IMPLEMENTATION OF AN IOT-BASED LABORATORY DOOR ACCESS CONTROL SYSTEM USING AN ESP32 MICROCONTROLLER

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ABSTRACT

Computer laboratories in universities require a reliable security system because they store high-value equipment. The use of conventional physical keys is considered ineffective due to the risk of loss, duplication, and limited real-time monitoring. This research develops an Internet of Things (IoT)-based laboratory door security system using an ESP32 microcontroller, a reed switch sensor as a door status detector, a solenoid door lock as an automatic lock, and a web interface as a control and monitoring medium. The system was designed through stages of literature study, hardware and software design, and prototype implementation. This system is integrated with a room reservation feature, so that door access is only granted to users with valid and active reservations. Verification is carried out automatically through a database and sent to the ESP32 to unlock the door. The test results show that the system is able to function properly, providing automatic access control and displaying the door status in real time. This system is considered effective as a modern laboratory door security solution in higher education environments.

***Keywords**: ESP32, Reed Switch, Solenoid Door Lock, Internet of Things, Computer Laboratory*

1. INTRODUCTION

Computer laboratories in higher education institutions are vital facilities that support learning, research, and information technology development activities. They house various important equipment such as computers, networking devices, inventory, documents, and high-value research equipment [1]. The high intensity of laboratory use by students and lecturers has created a need for a more stringent and modern security system. [2]. The door security system commonly used is still conventional, namely using physical keys. This approach has several weaknesses, including that it is easy to duplicate, lose, or manipulate by unauthorized parties [3]. In addition, the absence of a real-time monitoring and access control system makes laboratories vulnerable to security breaches and misuse of facilities [4].

However, most of the research and implementation of IoT-based door security systems that have been developed currently focus on simple door opening and closing mechanisms, without any integration with room usage management systems. As a result, access control does not fully consider the legality of laboratory use based on schedules or official loans. Therefore, this study aims to develop an IoT-based laboratory door security system that is not only capable of real-time door monitoring and control, but also integrated with a web-based access management system. This system is expected to improve security, laboratory management efficiency, and prevent unauthorized use of facilities [5]. The Internet of Things (IoT) is an innovative solution that enables the integration of physical devices and information systems through the internet [6]. Microcontrollers such as the ESP32 provide Wi-Fi connectivity and sufficient processing power to build distributed automation systems [7]. Through the use of HTTP (Hypertext Transfer Protocol)-based communication protocols, the system can receive access commands and send status information directly between the ESP32 and the web server [8].

In this study, an IoT-based door security system was designed using ESP32, a solenoid door lock, and a magnetic reed switch that can control and monitor the door status through a web interface [9]. Magnetic reed switches are used as door position sensors to detect whether the door is open or closed [10]. When users access the website to open or close the door, instructions are sent to the ESP32 via HTTP or MQTT requests. Next, the ESP32 controls the solenoid lock via a relay module, which functions as an electronic switch to regulate the flow of current to the door lock actuator [11]. This system not only enables online access control, but also displays door status in real time via a web interface.

2. LITERATURE REVIEW

2.1. Internet of Things

The Internet of Things (IoT) is a technology that enables various physical devices to connect, communicate, and exchange data via the internet without direct human interaction [12]. The concept of IoT is widely applied in various fields, such as smart homes, smart cities, healthcare, industry, and security systems. With its ability to integrate sensors, actuators, and information systems, IoT enables real-time remote monitoring and control of devices. In the context of security systems, IoT plays an important role in providing access control mechanisms that are more flexible, secure, and centralized than conventional systems [13].

2.2. Door Access Control System

A door access control system is a security mechanism used to regulate who is authorized to access a particular room or area [14]. This system aims to protect assets, data, and facilities from unauthorized access. In modern implementations, access control systems have evolved from the use of physical keys to electronic systems based on sensors and microcontrollers. The use of IoT-based access control systems enables dynamic access rights management, user activity logging, and real-time door status monitoring via the internet [15].

