Design of a Smart Motorcycle Parking System based on Wireless Sensor Network (WSN) in a Multilevel Building at Universitas Pendidikan Indonesia

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

The growing number of motorcycles parked at the UPI Motorcycle Parking Building, coupled with inadequate management and supervision by parking attendants, has led to issues such as vehicle congestion and haphazard parking within the parking area. Apart from being inefficient in terms of time and fuel consumption, these problems also increase the potential for accidents. This research aims to develop a prototype parking system using RFID-based Wireless Sensor Network (WSN) for the multi-story motorcycle parking building at UPI. The research method employed in this study is experimentation, where automatic parking gates equipped with RFID readers are installed at the entrance and exit of the main parking gate and on each floor. Additionally, ultrasonic sensors are placed along the vehicle passageways to detect any obstacles and communicate the information through the ESP32 Microcontroller utilizing Wi-Fi connectivity. Through the conducted experiments, the system effectively monitors motorcycle parking by providing information about available parking spaces on each floor, identifying unauthorized parking, and detecting obstacles along the ramp pathway, all of which are accessible through a website. Moreover, the system also imposes a fine tariff for motorcyclists who engage in unauthorized parking as a penalty to deter illicit parking behaviors within the parking area.

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Keywords: Smart Parking System; WSN; Motorcycle; Multilevel; RFID.

1. Introduction

The presence of a smart parking system aims to address the issue of parking space scarcity and its management utilizing technology [1]. This is due to the increasing population, which has led to a rise in transportation modes for human mobility [2]. According to the Central Statistics Agency (BPS), data for 2021 shows that motorcycles are the most widely used transportation mode in Indonesia, with a total of 121,209,304 riders [3]. Imam Muladi (2022) states that motorcycles are the preferred transportation mode among students compared to other modes of transportation [4]. Therefore, motor vehicle parking facilities at each university should be able to support motorcycle-riding students effectively and comfortably [5].

The high number of motorcycle-riding students, coupled with insufficient parking attendants' supervision, results in disorganized parking conditions, increasing the potential for accidents [5]. One such instance occurs in the UPI motorcycle parking area. Observations revealed several motorcycles parked improperly, such as in the pathway area shown in **Fig. 1**. Hence, the implementation of a smart parking system that utilizes technology is necessary to improve efficiency during the parking process and address the issue of unauthorized parking.

Fig. 1. Example case of unauthorized motorcycle parking at UPI

Various studies on the design of smart parking systems have been conducted. Agarwal et al. (2021) developed an IoT-based smart parking system for cars using RFID and IR (Infrared) Obstacle Sensors, which allowed parking reservation, real-time availability of parking slots, and mobile app-based payment [6]. Similarly, Sabber Ahmed et al. (2019) proposed a smart parking system design integrated with a blockchain- based architecture to enhance data security and accommodate large-scale service providers [7]. Additionally, Asaduzzaman et al. (2015) created a smart parking system for multi-story buildings utilizing infrared sensors and Zigbee communication protocol, connected through Wi-Fi and Bluetooth. The system displayed information on available parking spaces accessible via a mobile app and successfully reduced vehicle fuel consumption by 50% compared to Wi-Fi-only systems [8]. However, these studies primarily focused on displaying parking availability, reservations, and were more applicable to car parking. In contrast, the issue of unauthorized motorcycle parking in parking buildings remains unresolved.

Therefore, this research aims to develop a smart motorcycle parking system based on Wireless Sensor Network (WSN) for the multi-story building at UPI. The system will utilize RFID to store user data and provide real-time information on available parking slots. Additionally, the system will identify motorcycle riders who park in unauthorized areas within the parking facility and detect any obstructions along the parking pathways. To deter unauthorized parking, the system will impose a penalty in the form of a total tariff that must be paid by motorcycle riders who park improperly within the parking area.

2. Methods

2.1. Schematic Project

The overall system design is implemented on a PCB (Printed Circuit Board). The system is designed for 6 parking gates, utilizing 3 ESP32 microcontrollers. The circuit diagram of the system can be seen in **Fig. 2.**

