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Article

Prototype Development of IoT-Based Real-Time Smart Parking Monitoring System at Polije's Second Campus in Bondowoso

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Abstract: The increasing number of activities and students at Campus 2 of the State Polytechnic of Jember has led to high vehicle usage, creating pressure on limited parking facilities. Current policies relying on manual verification of Vehicle Registration Certificates (STNK) still result in inefficiencies and security risks due to the lack of automated data recording. This research aims to develop an Internet of Things (IoT)-based Smart Parking System with real-time monitoring to address these challenges. The proposed system integrates RFID for rapid identification, while data is recorded in a real-time database (MySQL with API integration) and displayed through a web-based dashboard. A QR code-based STNK scanning mechanism is also incorporated to strengthen vehicle authentication. Based on the results of trials and implementation, the system is able to run optimally with the RFID sensor reading success rate reaching 100% at a distance of 1–2 cm. The database integration performance shows stable results, with the average data storage time in the database being approximately 3.86 seconds, which is still categorized as real-time. This prototype successfully improves data collection accuracy, enables real-time supervision, and provides statistical insights into parking utilization. In conclusion, the implementation of this IoT-based smart parking system is proven to reduce manual intervention, enhance operational efficiency, and support campus parking management that is more transparent, efficient, and measurable. This innovation contributes to the transition toward a smart campus and supports digital governance at Polije's Second Campus in Bondowoso.

Keywords: Internet of Things, Smart Parking System, RFID Identification, Real-time Monitoring

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1. Introduction

The number of study programs at Polije's (Politeknik Negeri Jember) Second Campus has shown a positive trend year after year. Concurrently, the number of students enrolling and studying at Polije's Second Campus has also increased significantly. This growth not only reflects the institution's success in attracting prospective students but also has a direct impact on increasing daily activity on campus. One of the most striking impacts is the increase in the number of private vehicles, particularly motorcycles, used by students, lecturers, and educational staff for daily mobility.

This density puts pressure on available parking capacity. Space that was previously sufficient to accommodate vehicles is now limited, necessitating a more organized and controlled parking management system. Previously, the parking system relied on paper-based parking cards manually written with markers. However, the new policy eliminates the use of these cards and replaces them with a system where officers check Vehicle Registration Certificates (STNK) upon vehicles leaving the campus area. While simpler, this system does not yet provide an automatic recording mechanism for vehicles entering and exiting, potentially creating security gaps and weak administrative data for parking management.

As a solution to this problem, information technology integration is needed in the form of a Smart Parking System based on the Internet of Things (IoT) with real-time monitoring [1]. Smart parking has been implemented in various contexts, both urban and institutional areas, by utilizing digital sensors to detect vehicle movement [2]. This system can be developed by placing sensors such as RFID or ultrasonic sensors at the entrance and exit gates to automatically record vehicle activity [3].

In addition, the system can be integrated with real-time databases such as MySQL which are connected via API, so that all vehicle activities are recorded digitally and displayed via a web-based monitoring dashboard [4]. This integration will simplify monitoring for officers and provide campus management with statistical data on vehicle volume, peak hours, and land capacity. To improve identification accuracy, the system can be enhanced by scanning STNK using QR codes, minimizing manual processes and enhancing security through official document authentication.

This approach not only addresses the operational needs of the campus, but also supports the principles of digital governance in the smart campus concept which is based on data and technology [5]. With the implementation of this system, parking management at Polije's Second Campus in Bondowoso is expected to be more transparent and accountable, and encourage digital transformation in higher education. Furthermore, this system can serve as a model for other campuses in implementing IoT-based solutions for facility management. The implementation of an integrated system also has the potential to strengthen the academic community's trust in campus management [6]. Furthermore, the data generated from this system can be used as a basis for strategic decision-making related to infrastructure planning and campus transportation policies.

2. Materials and Methods

This research uses a research and development (R&D) approach with a prototyping model, which focuses on the design and implementation of an IoT-based Smart Parking system with real-time monitoring [7]. The research stages are presented in Figure 1.

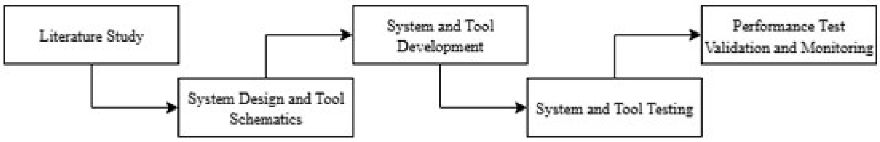

Figure 1. Research Stages

2.1. Literature Study

The research began with a literature review and field observations. The literature review was conducted to obtain a theoretical basis and references for the development of the Smart Parking system, while the field observations were conducted to understand the actual conditions occurring in the parking area of Polije's Second Campus. This activity is expected to produce a relevant literature review report as a basis for system design, and to identify the main problems encountered in the field as indicators of initial research achievements [8].