2.3. Mikrokontroller ESP32

ESP32 is a low-cost microcontroller developed by Espressif Systems and equipped with integrated Wi-Fi and Bluetooth modules [16]. This microcontroller has fairly high processing capabilities, relatively low power consumption, and supports various communication interfaces, such as GPIO, UART, SPI, and I2C. Thanks to its built-in connectivity features, the ESP32 is widely used in IoT system development, including security systems, home automation, and remote monitoring. In door access control systems, the ESP32 functions as the main controller that receives commands from the server and controls the door lock hardware.

Figure 1. Mikrokontroller ESP32

2.4. Selenoid Door Lock

Figure 2. Selenoid door lock

A solenoid door lock is an electromagnetic actuator used as an automatic door lock [17]. The working principle of a solenoid is based on the magnetic field generated when electric current flows through the coil, producing a pulling force to move the locking mechanism. Solenoid door locks are commonly used in electronic security systems because they can be electrically controlled and integrated with microcontrollers. Under normal conditions, the solenoid will be in the locked position, and will open when it receives an active signal from the control system.

2.5. Magnetic Reed Switch

A magnetic reed switch is a magnetic sensor used to detect whether an object, such as a door or window, is open or closed [18]. This sensor works based on changes in the magnetic field that cause the internal contacts to connect or disconnect. Reed switches are widely used in security systems because they have a simple structure, low power consumption, and a high level of reliability. In door access control systems, reed switches function as door status detectors. The detected status is then sent to the system and displayed in real time.

Figure 3. Magnetic reed switch

2.6. Website-Based Monitoring and Control

The web-based monitoring and control system allows users to access, control, and monitor devices remotely via a browser without the need to install additional applications [19]. The integration of IoT systems with web interfaces facilitates data management, device status visualization, and rapid decision-making. In laboratory door security systems, web interfaces serve as a control medium for opening or locking doors and displaying door status in real time based on data received from microcontrollers.

3. METHODOLOGY

This research uses the prototype method, a system development approach that emphasizes the creation of an initial model (prototype) to be visualized, implemented, and evaluated in stages before being fully utilized [20]. This method allows researchers and users to assess the system directly and provide feedback for improvement. The stages in this research include: (1) data collection, (2) system analysis and design, (3) system development, and (4) evaluation.

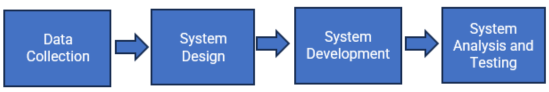

Figure 4. Research Methodology

3.1. Data Collection

The data was obtained through a literature study by reviewing various scientific sources such as national journals, reference books, and technical articles relevant to Internet of Things (IoT) technology, automatic door security systems, ESP32 microcontrollers, and data communication based on HTTP or MQTT protocols. In addition, a study was also conducted on the use of relay modules as actuators in microcontroller-based electronic device control systems. This study aims to establish a strong theoretical and technical foundation as a reference for system design and development [21].

3.2. System Design

The system design stage begins with developing the overall structure of the device based on the functional requirements of the laboratory door security system. The design includes determining the position and connections between key components such as the ESP32 microcontroller as the control center, the solenoid door lock as the electronic lock, the magnetic reed switch as the door position sensor, the relay module as the actuator current controller, and the 12V adapter as the main power source. On the software side, the web interface is designed to be able to send and receive data directly through HTTP (Hypertext Transfer Protocol)-based or MQTT (Message Queuing Telemetry Transport) communication integration. The system is designed so that all components can work in coordination to ensure security and ease of remote operation of the laboratory door [22].

3.3. System Development

This stage is the implementation of the designed system. The ESP32 is configured and connected to all necessary electronic components. The web system is developed as a user interface to send open or close door commands online via MQTT or HTTP requests, as well as to display the door status in real-time based on signals from the magnetic reed switch sensor. Commands from the web are processed by the ESP32 to activate or deactivate the solenoid door lock via a relay module. The integration between hardware and software is carried out in the form of a prototype that resembles the real conditions of use for a laboratory door [23].