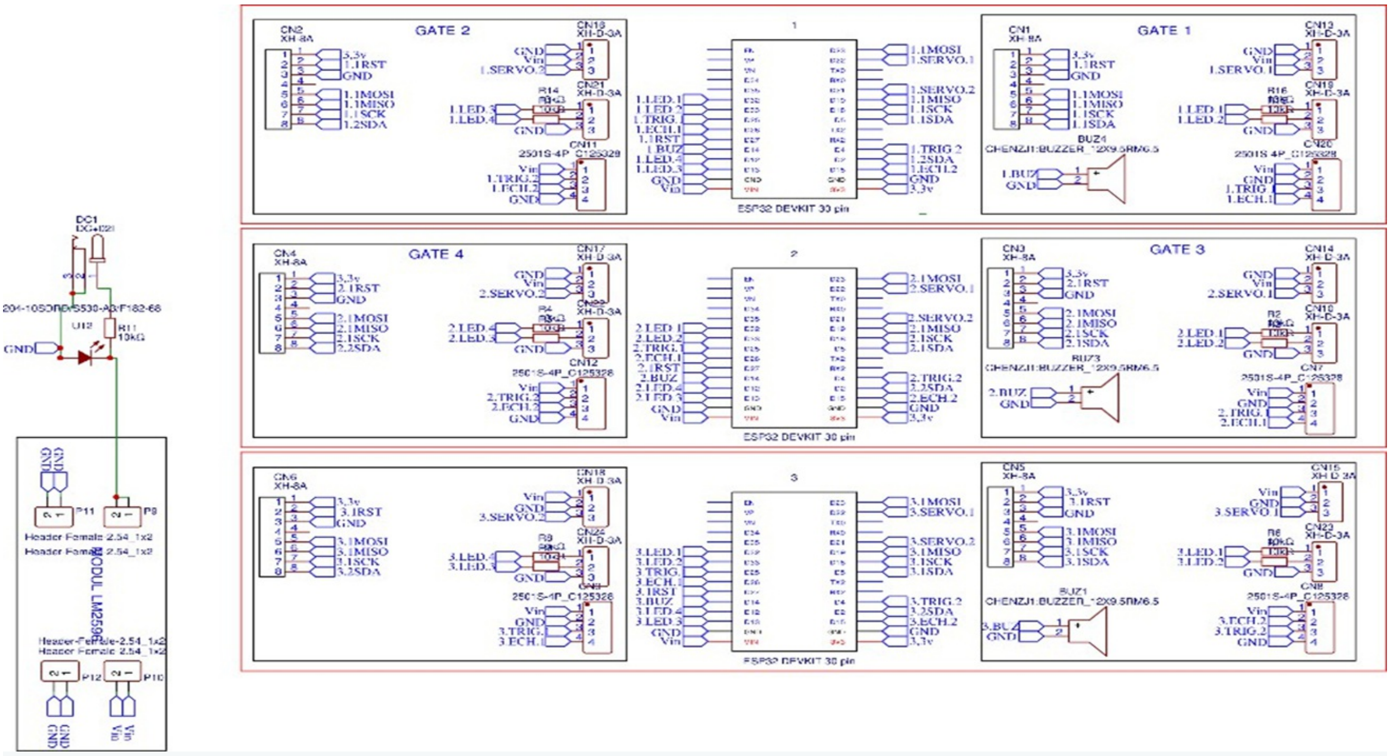


Fig. 2. Schematic of System

2.2. Work Principle

The system's working principle is illustrated by the block diagram shown in**Fig. 3.** The system design in this block diagram will be present at each parking gate, including the main entrance and each floor's gates, both for the entrance and exit doors. Each floor will have 1 ESP32 installed for 2 parking gate systems and 2 obstacle identification systems, except for the main entrance, which will only have 1 ESP without obstacle identification for the pathway. The block diagram explains that RFID Reader is used for ID identification, and HC-SR04 is used for obstacle identification. The system's output consists of DC Servo Motors, LEDs, and a Buzzer. Sensor data will be processed by ESP32 and displayed on the website.

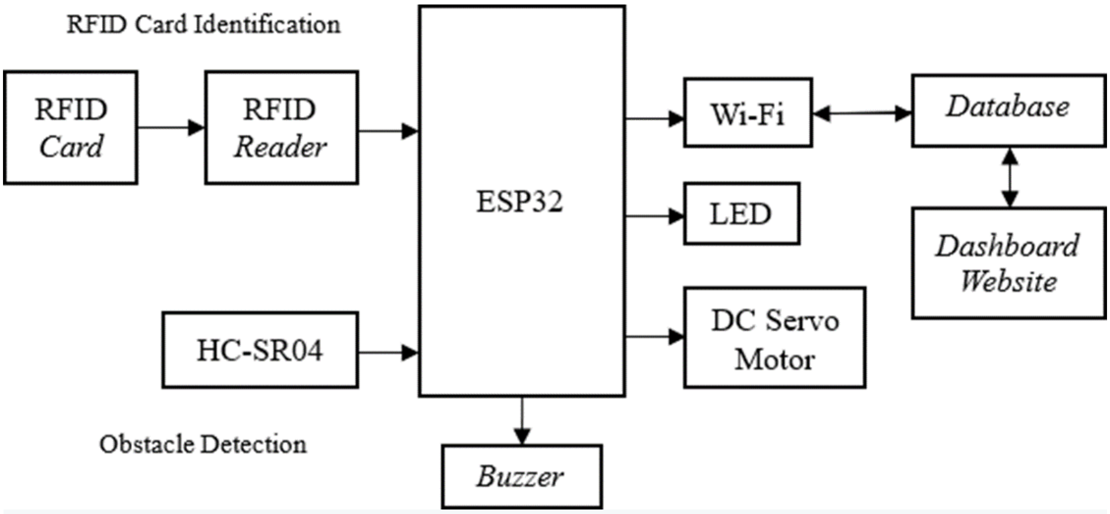


Fig. 3. Work principle of system

2.3. Algorithm

2.3.1. Rider Data Input

The algorithm for inputting rider data into the RFID card and the database is illustrated by the block diagram in **Fig. 4.**