2.2 System Design and Tool Schematics

At this stage, the system architecture and hardware scheme that will be used are designed [9]. The design includes the parking business process flow, sensor integration, and data flow to the database. A tool schematic is also outlined to ensure each hardware component is connected according to its function [10].

2.3 System and Tool Development

This stage focuses on building the system according to the established design. Hardware, such as sensors, is installed and connected to a microcontroller or IoT module, while software is developed to manage data, store it in a database, and display information via a dashboard [9]. At this stage, systems and tools begin to be integrated so that they can function as a single unit [11].

2.4 System and Tool Testing

Once the system is developed, a testing phase is conducted to ensure all components function as required. Testing is performed on both hardware (sensors, microcontrollers, and communication modules) and software (database and dashboard) [12]. The focus of the test is to evaluate whether the system is capable of automatically recording vehicle data, displaying real-time information, and running stably in field conditions.

2.5 Performance Test Validation and Monitoring

The final stage is validation, namely comparing the system output results with real conditions in the field to assess the level of accuracy and reliability of the system [13]. In addition, performance test monitoring is carried out over a certain period of time to determine the extent to which the system can operate consistently [14]. The results of this validation and monitoring will be the final evaluation material as well as the basis for system improvements in the next stage.

3. Results and Discussion

This section presents the results of the development of a prototype IoT-based smart parking monitoring system. This discussion will present a comprehensive analysis of the prototype's performance, including validation of the functionality of each component and evaluation of its effectiveness in presenting real-time parking information.

3.1. Application Architecture

Application architecture is the fundamental structure that defines how the components of an application are arranged, connected, and interact with each other [15]. This architecture includes not only the software components, but also the relationships between those components, the data that flows within them, and the environment in which the application will operate [16]. The application architecture of the Smart Parking system is presented in Figure 2.

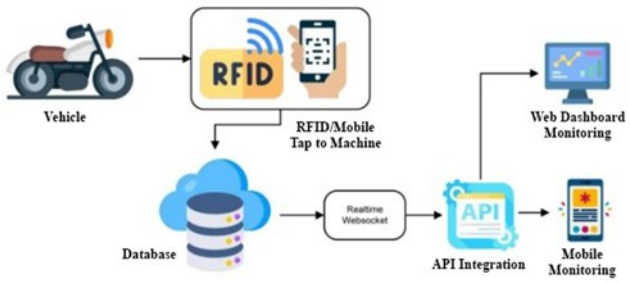

Figure 2. Application Architecture

Figure 2 shows the application architecture of a smart parking monitoring system designed to integrate data from the field to the end user. This system operates automatically through several key interconnected components. The process begins with a vehicle equipped with an RFID or mobile device used to tap a machine (RFID/Mobile Tap to Machine). Each time a vehicle taps, the vehicle's identity data and transaction time are automatically recorded and sent to a database for storage.

Data from the database is then forwarded in real time via websocket, ensuring a fast and seamless information transfer process. The transmitted information is then processed by API Integration, which serves as a link between the data storage system and the user interface. From this API integration, data can be displayed on two main platforms: Web Dashboard Monitoring, which managers use to monitor overall parking activity via computer, and Mobile Monitoring, which allows users or field officers to monitor parking information directly via mobile devices. This architecture ensures that the parking system operates efficiently, is integrated, and can be accessed in real time by various stakeholders.

3.2 Tool Schematic

IoT schematic is a diagram that visualizes the overall IoT system architecture [17]. This diagram serves as a blueprint that shows how the various components of the hardware are connected and interact to form a system [18]. The schematic of the tool in the Smart Parking system is presented in Figure 3.

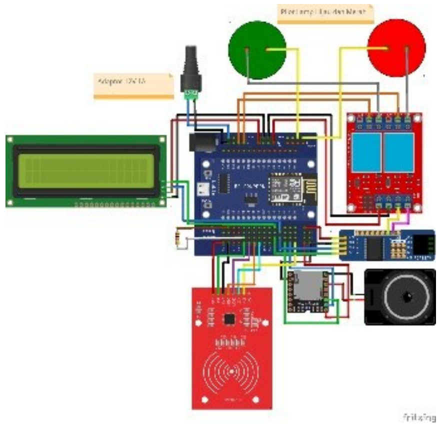

Figure 3. Tool Schematic Smart Parking

Based on Figure 3, the schematic circuit shows an integrated RFID-based parking system, with the NodeMCU V3 ESP8266 as the main controller. When an RFID tag is detected by the RC522 RFID module, the ID data will be sent to the NodeMCU. The microcontroller then processes this information to provide various responses. The tag status will be displayed on a 16x2 LCD and Green/Red Pilot Light, while the DFPlayer Mini and Speaker will provide audio notifications. In addition, a relay module is also connected to control other devices such as the parking barrier. The entire system is powered by a 12V 1A adapter whose voltage is adjusted to suit the needs of the components.

3.3 Prototype Design Results

The prototype design for the IoT Smart Parking product is the result of a systematic process to design and build an initial model of an Internet of Things (IoT)-based smart parking system. The prototype design results for the Smart Parking system are presented in Figure 4.

