent and received. The recorded time interval will be the benchmark for the average data delivery speed in one delivery cycle.

TABLE XII. *TOOL RESPONSE TEST RESULTS TO COMMANDS FROM THE WEB*

Test	Time *Update* Data		Response Time (seconds)
	Input Web	ESP32	
1	00:47:31	00:47:33	2
2	00:47:58	00:47:59	1
3	00:48:12	00:48:14	2
4	00:48:38	00:48:39	1
5	00:48:56	00:48:58	2
6	00:49:21	00:49:22	1
7	00:49:40	00:49:41	1
8	00:49:59	00:50:01	2
9	00:50:22	00:50:24	2
10	00:50:48	00:50:49	1
Average			1,5

From the results of the table above it can be seen that the response of the system in executing user commands is quite fast. Average the time required to execute one user command is 1.5 seconds.

E. Testing the Status of Parking Slot Recommendations

Testing the status of parking slot recommendations serves to find out how the recommendations provided are performing website to existing parking slots. This recommendation is formed based on empty parking slots, then the system will recommend the closest parking slot to the entrance mall. In this experiment, nine simulations of recommended parking slots were used. The following are nine simulations that have been carried out:

TABLE XIII. PARKING SLOT CONDITIONS

Condition	Parking Slot Status							
	A1	A2	A3	A4	B1	B2	B3	B4
1	Empty	Empty	Empty	Empty	Empty	Empty	Empty	Empty
2	Empty	Empty	Empty	Empty	Empty	Empty	Empty	Filled
3	Empty	Empty	Empty	Empty	Empty	Empty	Filled	Filled
4	Empty	Empty	Empty	Filled	Empty	Empty	Filled	Filled
5	Empty	Empty	Filled	Filled	Empty	Empty	Filled	Filled
6	Empty	Empty	Filled	Filled	Empty	Filled	Filled	Filled
7	Empty	Filled	Filled	Filled	Empty	Filled	Filled	Filled
8	Empty	Filled	Filled	Filled	Filled	Filled	Filled	Filled
9	Filled	Filled	Filled	Filled	Filled	Filled	Filled	Filled

TABLE XIV. SYSTEM RECOMMENDATION RESULTS FOR PARKING SLOT CONDITIONS

Condition	System Recommendations
1	B4
2	B3
3	A4
4	A3
5	B2
6	A2
7	B1
8	A1
9	*FULL*

From the simulation above, the earliest recommended slot is B4, where slot B4 is the slot closest to the entrance. mall. The system works well in recommending empty parking slots. The resulting recommendation data is quite accurate in selecting the closest parking slot to the entrance mall. When the parking slot has reached the maximum limit or full, the recommendation status will show the status FULL and do not recommend any slots.

F. Whole System Testing

The overall testing of this system aims to ensure that the entire system can work well and is synchronized with one another. In this test, all sensors were tested, in this case the test used the HC-SR04 ultrasonic sensor. All sensors will detect each parking slot. Empty parking lots will be processed and visualized in the form of a web page display. From the process that has been carried out, the system will recommend the empty parking slot closest to the mall entrance.

Users can access the portal by pressing a button on the website which will then initiate the servo to rotate open. The car will enter the parking area and fill the recommended space. If the car does not enter the recommended slot, the slot occupied by the car will turn red and the status will become occupied. Recommendations will continue to recommend parking in the nearest slot until the slot closest to the entrance is filled by the next car. If the car leaves the parking lot, the parking slot will read empty, and the parking slot status will be "Available" in green.

TABLE XV. WHOLE SYSTEM TESTING

Simulation	Condition	Recomendation System	Status	Information
1	1	B4	Opened successfully	Succeed
2	2	B3	Opened successfully	Succeed
3	3	A4	Opened successfully	Succeed
4	4	A3	Opened successfully	Succeed
5	5	B2	Opened successfully	Succeed
6	6	A2	Opened successfully	Succeed
7	7	B1	Opened successfully	Succeed
8	8	A1	Opened successfully	Succeed
9	9	FULL	Not Opened	Succeed
Success Rate				Succeed (100%)

The table above can be a table of test results for the entire system. In table XII there is a condition column which refers to Table XII Parking Slot Conditions in the parking slot recommendation status testing sub-chapter. In testing the entire system, the entire system is running well and is structured. Each simulation cycle will involve success in monitoring parking slots, the system's success in recommending the parking slot closest to the mall entrance, and the success of the portal in opening and closing. The parking slot recommendations provided by the system work well and correctly. In testing the entire system, the portal succeeded in running as expected. The portal will open when receiving input from the user via a button on the website. The success rate obtained in testing the entire system was 100%. The entire system has worked well and as expected.

IV. Result

The HC-SR04 ultrasonic sensor is utilized in this study to measure the distance in each parking slot. This system is based on the Internet of Things (IoT) and is integrated with a Web Server, enabling real-time monitoring and control. A parking spot recommendation system is implemented to suggest the nearest available parking slot to the mall entrance. All sensor readings are stored in a MySQL database, which is later accessed by a PHP program to be displayed on the website.

The hardware design in this study employs a multiplex board with dimensions of 60 cm × 60 cm and a thickness of 0.5 cm. Each parking slot is equipped with a sensor bracket that holds the HC-SR04 ultrasonic sensor. Additionally, an SG90 servo bracket and a miniature parking gate are installed to simulate real parking operations. The hardware components are interconnected to ensure efficient data communication. This study utilizes two ESP32 microcontrollers, where the workload is divided to prevent overburdening a single microcontroller while ensuring real-time data transmission. The ESP32 Master receives data from the ESP32 Slave, processes readings from three HC-SR04 ultrasonic sensors, controls the servo motor, and transmits data to the server. Meanwhile, the ESP32 Slave is responsible for processing data from five HC-SR04 ultrasonic sensors.

The operating principle of this system is based on distance measurements for each parking slot. If the detected distance is less than 10 cm, the parking slot is identified as occupied. Conversely, if the measured distance exceeds 10 cm, the slot is classified as vacant. The system then provides parking recommendations, prioritizing the closest available parking slot to the mall entrance for user convenience.

System testing was conducted to evaluate sensor accuracy, servo performance, data transmission speed, response time, and recommendation system reliability. The ultrasonic sensor tests yielded an average error rate of 0.1%, with a measurement difference of 0.2 cm in the US 4 experiment, resulting in an accuracy rate of 98.88%. Experiments conducted on US 1, US 2, and US 6 showed an error rate of 0.005556% and an accuracy rate of 99.4%, while US 3, US 5, US 7, and US 8 achieved 100% accuracy with 0% error. The SG90 servo motor tests demonstrated successful operations across all trials. The data transmission speed tests revealed an average time difference of 1.1 seconds per transmission cycle, while system response time tests showed a 1.5-second delay between input and execution. The recommendation system testing confirmed that the system accurately suggests the nearest available parking slot to the mall entrance. The overall system testing demonstrated a 100% success rate, validating the proper integration of hardware and software components.

V. Conclusions

Based on the test results, the system demonstrates a high level of accuracy and reliability in parking space detection, data transmission, servo control, and recommendation generation. The effective division of processing tasks between two ESP32 microcontrollers ensures real-time operation without overburdening any single component.

Although the system performs well, there is room for enhancement. Future improvements may include optimizing traffic flow to reduce congestion and increasing system scalability. Integrating artificial intelligence (AI) or machine learning (ML) into the parking recommendation algorithm could significantly improve its performance, especially in larger, more complex parking environments.

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