3.4. System Analysis and Testing

This stage aims to thoroughly analyze and test the performance of the Internet of Things (IoT)-based door security system. The analysis is conducted to ensure that all components, both hardware and software, are properly integrated and comply with specifications. System testing covers the ESP32 as the main controller, a solenoid door lock activated via a relay module as an actuator, and a magnetic reed switch as a door status sensor. In addition, verification is performed on the connectivity and reliability of HTTP or MQTT communication in delivering commands and feedback in real time via a web interface [24].

3.5. Flowchart

Flowcharts are used to illustrate the overall workflow of the system, starting from the device initialization process, connection to the Wi-Fi network, to monitoring the door status using a magnetic reed switch. This flowchart also shows the process of receiving commands from the web interface via HTTP or MQTT, controlling the solenoid door lock via a relay module, and sending the door status to the web in real-time. Flowcharts help visualize program logic so that it is easier to understand and implement.

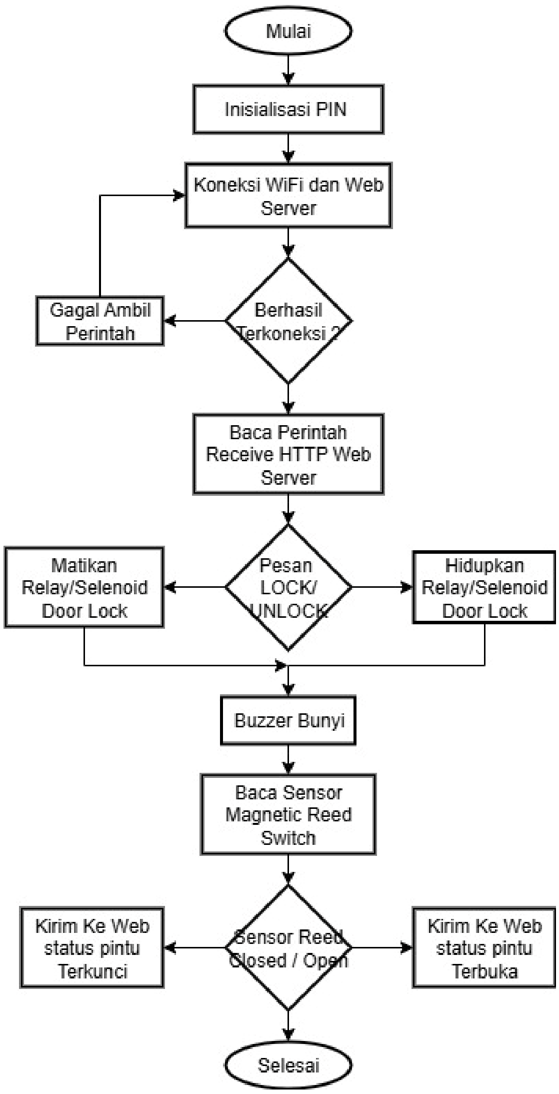

Figure 5. Flowchart Sistem

The flowchart in Figure 5 shows the workflow of an IoT-based automatic door control system using ESP32, relays, and magnetic reed switch sensors that communicate with a web server via a Wi-Fi network using the HTTP or MQTT protocol. The process begins with the initialization of input and output pins on the ESP32, then the system connects to the Wi-Fi network and web server. If the connection fails, the system will repeat the connection process until a connection is established.

Once connected, the ESP32 reads control commands from the web server via HTTP or MQTT. Before processing the command, the system validates the room reservation to ensure that the user has access rights and an active reservation schedule. If validation fails, the command is rejected and the door remains locked. If validation is successful, the system processes the LOCK or UNLOCK command. The LOCK command deactivates the relay so that the solenoid door lock is locked, while the UNLOCK command activates the relay to unlock the door. The buzzer is then activated as a local notification.

Next, the ESP32 reads the door status via a reed switch sensor and sends it (open or closed) for real-time display on the dashboard and storage in the database. Although the flowchart ends with a Finish symbol, the system runs repeatedly (looping) to continuously monitor the door status and respond to commands while the system is active.

4. RESULTS AND DISCUSSION

4.1. Design Result

The design phase is a crucial part of the system development process, where user requirements are translated into structured technical specifications. The results of this design will serve as the basis for the system implementation[25].

4.2. Architectural Design

This section describes the representation of the system architecture developed in this study. The security door system architecture design is illustrated in Figure 6 below.