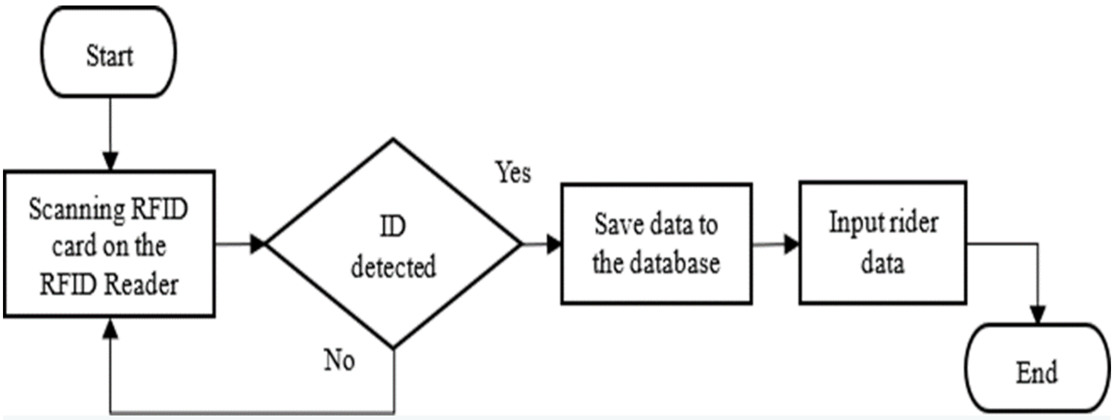


Fig. 4. Algorithm for rider data input

2.3.2. Overall Parking System Algorithm

The algorithm for the entire parking system processing is illustrated by the block diagram in **Fig. 5.**

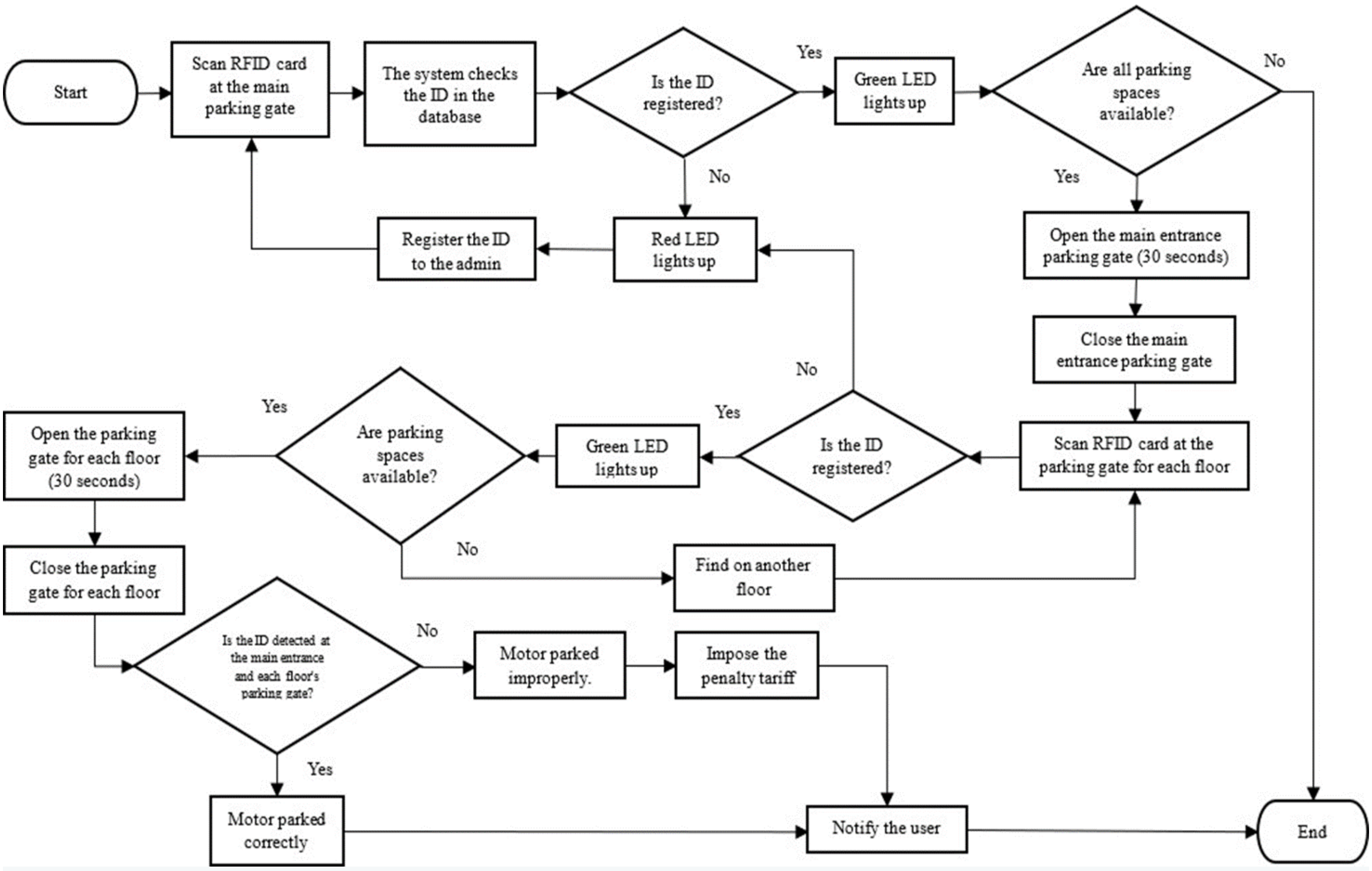


Fig. 5. Overall parking system algorithm

2.3.3. Algorithm for Obstacle Warning on the Pathway

The algorithm for obstacle warning on the pathway is illustrated by the block diagram in**Fig. 6.**