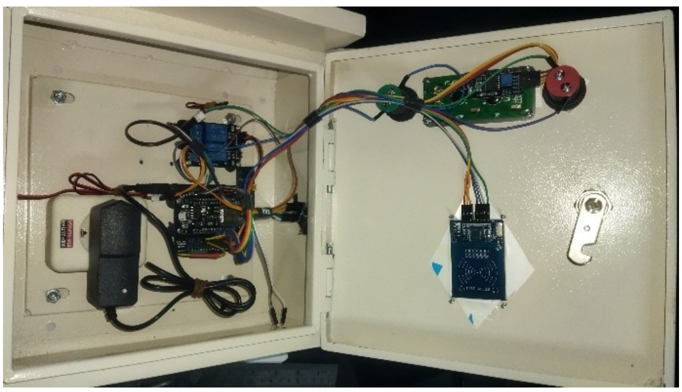

Figure 4. Prototype Design Results

Once the prototype assembly is complete, the next step is to integrate all components into a system enclosure or box to protect the device from external factors. The results of the prototype box installation in the Smart Parking system are shown in Figure 5.

Figure 5. Box Prototipe

This process is critical to ensure the system can function stably and safely in a real operational environment.

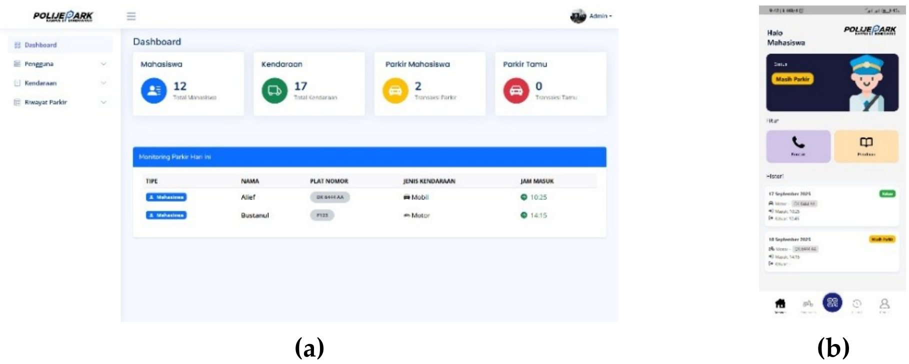

Figure 6. Consists of 2 images which are displays of the system dashboard page. **(a)** This is a website dashboard display real-time parking space availability, details of ongoing parking transactions (such as name, license plate number, vehicle type, and entry time), and a summary of key statistics (such as the total number of registered users and vehicles). **(b)** This is a mobile application dashboard display allows users (administrative staff) to monitor and manage parking activities remotely via a browser or smartphone, ensuring high operational efficiency and data accountability.

3.4 Test Results

The IoT-based Smart Parking testing phase is a systematic process to verify and validate whether a prototype or final product functions as designed and meets all functional requirements. The testing conducted in this study involved RFID sensitivity testing. RFID sensor sensitivity testing was conducted to determine the maximum card reading distance, allowing the system to correctly read and verify the card. The test results are presented in Table 1.

Table 1. RFID Sensor Sensitivity Test Results

Distance (cm)	Test Results	Number of Trials	Information
1	Succeed	5	Responsive

2	Succeed	5	Responsive
3	Fail	5	Can Not Be Read
4	Fail	5	Can Not Be Read
5	Fail	5	Can Not Be Read

Further testing, integrating the system and database, was conducted to ensure that the data read by the sensor could be displayed in real time on the LCD and properly stored in the database. Testing was conducted with the RFID card at a distance of 1 cm from the device. The test results are presented in Table 2.

Table 2. System and Database Integration Test Results

Th Test	Data Read Time on LCD (seconds)	Data Stored Time in Database (seconds)
1	1,1	3,3
2	1,1	3,7
3	1,3	4,2
4	1,2	3,8
5	1,1	4,3
Average	1,16	3,86

Data read on the LCD is generally faster because it's processed directly by the microcontroller without any additional communication. Meanwhile, storing data into the database takes slightly longer because it involves IoT communication processes, such as sending data over a WiFi network or HTTP requests, which adds to the delay before the data is actually saved to the server.

4. Conclusions

Based on the results of the trial and implementation, the IoT-based smart parking system at Polije's Second Campus in Bondowoso can run well according to the design. The RFID sensor shows optimal sensitivity with a 100% reading success rate at a distance of 1–2 cm, starting to become unreadable at a distance of 3–5 cm. The system integration with the database also shows stable performance, where the average time for data to be read on the LCD is 1.16 seconds, while the average time for data to be stored in the database is 3.86 seconds. This difference is normal due to the communication process through the IoT network, but the results are still in the real-time category. These findings prove that the system has been able to provide parking information quickly and accurately and support campus parking management in a more transparent, efficient, and measurable manner.

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