IoT Prototype In Vertical Parking System For Optimizing Parking Space Management

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***Abstract*— As the number of vehicles in major cities like Jakarta increases each year, the availability of parking spaces decreases, causing various problems in economic, social, health, and safety aspects. This study explains the implementation of the Internet of Things (IoT) in a vertical parking model to help optimize parking space. IoT is used to monitor the status of parking slots, whether they are occupied or vacant, and the system can be operated by booking through a website to check available parking slots. Based on test results, the parking lift can lift a 60-gram load to the second floor in 16 seconds and lower the load from the second floor to the first floor in 15 seconds. IoT sensors can detect vehicles in parking slots with a low throughput value of 16.26 bytes/s and 0.00163 kbps. Finally, website testing showed only a delay of 395.8 milliseconds when making reservations.**

Keywords*— *IoT, Throughput, Delay, Prototype, Website, Parking Lot, Lift

I. INTRODUCTION

Jakarta, the capital city of Indonesia, is one of the most populous cities with a relatively large land area. According to the World Population Review, Jakarta has a dense population of 11 million people, ranking 28th among the 781 most populous cities in the world [1]. This fact makes Jakarta more populous than several other capital cities such as Paris, Bangkok, Lima, and many others. With this large population, Jakarta also has a land area coverage of 660 km² [2].

As the population increases, the number of private and public vehicles in Jakarta also continuously rises. This number even reached 26 million units in 2022, which is a 4.39% increase from the previous year [3]. Consequently, the number of vehicles on the road is very high, often causing traffic congestion, which has become an integral part of daily life. However, traffic congestion is not only caused by the number of vehicles but also by the continuously developing residential areas and high-rise buildings, which ultimately limit the amount of road space available.

This paper includes several critical tests to ensure that the prototype functions optimally. These tests are: 1) Lift Ascending and Descending Capability, 2) Functionality and Accuracy of the Ultrasonic Sensor, and 3) Quality of Service (QoS) metrics such as Throughput, Packet Loss, and Delay of the entire system [4]. The tests are conducted within a fully operational model scenario.

II. METHODOLOGY

This research begins with identifying existing problems and their potential solutions. It then proceeds to review the literature on vertical parking models, the IoT technology used, and the website application. The paper concludes with an analysis of the results and the conclusions drawn from the research.

A. *Problem Identification*

The problem addressed in this paper is the depletion of parking spaces in large cities, which leads to issues such as vehicles being parked on the roadside and difficulties in daily mobility. The proposed solution is the development of a vertical parking model. This model aims to minimize the use of available land by constructing parking spaces vertically and utilizing a lift system to transport vehicles. The model is supported by IoT technology, which monitors the availability of parking slots, and a booking-only system to facilitate user parking.

B. *Literature Review*

In this research, the foundation of the literature review is used to determine whether the existing system can support the study and meet the required specifications. The literature is sourced from relevant research, discussions, and practical experience.

1. Vertical Parking

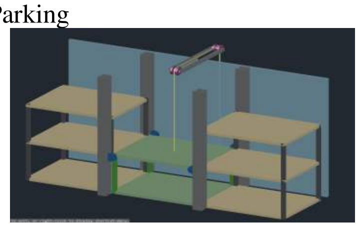

FIGURE 1
Parking Design

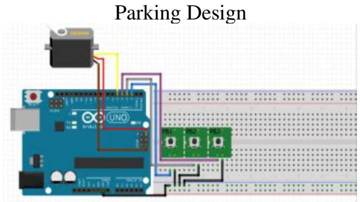

FIGURE 2
Wiring Diagram of Lift System

The designed vertical parking model measures 30x10x30 cm and features 3 parking slots. It includes a lift in the center to transport vehicles to the parking slot on the second floor. The lift weighs 210.8 grams and uses an MG996R servo motor with a pulley system.

