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Design and Development of an Internet of Things (IoT)–Based Parking Lot Monitoring System

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Abstract

The rapid advancement of the Internet of Things (IoT) has enabled the development of smart systems that automate various aspects of urban infrastructure, including parking management. This study aims to design and implement an IoT-based parking lot monitoring system that assists drivers in identifying available parking spaces and locating them accurately within a parking area. The system provides real-time information regarding slot availability through a display installed at the entrance gate. The prototype employs an ESP32 microcontroller, ultrasonic sensors, a PIR (Passive Infrared) sensor, a servo motor, LED indicators, and a buzzer as the main hardware components. The system software was developed using the Arduino IDE for embedded programming and Microsoft Visual Studio (C#) for the desktop monitoring application. System testing demonstrates that the prototype successfully delivers real-time information on parking slot occupancy and overall parking capacity. The proposed system enhances the effectiveness and efficiency of parking management for both operators and users.

Keywords

Monitoring, Internet of Things, ESP32, Smart Parking System

Article History

Received 01 August 2024
Accepted 30 October 2025

How to Cite

Yolanda, T., & Fatoni. (2024). Design and Development of an Internet of Things (IoT)–Based Parking Lot Monitoring System. ***Jurnal Jaringan Komputer dan Keamanan**, 5*(3), 90-97.

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Introduction

Parking management constitutes a critical component of urban transportation infrastructure, particularly in densely populated areas where vehicle congestion and limited land availability frequently become major challenges. Inefficient parking systems not only lead to traffic bottlenecks but also increase fuel consumption, air pollution, and user frustration (Shoup, 2011; Litman, 2013). In office and industrial environments such as PT PLN (Persero) UP3 Ogan Ilir, the availability of well-managed parking facilities is essential to support employee mobility, visitor access, and operational efficiency.

At PT PLN (Persero) UP3 Ogan Ilir, the existing parking system has not yet implemented automated information delivery regarding parking availability. Consequently, vehicle users must manually search for vacant parking spaces, resulting in inefficiency, increased waiting time, and potential congestion within the parking environment. Similar issues have been reported in conventional parking systems in many institutions where the absence of real-time information leads to suboptimal parking utilization and increased operational costs (Geng & Cassandras, 2012; Idris et al., 2019).

To overcome these limitations, a smart parking system capable of providing real-time parking availability information is required. The Internet of Things (IoT) offers a technological foundation for such automation by enabling physical objects to communicate, collect, and exchange data through the internet using wired and wireless connections (Tito Nursyahbani & Munadi, 2021; Atzori, Iera, & Morabito, 2010). Through IoT integration, sensor-based devices can monitor vehicle presence, transmit occupancy data to central servers, and support real-time visualization for users and administrators.

An IoT-based parking monitoring system typically utilizes sensors for vehicle detection and microcontrollers for data processing and transmission. Ultrasonic sensors are widely used due to their accuracy in detecting distance and object presence in parking slots (Al-Turjman, 2019; Wahyudi et al., 2020). Meanwhile, the ESP32 microcontroller has become a popular choice for IoT applications due to its low power consumption, compact size, and integrated Wi-Fi and Bluetooth connectivity (Yulizar & Nugroho, 2021; Kusuma et al., 2020). The combination of ultrasonic sensors and ESP32 enables reliable, real-time parking status detection and data transmission.

Several previous studies have demonstrated that IoT-based smart parking systems significantly improve parking efficiency, reduce search time for parking spaces, and enhance user satisfaction. Research by Khanna and Anand (2016), Rizal et al. (2020), and Pratama et al. (2021) shows that real-time parking information systems can reduce congestion, optimize space utilization, and support better decision-making for both users and operators. These systems also contribute to smart city initiatives by improving transportation efficiency and urban mobility (Batty et al., 2012; Zanella et al., 2014).

Therefore, this study focuses on the design and development of an IoT-based smart parking monitoring prototype at PT PLN (Persero) UP3 Ogan Ilir that provides real-time information to users and supports more efficient parking control. The system utilizes ultrasonic sensors for vehicle detection and an ESP32 microcontroller for data processing and wireless communication. The implementation of this system is expected to enhance parking management efficiency, reduce congestion, and support digital transformation within the organization in line with smart infrastructure development.

Research Method

This study employed an Action Research Method, which emphasizes iterative system improvement through systematic cycles of diagnosing problems, planning actions, implementing solutions, evaluating outcomes, and learning from the results (Nalakhudin, Imron, & Prasetyo, 2021; Putri & Prasetyaningsih, 2020). This method was selected to ensure that the parking monitoring system was developed and refined based on real operational needs.