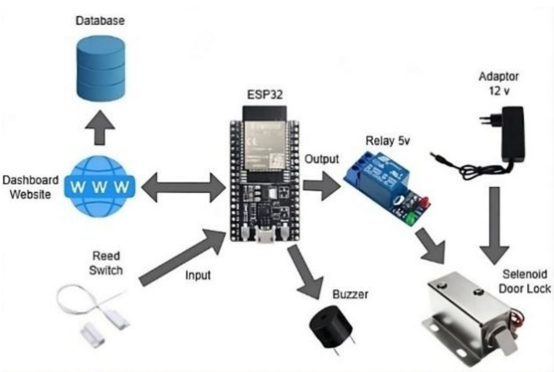

Figure 6. Door Security System Architectural Design

In the system shown in Figure 6, the control and monitoring process of the automatic door is carried out using an ESP32 microcontroller integrated with several supporting components. When the door condition changes, the magnetic reed switch sensor installed on the door frame and door leaf detects changes in the magnetic field caused by its movement. The signal generated by the reed switch is then sent to the ESP32 as a digital input.

After receiving the signal from the sensor, the ESP32 performs two main functions. First, the ESP32 activates a buzzer as an audible indicator to provide an immediate local warning that the door is open. Second, the ESP32 sends door status to a web-based dashboard via a Wi-Fi connection using the HTTP or MQTT protocol. This door status is displayed in real-time on the web interface and stored in a database for administrative recording and long-term monitoring purposes.

In addition to sending data, the ESP32 also receives control commands from the website dashboard. When the user gives a command to open the door through the web interface, the ESP32 activates the single-channel relay module connected to it. The relay module acts as an electronic switch that channels 12V from an adapter to the door lock solenoid. When the relay is active, the solenoid receives an electric current supply, causing the door lock mechanism to open automatically. This system is designed so that the entire process, from door status detection, to automatic locking / unlocking, to internet monitoring, can run efficiently and in real time.

4.3. Hardware Design

The hardware design describes the configuration and arrangement of electronic components used in the development of this door security system. All components are integrated to form a single system, as shown in Figure 6. This circuit is designed to support the system's functionality optimally in accordance with the research objectives.

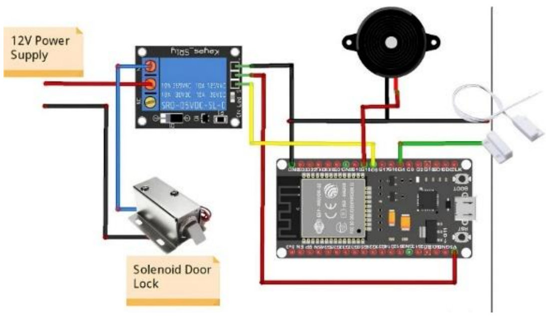

Figure 7. Circuit Schematic

The hardware design of this system aims to control electric door locks (solenoid door locks) and monitor door status in real-time via an internet connection using the HTTP or MQTT protocol. All components are integrated and controlled by the ESP32 Dev Module as the control center.

The following are the main components and connections between devices:

a. ESP32 Dev Module as the main microcontroller with Wi-Fi connectivity. As the brain of the system, ESP32 connects the device to the Wi-Fi network. It reads the status of the reed switch and controls the relay and buzzer, sends door status data (open/close) to the web interface, and receives unlock commands via HTTP from the web server.
b. Reed Switch (Magnetic Door Sensor) to detect the door status (open or closed). It is closed when the magnet sticks to the reed switch and open when the magnet moves away. It provides a digital logic signal to the ESP32 (HIGH/LOW).
c. The Active Buzzer provides an audible alert when the door is open or closed. The 1-Channel Relay functions as an electronic switch, connecting or disconnecting the power supply to the solenoid door lock, and is controlled by the ESP32 digital pin.
d. Solenoid Door Lock (Electric Door Lock) is an electronically controlled door lock. The lock mechanism opens when 12V voltage is applied through a relay. When the relay is ON, the door can be opened, and when the relay is OFF, the door will return to the locked position again.
e. 12V DC adapter Supplies power to the solenoid lock via a relay. It is power source for the solenoid lock. It should not be connected directly to the ESP32 due to differences in operating voltage.