Intenet of Things

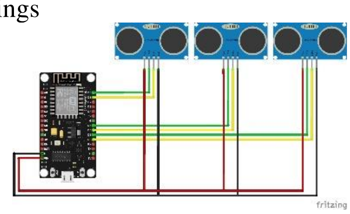

FIGURE 3
IoT Design

In this research, the Internet of Things (IoT) utilizes the NodeMCU ESP8266 along with 3 piece HC-SR04 ultrasonic sensors. The ESP8266 was chosen for its capability and ease of connecting to Wi-Fi, allowing it to send sensor data to a real-time Firebase database. Additionally, the ESP8266 facilitates the control of sensors connected to each parking slot.

2. Web Application

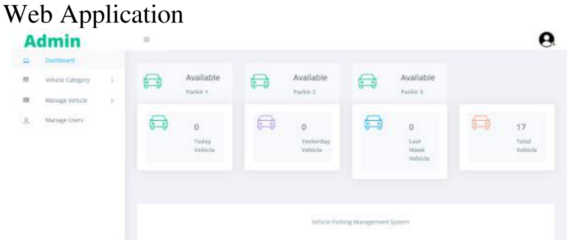

FIGURE 4
Website Design

In the research, the website includes several features: 1) Admin and User roles, 2) Registration and Login, 3) Reservation and Details, and 4) Parking Slot Monitoring [5]. All processed data is linked to both a phpMyAdmin database and Firebase. The website dashboard displays available parking slots to assist users in identifying and reserving vacant slots.

3. Throughput

Throughput testing is conducted by measuring the data transmission time at various distances and calculating how quickly data can be sent through the system. To calculate throughput in bits per second (bit/s), the following formula is used:

$$Throughput(bit/s) = \frac{Total\ Data\ Transferred\ (bit/s)}{Total\ Time\ Taken\ (seconds)} \quad [6]$$

4. Packet Loss

Packet loss refers to the percentage of data packets sent over a network that do not arrive at their destination. It indicates network reliability and performance. To calculate packet loss, following formula is used:

$$Packet\ Loss = \frac{packet\ sent - packet\ received}{packet\ sent}\ x\ 100\% \quad [7]$$

5. Delay

Delay in networking refers to the time it takes for a data packet to travel from its source to its destination. It is often measured in milliseconds (ms) and used the formula below:

$$Delay\ (ms) = time\ received - time\ sent \quad [8]$$

C. System Architecture

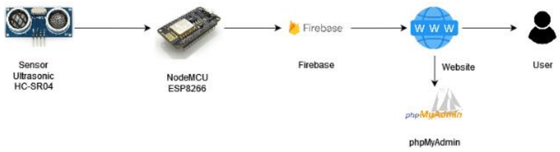

FIGURE 5
System Diagram

The system architecture shown in Figure 4 represents the system diagram for the research. It illustrates that the study employs HC-SR04 ultrasonic sensors in conjunction with the ESP8266, which are connected to Firebase. The website then processes and exchanges data with both Firebase and phpMyAdmin before presenting it to the user.

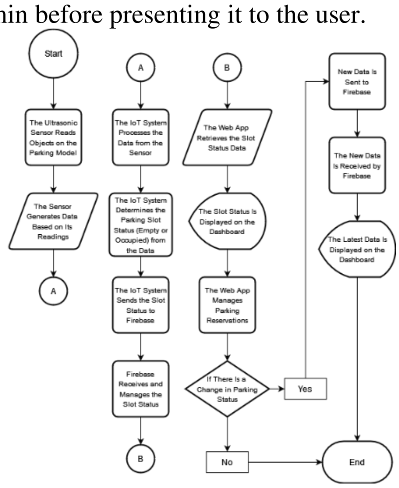

FIGURE 6
System Flowchart

The system architecture shown in Figure 5 represents the system flowchart for the research. It illustrates the workflow from the starting point to Point B, which covers the IoT components of the system. The process then continues from Point B to the End, encompassing the website's functionality.

D. System Implementation

FIGURE 7
Parking and IoT Implementation

As shown in Figure 6, which represents the implementation of the vertical parking model and IoT system, the model features ultrasonic sensors (yellow boxes) installed above each parking slot and a servo motor (red box) for controlling the lift. The black box in the lower right corner houses the Arduino Uno R3, which controls the servo, and the ESP8266, which serves as the microcontroller for the IoT functionality.