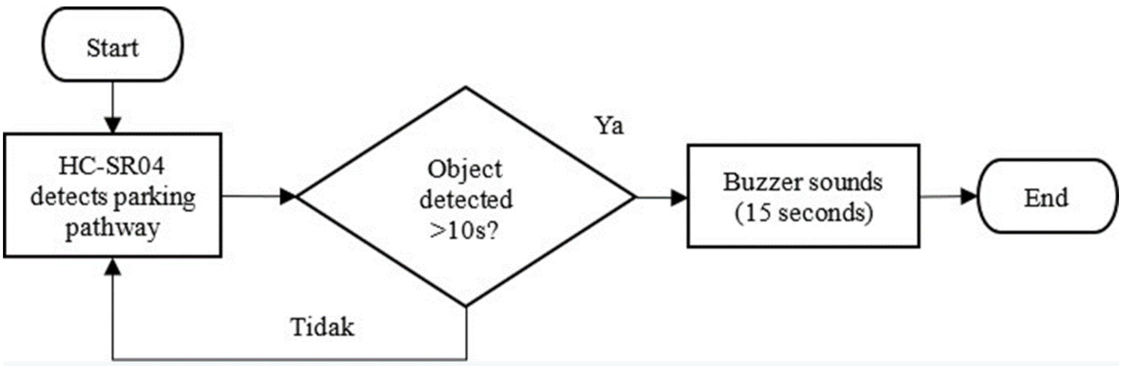


Fig. 6. Algorithm for obstacle warning on the pathway

2.4. Hardware Aspect

2.4.1. ESP32

The ESP32 is an affordable System-on-Chip (SoC) with low power consumption. It comes equipped with various integrated components such as built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power management module [9]. As a web server for real-time applications, ESP32 utilizes the Wi-Fi module supporting IEEE 802.11b/g/n, with data transfer rates up to 150 Mbps. Additionally, this microcontroller incorporates Bluetooth 4.2 and Bluetooth Low Energy (BLE) protocols. ESP32 is highly regarded for its strong and efficient Radio Frequency (RF) capabilities, making it particularly beneficial in power-sensitive scenarios [10].

2.4.2. RFID. (Radio Frequency Identification)

RFID consists of two main devices, namely the reader and the tag. The RFID tag or transponder (transmitter-responder) can store data information about an object. The tag contains an antenna integrated with a silicon microchip. The transmission and reception of radio frequency (RF) signals between the tag and reader are carried out by the antennas. The RFID reader, also known as an interrogator, requests information from the tag through radio waves and then interprets the data [11].

2.4.3. HC-SR04

This sensor serves to detect the distance of an object by utilizing sonar technology. It is capable of detecting distances within the range of 2 cm to 400 cm without direct contact. The sensor consists of a transmitter and a receiver module. The ultrasonic waves emitted by the sensor operate in the air at a frequency of 40,000 Hz [12].

2.4.4. LED (Light Emitting Diode)

LED is one type of diode made of a semiconductor material that can produce light when forward voltage is applied. The light emitted by LEDs is monochromatic and incoherent, meaning it has a narrow frequency spectrum. LEDs are made of a semiconductor compound comprising Aluminum-Gallium-Arsenide (AlGaAs) [13].

2.4.5. Buzzer

The buzzer can convert the incoming electric current into mechanical vibrations on a diaphragm or resonant element, thus producing sound vibrations. Buzzers are commonly used for sound indication or alarm systems. Piezoelectric buzzer is one of the most widely used types. This type can produce sound frequencies ranging from 1 kHz to 6 kHz up to 100 kHz [14].

2.4.6. DC Servo Motor

A DC motor consists of a series of gears, a control circuit, and a potentiometer. The DC Servo motor can work in two directions, namely clockwise and counterclockwise. The direction and rotation of the rotor or angle are controlled by varying the width of the Pulse Width Modulation (PWM) signal on the control pin [15].

2.5. Software Aspect

2.5.1. Arduino IDE

The Arduino IDE consists of three parts: the program editor, compiler, and uploader. The program editor allows users to edit and write programs in the Processing language. The compiler functions to convert the program code into binary code. To upload this binary code to the microcontroller, it can be done through the uploader [16].

2.5.2. VS Code (Visual Studio Code)

VS Code is a lightweight and reliable text editor developed by Microsoft, which can be used on various operating systems, including Linux, Mac, and Windows. VS Code supports programming languages such as JavaScript, Typescript, and Node.js, as well as other languages through plugins available on the VS Code marketplace (such as C++, C#, Python, Go, Java, and others). Features like Intellisense, Git Integration, Debugging, and extensions, along with other developments, make the text editor more robust. Additionally, as an open-source project, developers can view and contribute to the VS Code source code on GitHub [17].

2.5.3. PHP (Hypertext Preprocessor)

PHP is a programming language used to build dynamic websites. This allows PHP to interact with databases, files, and folders, enabling the website's content to change compared to static HTML. PHP is referred to as server-side scripting, meaning the script is processed on the server-side [18] [19].

2.5.4. MySQL (My Structured Query Languange)

MySQL is a popular open-source and multi-threaded Database Management System (DBMS). It utilizes the SQL query language [18]. MySQL is a relational database server, and this type of database can be accessed by PHP[20].

2.5.5. Bootstrap

Bootstrap is a front-end framework that serves as a tool to create responsive and mobile- friendly websites. It is built using HTML, CSS, and JavaScript. Bootstrap offers various features, including typography, forms, buttons, tables, navigation, modals, image carousels, and many others. Additionally, there are plugins available that enhance the user interface and make it more appealing [21].