The device connection scheme in this system is designed to ensure stable and secure communication and control between components. The connection circuit between the ESP32 and supporting components is described as follows.
Device Connection Scheme

a. Reed Switch:
   - One cable is connected to pin D4 (GPIO4) of the ESP32.
   - The other cable is connected to the GND pin of the ESP32.
b. Active Buzzer
   - The positive cable (red) is connected to pin D18 (GPIO18) of the ESP32.
   - The negative wire (black) to the ESP32's GND.
c. 1 - Channel Relay
   - IN → pin D5 (GPIO5) ESP32.
   - VCC → 3V3 ESP32.
   - GND → GND ESP32.
   - NO (Normally Open) → one of the solenoid lock wires.
   - COM → positive terminal of the 12V power supply.
   - Negative terminal of the power supply → black wire of the solenoid lock.
d. Solenoid Door Lock:
   - Connected to the NO terminal on the relay and the negative terminal of the 12V power supply.
   - Only active when the relay connects current from COM to NO.
e. 12V Power Supply Adapter: Provides power to the solenoid lock via the relay. Not directly connected to the ESP32.
f. ESP32Dev Module: Powered via a USB cable from a computer or adapter.

4.4. Website Interface Implementation

The website interface was developed as the primary interface for integrated monitoring, management, and access control of laboratory doors within the IoT system. This website serves as an interface between users and ESP32 devices, as well as a room rental management system that grants door access only to authorized users during the scheduled rental time. The website interface is designed to be informative, responsive, and capable of displaying real-time system conditions.

4.5. Main System Dashboard

The main dashboard displays a summary of the overall system status, including the total number of rooms, rented rooms, available rooms, and locked rooms. This information is displayed as summary cards so that users can quickly view the real-time operational status of the laboratory. The dashboard also features a main navigation menu with Room Rental, Attendance, Add Room, and Logout, making it easy for users to access system features according to their access rights.

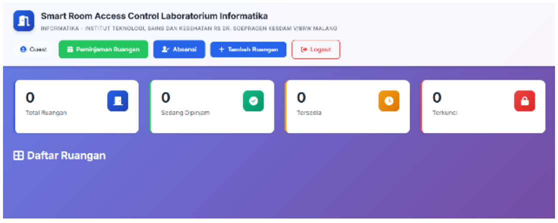

Figure 8. Main Dashboard

4.6. Room Data Management Feature

The system provides an Add Room feature that allows administrators to add new room data to the system. The data entered includes the room name, room code, location, capacity, and supporting facilities. Once the data is saved, the room information will be immediately integrated into the dashboard and available for use in the rental process and door access control. This feature facilitates centralized laboratory management and reduces dependence on manual recording.

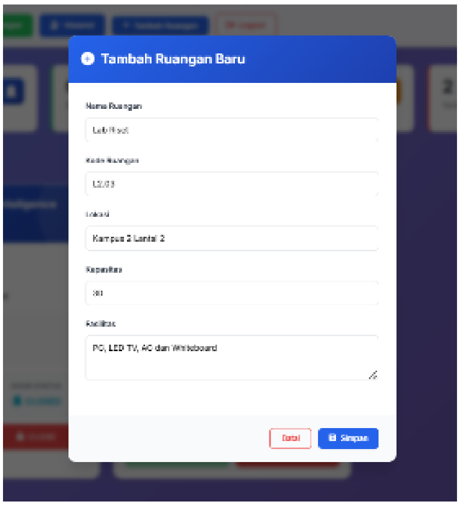

Figure 9. Room Management

4.7. Room List Display and Real-time Status

In the Room List section, the system displays all laboratory rooms as information cards. Each card contains room details such as name, code, location, capacity, and facilities, as well as room availability status. In addition, the Key Status and Door Status obtained in real-time from the ESP32 device are displayed. Users can see whether the door is locked or unlocked and whether it is physically closed or open based on the reed switch sensor.