The stages of the Action Research Method are as follows:

1. Diagnosing – Identifying weaknesses in the existing parking management system.
2. Action Planning – Designing a prototype of the IoT-based parking monitoring system.
3. Action Taking – Implementing the system using hardware and software components.
4. Evaluating – Conducting functional testing of the prototype.
5. Learning – Revising and improving the system based on testing results.

System Architecture

The architecture of the IoT-based parking monitoring system consists of an ESP32 microcontroller connected to multiple sensors and output devices. The PIR sensor detects vehicle movement at the entrance and exit gates and activates the servo motor as a barrier controller. The buzzer provides an audible warning during gate operation. Each parking slot is equipped with an ultrasonic sensor to detect the presence of a vehicle. LED indicators display parking status, where green indicates an occupied slot and yellow indicates an available slot. All sensor data are transmitted wirelessly to a desktop monitoring application via a local network.

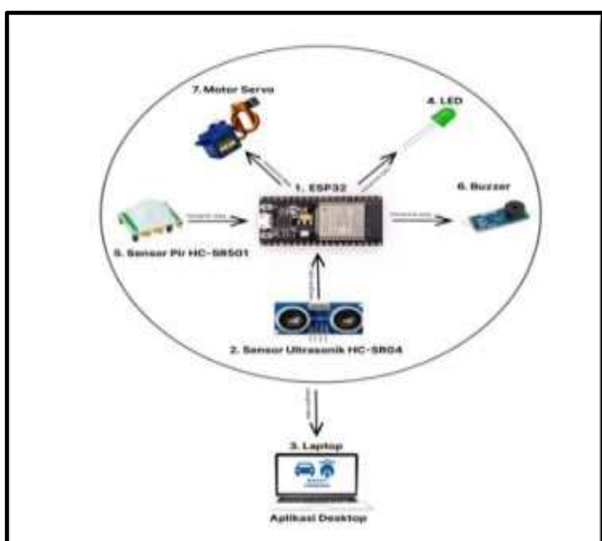

Figure 1. System Diagram

Circuit Schematic

The system utilizes a hybrid network topology combining wired and wireless communication. The ESP32 functions as a client device that sends parking slot data using the User Datagram Protocol (UDP) over a Local Area Network (LAN) to a personal computer, which operates as the monitoring server.

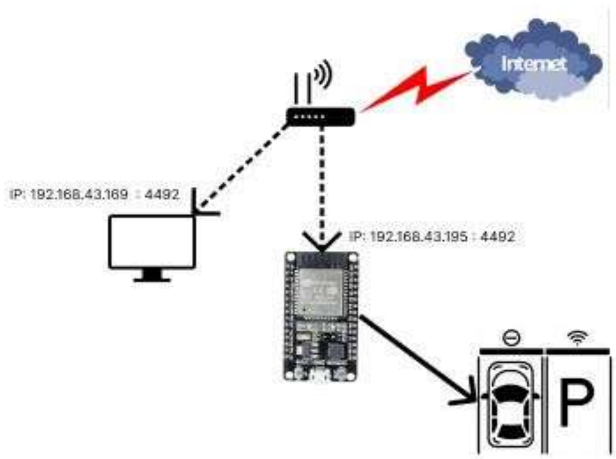

Figure 2. Circuit Schematic

Hardware Implementation

The hardware implementation includes the ESP32 microcontroller, ultrasonic sensors, PIR sensors, a servo motor, buzzer, and LEDs. These components were integrated to form a functional prototype capable of detecting vehicle presence, controlling gate access, and displaying slot availability status.

Software Implementation

The embedded system was programmed using the Arduino IDE, while the desktop monitoring application was developed using Microsoft Visual Studio (C#). The desktop interface displays real-time information regarding parking slot availability in the form of color-coded blocks:

1. Yellow block: Slot available
2. Green block: Slot occupied

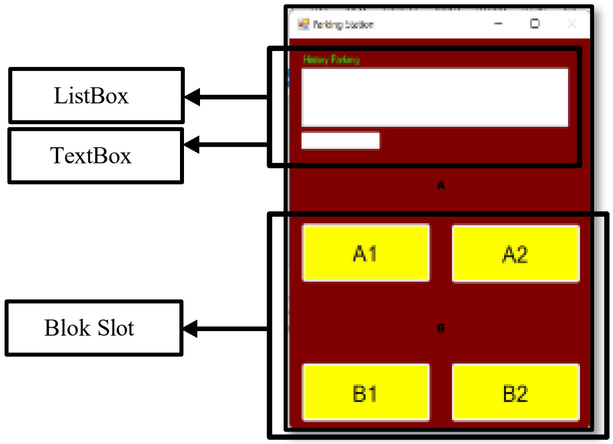

Figure 3. Desktop-Based Application View

Results

System Testing

Functional testing was conducted to evaluate the performance of each system component and the integrated prototype. The test results confirm that the system operates according to the designed specifications and successfully displays real-time parking status.