3. Experimental Result

The system is designed for a 2-floor parking lot and consists of 6 gates. These six parking gates consist of 2 main entrance and exit gates, 2 entrance and exit gates for the first floor, and 2 entrance and exit gates for the second floor. The main parking gates are located at the front of the parking building. The system is then installed on a miniature model, as shown in **Fig. 7.**

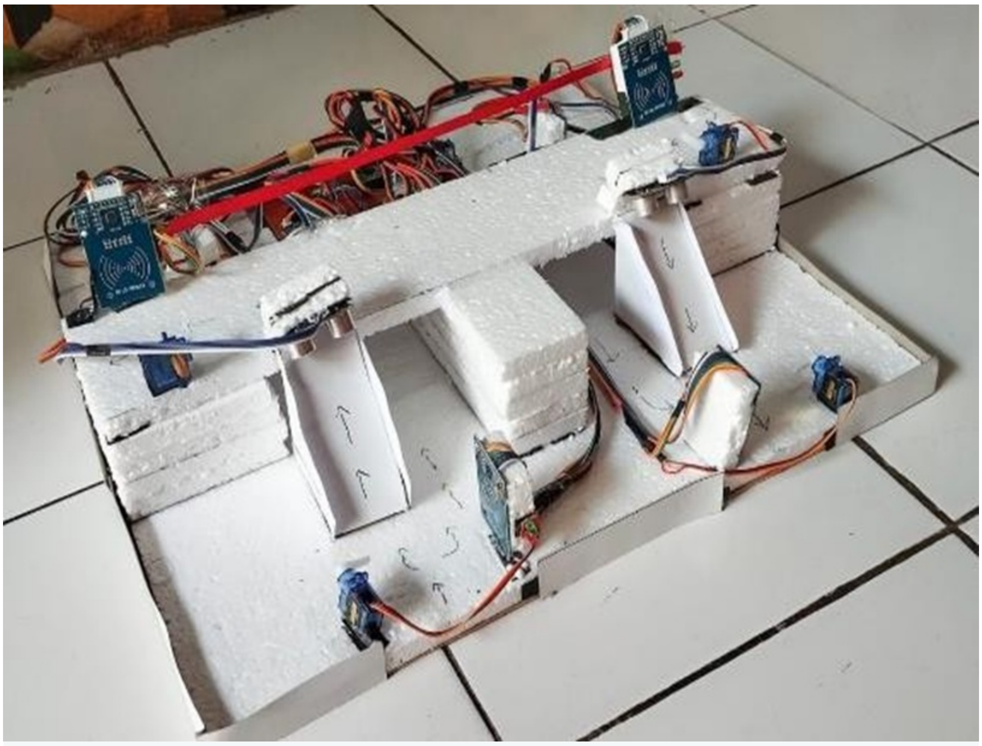


Fig. 7. Miniature system

3.1. System Website

This smart motorcycle parking system has a website accessible to two entities (roles): Admin (parking attendants) and User (students). The role of the Admin is to manage parking spaces and register user IDs in the database. On the other hand, Users, whether students or the public, can only view the available parking spaces on each floor along with the list of motorcycle riders. The website pages accessible by the Admin can be seen in **Fig. 8** and **Fig. 9**. Meanwhile, the website pages accessible by all entities can be seen in **Fig. 10**.