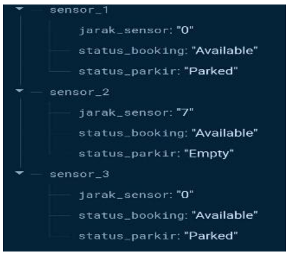

FIGURE 8
Firebase Database

As shown in Figure 7, Firebase is used to manage data for the system. Firebase serves as the data exchange platform between the IoT system and the website. The IoT system controls the "status_parkir" (parking status), while the website manages the "status_booking" (booking status).

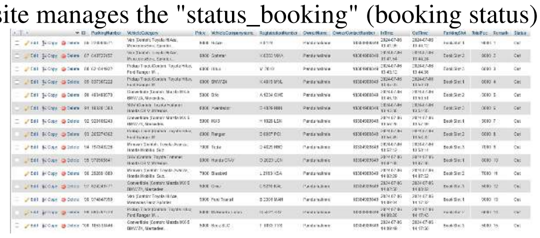

FIGURE 9
phpMyAdmin Database

Finally, as shown in Figure 8, the phpMyAdmin database manages almost all aspects of the website, from user login and registration to the reservation process.

III. RESULTS AND ANALYSIS

This chapter presents the results obtained from the implementation and testing of the vertical parking model integrated with IoT technology. The data collected from various tests, including the lift's ascending and descending capabilities, the functionality and accuracy of the ultrasonic sensors, and the overall system's Quality of Service (QoS) metrics, are analyzed in detail. The effectiveness of the system is evaluated based on its ability to optimize parking space utilization and improve user convenience through real-time monitoring and reservation features.

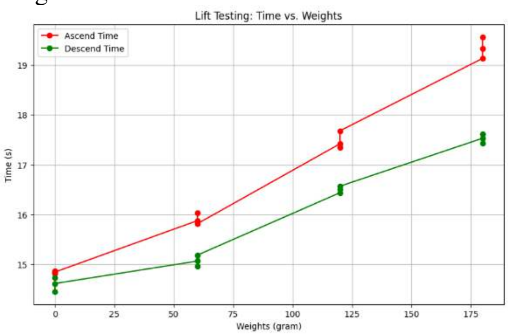

FIGURE 10
Lift Testing Performance

As shown in the Figure 9, the lift testing results indicate a clear correlation between the weight added to the lift and the time it takes for the lift to ascend and descend. As the weight increases, the time required for the lift to complete its ascent also increases, which is expected as the motor has to work harder to lift heavier loads. For example, with no additional weight, the average ascend time is around 14.85 seconds. This time increases to approximately 15.91 seconds with a 60-gram weight, 17.48 seconds with a 120-gram weight, and 19.34 seconds with a 180-gram weight. Similarly, the descend time also increases with additional weight, although the change is less pronounced. With no added weight, the average descend time is about 14.60 seconds. This increases to approximately 15.08 seconds with a 60-gram weight, 16.51 seconds with a 120-gram weight, and 17.52 seconds with a 180-gram weight. These results demonstrate the efficiency and consistency of the lift mechanism, powered by the Motor Servo MG996R, in handling varying loads.

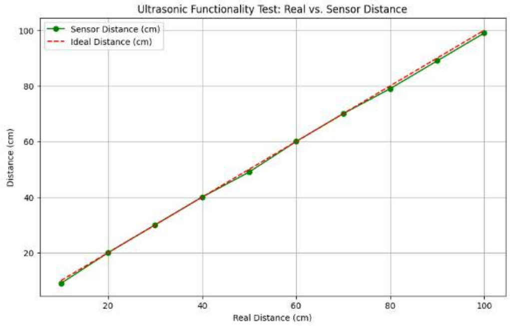

FIGURE 11
Ulrasonic Functionality Test

Figure 10 above illustrates the results of the sensor functionality test compared to the actual distance between the sensor and a manual measuring device. Based on the initial test results, at a distance of 10 cm, the sensor read a distance of 9 cm, resulting in an error percentage of 10%. In the second test, conducted at a distance of 20 cm, the sensor correctly read 20 cm, yielding a 0% error. In the tenth test, with a distance of 100 cm, the sensor measured 99 cm, resulting in a 1% error. It can be concluded from the table of test results that as the distance between the sensor and the object increases, the percentage error decreases. Conversely, as the distance between the object and the sensor decreases, the percentage error increases.