PIR and Servo Motor Testing

Testing of the PIR sensors and servo motors demonstrated that vehicle movement at the entrance and exit gates was detected accurately. The servo motors opened and closed the barriers automatically, with an average response delay of 5.2 seconds, consistent with the programmed configuration.

Ultrasonic Sensor Testing

Ultrasonic sensor tests conducted on each parking slot confirmed accurate distance measurement and correct detection of vehicle presence. The sensors reliably activated LED indicators and the buzzer based on vehicle entry and exit, with a detection tolerance of less than 5 cm.

ESP32 Connectivity Testing

Network connectivity tests showed that the ESP32 maintained stable Wi-Fi connections across multiple devices and access points. Data transmission was successful for different IP configurations, including 192.168.x.x and 172.20.x.x, indicating strong system reliability and compatibility.

Desktop Application Testing

Compatibility testing indicated that the desktop application functioned correctly on Windows 10 Home and Windows 11 Home operating systems. However, the application did not operate properly on Windows 10 Enterprise 2016 LTSB due to framework limitations.

Discussion

The results demonstrate that the IoT-based parking monitoring system was successfully implemented and functioned as intended at PT PLN (Persero) UP3 Ogan Ilir. The integration of the ESP32 microcontroller, ultrasonic sensors, and PIR sensors enabled precise detection of vehicle presence in each parking slot. Ultrasonic sensors effectively measured the distance between vehicles and the parking area, while PIR sensors enhanced detection accuracy by identifying motion. This combination ensured reliable real-time detection, supporting the core objective of improving parking availability monitoring through IoT technology (Tito Nursyahbani & Munadi, 2021).

The implementation of the UDP protocol for data transmission proved to be effective in achieving low-latency communication between the sensor nodes and the desktop monitoring application. Compared to TCP-based transmission, UDP provided faster data transfer with minimal overhead, which is essential for real-time parking systems where delays can reduce system responsiveness. This confirms that lightweight communication protocols are well suited for smart parking environments that prioritize speed and efficiency in data delivery.

The desktop-based visualization interface significantly improved the accessibility and usability of parking information for both operators and system administrators. By converting raw sensor data into intuitive real-time indicators of parking availability, the system minimizes the need for manual inspection and allows users to quickly identify vacant spaces. This visualization capability directly addresses the inefficiencies observed in the initial condition at PT PLN (Persero) UP3 Ogan Ilir, where users previously had to search for parking spots manually.

From an operational efficiency perspective, the smart parking system reduces congestion within the parking area and shortens vehicle circulation time. Faster identification of vacant spaces not only saves time for employees and visitors but also improves traffic flow within the facility. This finding aligns with previous studies that report smart parking systems as effective tools for reducing internal traffic congestion and optimizing space utilization in institutional environments (Tito Nursyahbani & Munadi, 2021).

In terms of system architecture, the use of ESP32 as the main controller offers significant advantages for future development. Its integrated Wi-Fi and Bluetooth modules, along with low power consumption, make the system scalable and ready for integration with cloud platforms or mobile-based applications. This design flexibility supports future enhancements such as mobile monitoring, cloud-based data storage, and broader integration with smart city infrastructure.

Overall, the successful implementation of this IoT-based smart parking prototype confirms that sensor-based monitoring combined with real-time communication and visualization significantly improves parking management efficiency. The system not only provides accurate real-time parking information but also supports the digital transformation of facility management in line with Industry 4.0 principles. Future development may include mobile application integration, predictive parking analytics, and wider deployment across other PT PLN operational units to further enhance system impact and usability.

Conclusion and Recommendations

The IoT-based parking lot monitoring system prototype developed in this study operates effectively and meets the intended design objectives. The integration of the ESP32 microcontroller, ultrasonic sensors, PIR sensors, servo motor, LED indicators, and buzzer successfully provides automated detection and real-time reporting of parking slot availability.

The desktop-based monitoring application enhances system usability by presenting clear, real-time visualization of parking conditions. The proposed system improves efficiency, convenience, and management effectiveness and may serve as a reference model for the development of large-scale smart parking solutions.

Disclosure Statement

The authors declare that there is no conflict of interest regarding the research, authorship, and publication of this article.

Acknowledgments

The authors would like to express their sincere gratitude to Universitas Bina Darma for technical and academic support, and to PT PLN (Persero) UP3 Ogan Ilir for providing the research location and operational data used in this study.

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Biographical Notes

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