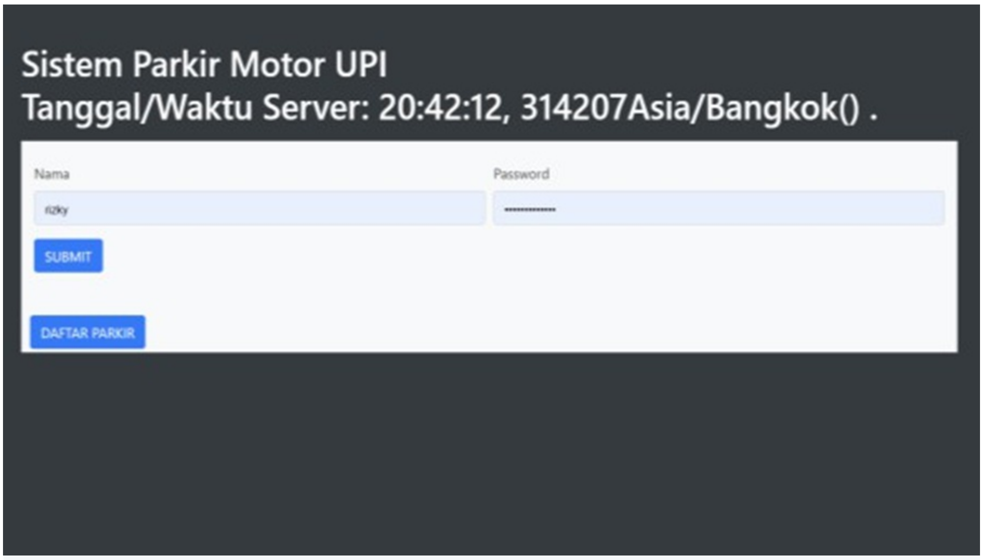


Fig. 8. Admin LOGIN page

Fig. 9. Rider data entry page

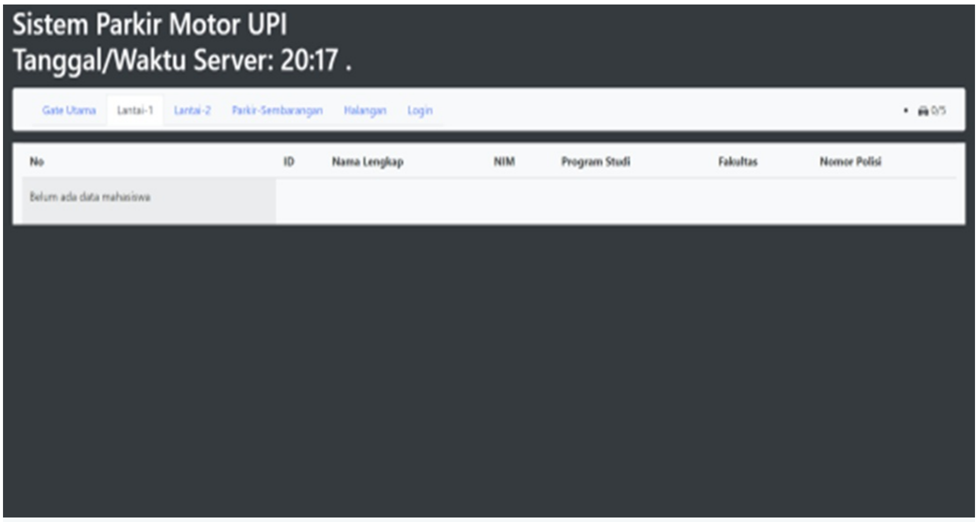


Fig. 10. System website page

3.2. Overall System Testing Result

3.2.1. Unregistered ID Testing Result

When the Reader reads a card and finds that the ID is not registered in the database, the red LED lights up, and the parking gate remains closed, as shown in **Fig. 11**.

Fig. 11. Unregistered ID testing result

3.2.2. Correct Parking Testing Results

The testing mechanism was performed by tapping the RFID card with a registered ID on the Reader at the main entrance and the entrance of the desired floor. After tapping, the green LED lights up, and the parking gate opens both at the main entrance and the floor entrance, as shown in **Fig. 12**, **Fig. 13**, and **Fig. 14**. Information about the motorcycle riders parked on each floor is displayed on the website, visible in **Fig. 15** and **Fig. 16**. This applies to both the entry and exit parking processes, where the data will change in real-time based on the parked vehicles. If the parking capacity is full, the red LED lights up, and the parking gate will not open.