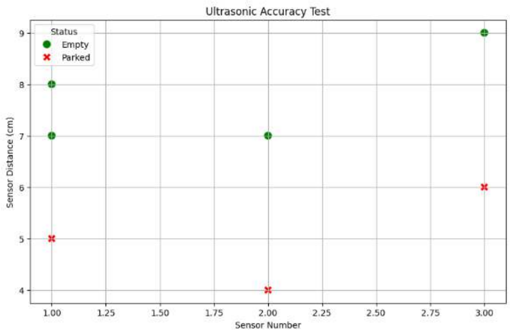

FIGURE 12
Ultrasonic Accuracy Test

Based on Figure 11, the first test shows that Sensor 1, with a distance of 8 cm, has a parking slot status of "empty"; Sensor 2, with a distance of 7 cm, also indicates a parking slot status of "empty"; and Sensor 3, with a distance of 6 cm, indicates a parking slot status of "parked." It can be concluded that the sensor is capable of detecting the presence of an object when the distance between the sensor and the vehicle is 6 cm or less. If the sensor detects a vehicle at a distance greater than 6 cm, it will report the parking slot as "empty."

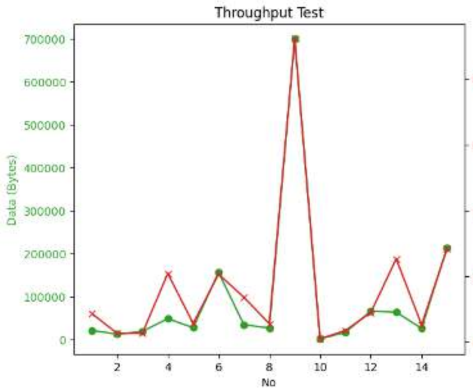

FIGURE 13
Throughput Test

The results of the test shown in Figure 12 indicate that the data transmission speed varies significantly. In 15 tests conducted, the throughput ranged from 0.86 bit/s to 92.07 bit/s. The average throughput achieved was approximately 16.26 bit/s. When converted to kilobits per second (kbps), the average throughput is 0.0163 kbps. Based on commonly used throughput categories, this system is categorized as having low throughput (below 1 kbps). Therefore, the overall index for this system is 1, indicating very poor data transmission performance.

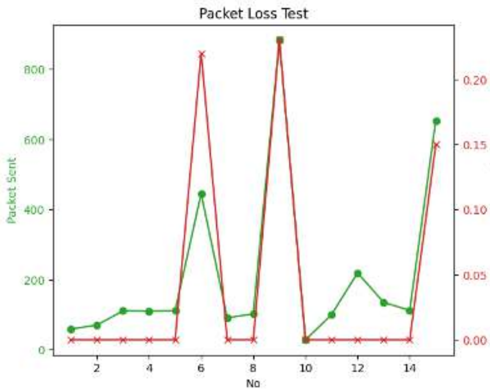

FIGURE 14
Packet Loss Test

In the packet loss test results shown in Figure 13, the designed IoT system demonstrates excellent performance with an average packet loss of 0.04%. Out of 15 tests conducted at various distances, the majority showed no packet loss (0%), while only a few tests exhibited minimal packet loss (0.22%, 0.23%, and 0.15%). With such a low packet loss rate, the system falls into the low degradation category and is assigned an overall index of 9. This indicates that the network is highly reliable with very minimal data loss during transmission, making it suitable for applications requiring high reliability and minimal data loss.