Fig. 12. Result for registered ID at the main gate

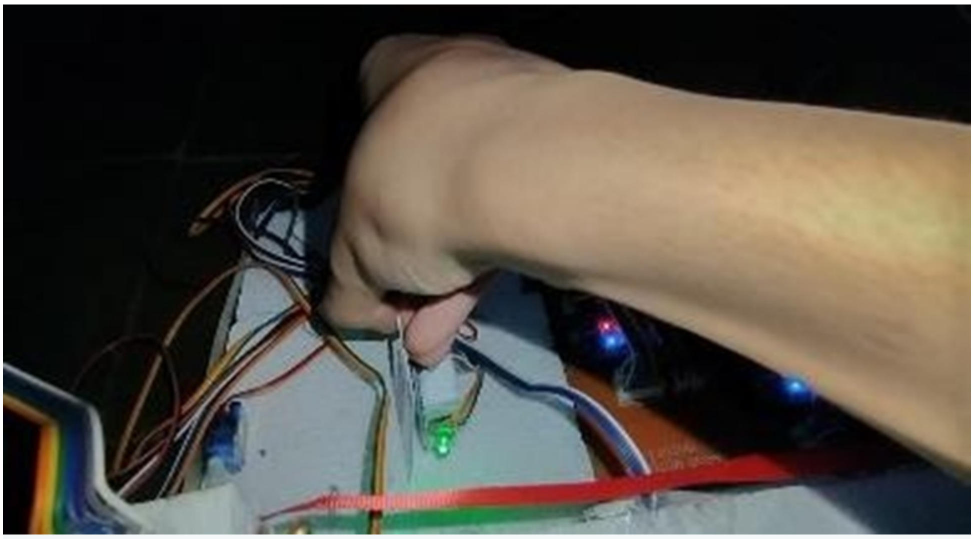


Fig. 13. Result for registered ID at the floor 1 gate

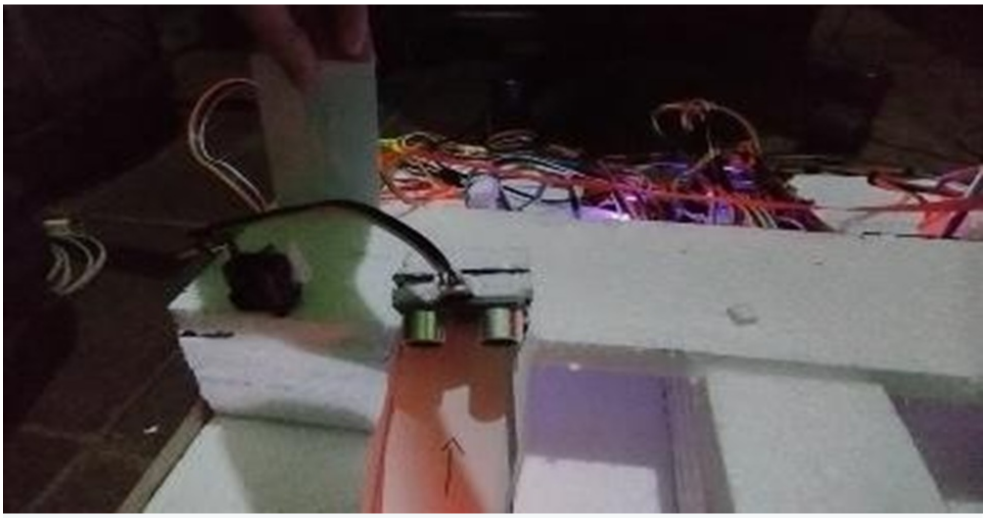
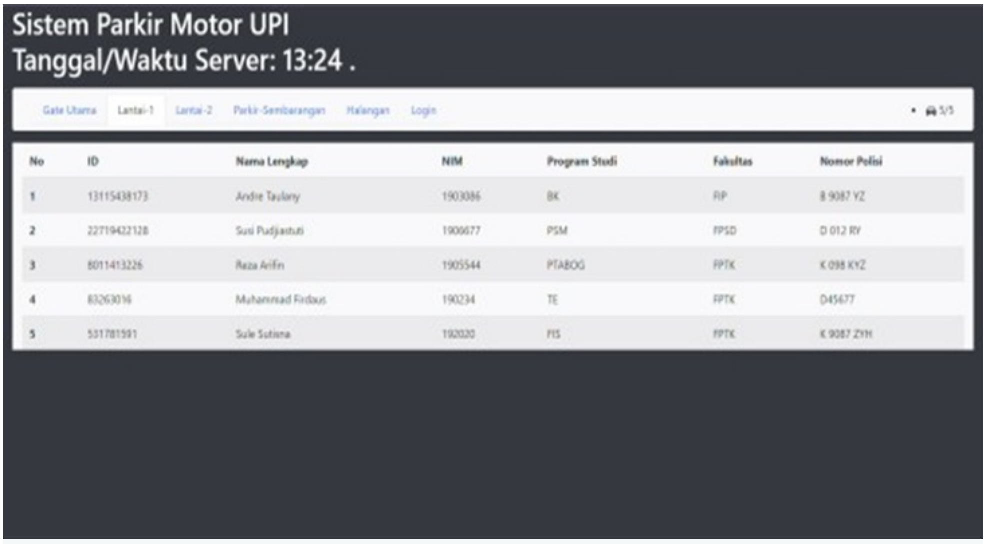


Fig. 14. Result for registered ID at the floor 2 gate.

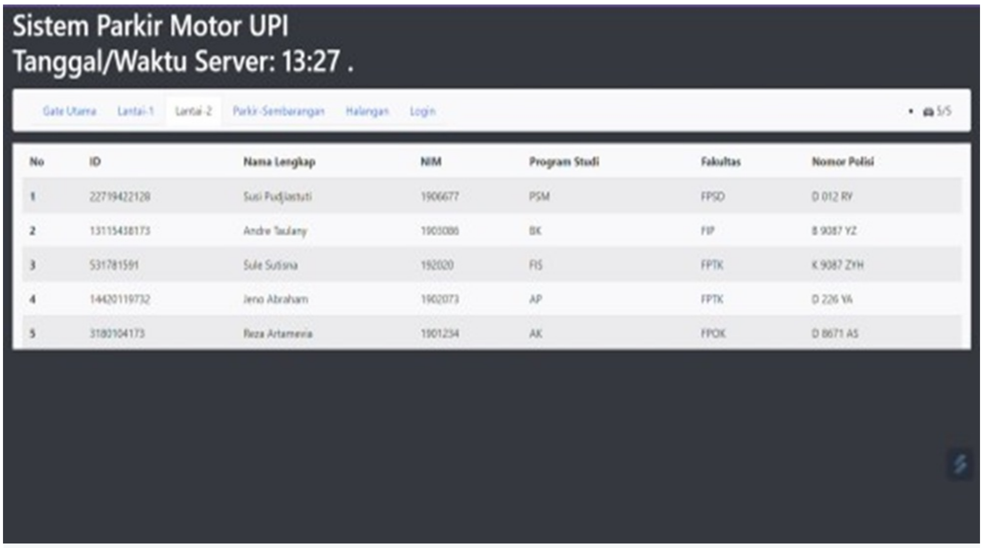


Sistem Parkir Motor UPI
Tanggal/Waktu Server: 13:24 .

Gate Utama | Lantai-1 | Lantai-2 | Parkir-Sembarangan | Halangan | Login • 5/5

No	ID	Nama Lengkap	NIM	Program Studi	Fakultas	Nomor Polisi
1	13115438173	Andre Taulany	1903086	BK	FIP	B 9087 YZ
2	22719422128	Susi Pudjiastuti	1906677	PSM	FPSD	D 012 RY
3	8011413226	Raza Arifin	1905544	PTABOG	FPTK	K 098 KYZ
4	83263016	Muhammad Firdaus	190234	TE	FPTK	D45677
5	531781591	Sule Sutisna	192020	FIS	FPTK	K 9087 ZYH

Fig. 15. Floor 1 web page



Sistem Parkir Motor UPI
Tanggal/Waktu Server: 13:27 .

Gate Utama | Lantai-1 | Lantai-2 | Parkir-Sembarangan | Halangan | Login • 5/5

No	ID	Nama Lengkap	NIM	Program Studi	Fakultas	Nomor Polisi
1	22719422128	Susi Pudjiastuti	1906677	PSM	FPSD	D 012 RY
2	13115438173	Andre Taulany	1903086	BK	FIP	B 9087 YZ
3	531781591	Sule Sutisna	192020	FIS	FPTK	K 9087 ZYH
4	14420119732	Jeno Abraham	1902073	AP	FPTK	D 226 YA
5	3180104173	Reza Artamevia	1901234	AK	FPOK	D 8671 AS

Fig. 16. Floor 2 web page

The website can also display the overall history of riders when they enter and exit the parking area, as shown in **Fig. 17** and **Fig. 18**. This page can only be accessed by parking attendants. On the website, the date and time of each motorcycle rider's entry and exit from the parking area are visible.

History Masuk

No	ID	Nama Lengkap	NIM	Program Studi	Fakultas	Nomor Polisi	Waktu
36	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:40:19
41	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:47:04
42	531781591	Sule Sutisna	192020	FIS	FPTK	K 9087 ZYH	2023-07-15 14:47:13
43	22719422125	Susi Pudjiastuti	1906677	PSM	FPSD	D 012 RY	2023-07-15 14:47:17
44	14420119732	Jeno Abraham	1902073	AP	FPTK	D 226 YA	2023-07-15 14:47:23
45	13115438173	Andre Taulany	1903086	BK	FIP	B 9087 YZ	2023-07-15 14:49:14
46	8011413226	Reza Arfin	1905544	PTABOG	FPTK	K 090 KYZ	2023-07-15 14:49:21
47	83263016	Muhammad Firdaus	190234	TE	FPTK	D45677	2023-07-15 14:49:29

Fig. 17. Rider parking entrance history

History Keluar

No	ID	Nama Lengkap	NIM	Program Studi	Fakultas	Nomor Polisi	Waktu
35	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:40:13
37	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:40:28
38	13115438173	Andre Taulany	1903086	BK	FIP	B 9087 YZ	2023-07-15 14:40:37
39	13115438173	Andre Taulany	1903086	BK	FIP	B 9087 YZ	2023-07-15 14:46:22
40	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:46:38
48	3180104173	Reza Artamevia	1901234	AK	FPCK	D 8671 AS	2023-07-15 14:52:08
49	531781591	Sule Sutisna	192020	FIS	FPTK	K 9087 ZYH	2023-07-15 14:52:18
50	22719422125	Susi Pudjiastuti	1906677	PSM	FPSD	D 012 RY	2023-07-15 14:52:25

Fig. 18. Rider parking exit history

3.2.3. Unauthorized Parking Testing Results

The testing mechanism was conducted by tapping the RFID card on the Reader at the main gate only. This indicates that after motorcycles pass through the main gate, they do not park in the designated areas on each floor. As a result, the drivers will be listed in the random parking violators' list displayed on the website, along with the corresponding penalty rates as shown in **Fig. 19**.

Fig. 19. Unauthorized parking page

3.2.4. Obstacle Presence Testing Results

The testing mechanism involved placing an object on the incline track area of the parking lot within 3 cm from the HCSR-04 sensor for a duration of 10 seconds. This action triggers the Buzzer to sound for 15 seconds as a warning. The testing results are also displayed on the website, as shown in **Fig. 20**.

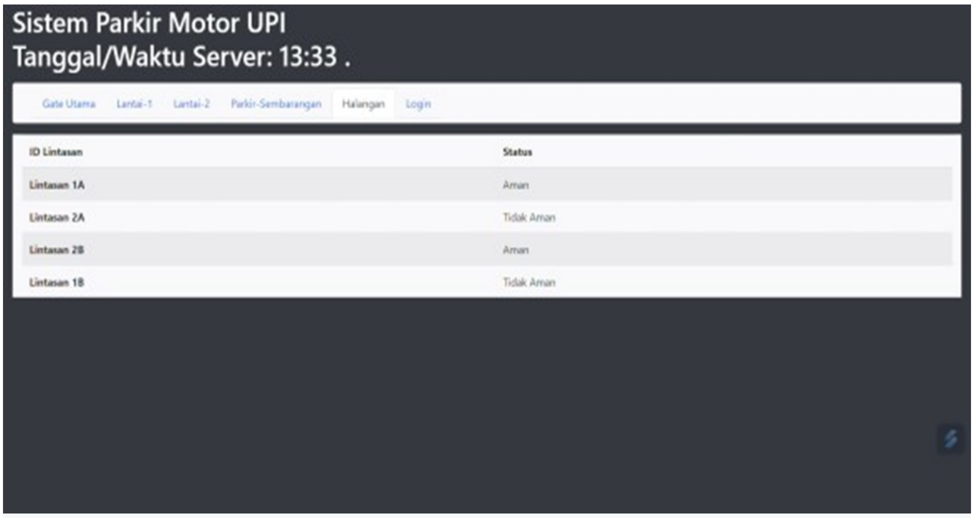


Fig. 20. Parking lot obstacle page

3.3. Data Communication between ESP32 and Web Server

By using HTTP requests through communication using HTTP GET, the ESP32 microcontroller can send data to the web server API via query "gate=" and so on. After the data is sent via HTTP GET, the PHP web server will receive the data. Subsequently, the received data will be forwarded to the database, and the commands sent to the database depend on the situation and conditions, for example, entry and exit gates with responses in the form of HTTP echo.

4. Conclusion

Based on the results of the conducted research, it can be concluded that the smart parking system can be connected to a website to display real-time information about available parking spaces on each floor, drivers who engage in random parking, and the presence of obstacles on the incline track area.

Acknowledgments

The author expresses gratitude to the Department of Electrical Engineering Education at Universitas Pendidikan Indonesia for the support provided throughout this research.

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