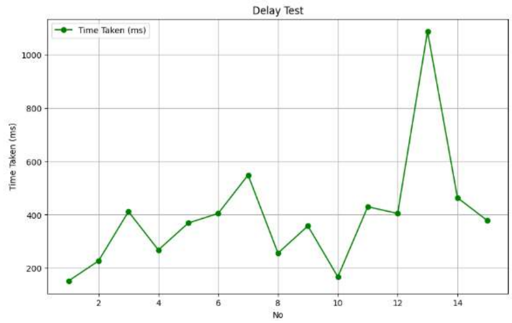

FIGURE 15
Delay Test

Based on the website delay test results shown in Figure 14, the average time difference between recording on the web and the database is approximately 395.2 milliseconds. The spread of this time difference is quite significant, with a minimum value of 152 milliseconds and a maximum value of 1088 milliseconds, resulting in a range of 936 milliseconds. This large variation in time difference indicates inconsistency in the recording times, which could be attributed to various factors such as network latency, server load, or the efficiency of the recording algorithm.

IV. CONCLUSIONS

The system evaluation results generally show satisfactory performance with a few caveats. The lift model demonstrates consistent operational time stability despite varying loads, indicating reliable performance for everyday use. The HC-SR04 ultrasonic sensor shows reasonably accurate vehicle detection, although there is variation in the percentage error depending on the distance between the sensor and the object, highlighting the need for improvements to enhance reliability. Throughput testing shows an average value of 16.26 bytes/s (0.0163 kbps), which is categorized as low with an index of 1, but data transmission stability remains intact. Meanwhile, packet loss testing shows excellent results with an average packet loss of 0.04%, categorized as low degradation with an index of 9, and most tests show no packet loss. Lastly, website delay testing shows an average time difference between web and database recording of approximately 395.2 milliseconds, with a range spread between 152 and 1088 milliseconds.

REFERENCES

[1] "Jakarta Population 2024," World Population Review. Accessed: Jun. 10, 2024. [Online]. Available: https://worldpopulationreview.com/world-cities/jakarta-population

[2] Ulfa Afrieza, "10 Kota Terpadat di Dunia 2023, Jakarta Nomor Berapa?," Kompas.com. Accessed: Dec. 09, 2023. [Online]. Available: https://travel.kompas.com/read/2023/03/06/120600027/10-kota-terpadat-di-dunia-2023-jakarta-nomor-berapa-?page=all

[3] "Luas Daerah Menurut Kabupaten/Kota (Km2), 2020-2022," Badan Pusat Statistik Indonesia. Accessed: Jul. 23, 2024. [Online]. Available: https://jakarta.bps.go.id/indicator/153/38/1/luas-daerah-menurut-kabupatenkota.html

[4] C. BasuMallick, “What Is QoS (Quality of Service)? Meaning, Working, Importance, and Applications,” spicworks. Accessed: May 21, 2024. [Online]. Available: https://www.spiceworks.com/tech/iot/articles/what-is-qos/

[5] Anuj Kumar, “Vehicle Parking Management System using PHP and MySQL.” Accessed: May 03, 2024. [Online]. Available: https://phpgurukul.com/vehicle-parking-management-system-using-php-and-mysql/

[6] S. Datta and M. Aibin, “How to Calculate Packet Time from Latency and Bandwidth,” Baeldung. Accessed: Jul. 19, 2024. [Online]. Available: https://www.baeldung.com/cs/packet-time-latency-bandwidth

[7] P. Prahatama, M. Murti, and D. Darlis, “Single Load Amperemeter berbasis LoRa,” *Telkom University Open Library*, 2022.

[8] I. G. K. P. Wenanda, P. H. Prahatama, M. A. Murti, and D. Rahmawati, “Analysis of LoRa (Long Range) Performance as The Development of Remote Communication for Earthquake Detection Systems in High-rise Buildings,” in *2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE)*, IEEE, Feb. 2023, pp. 313–318. doi: 10.1109/ICCoSITE57641.2023.10127702.