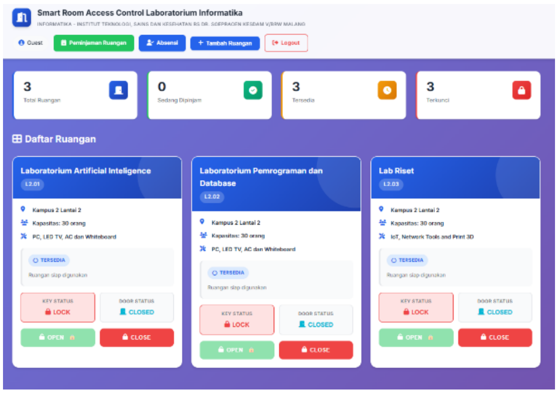

Figure 10. Room list display

4.8. Web-Based Door Access Control

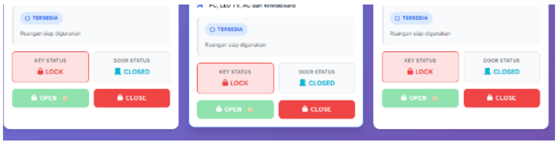
Figure 11. Access Control

The website interface provides OPEN and CLOSE buttons to control door access remotely. However, this control cannot be done freely. The system implements a room rental validation mechanism. The door opening button is only enabled if the room is currently rented and the rental has been approved. If the room has not been rented or the rental is not yet active, the system will maintain the door in the LOCK position. This mechanism enhances security and ensures that door access is only granted to authorized users.

4.9. Room Rental System

The website provides a Room Rental Form page that allows users to request a room rental online. The data entered includes the room selection, the rental purpose, the number of participants, the date, and the start and end times for room usage. After the request is submitted, the rental data will be stored in the database awaiting admin approval. The system automatically records the user's rental history so that every room usage activity is well documented.

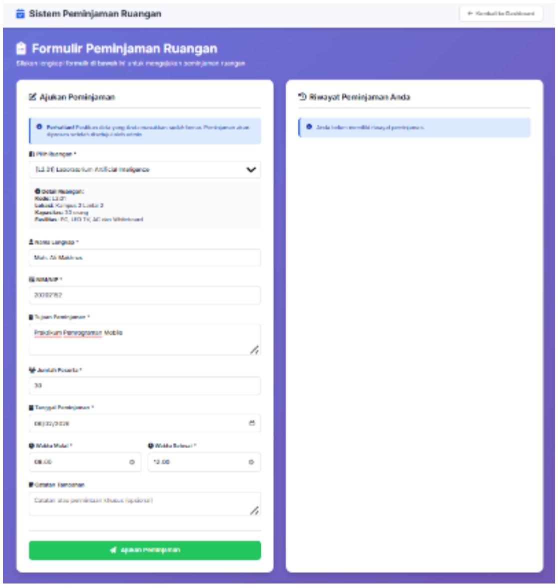

Figure 12. Room Reservation System

4.10. Schedule Validation and Integration with Door Control

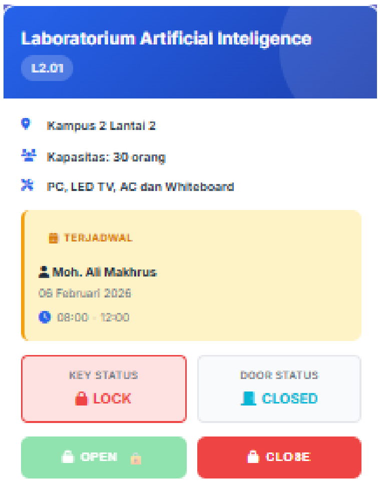

Figure 13. Validation and Integration

When a reservation has been approved and the rental period starts, the room status will change to currently reserved. In this state, the system enables door control via the web interface and allows UNLOCK commands to be sent to the ESP32. The integration between rental data and the door control system ensures that physical access to the laboratory is only possible according to the predetermined schedule, thereby minimizing potential misuse of the facility.

4.11. Monitoring and Activity History

All rental activities and door statuses are recorded and displayed in the rental history. This information includes the user's name, the room used, the date, and the time of use. This feature allows laboratory managers can monitor room usage in a transparent and structured manner.

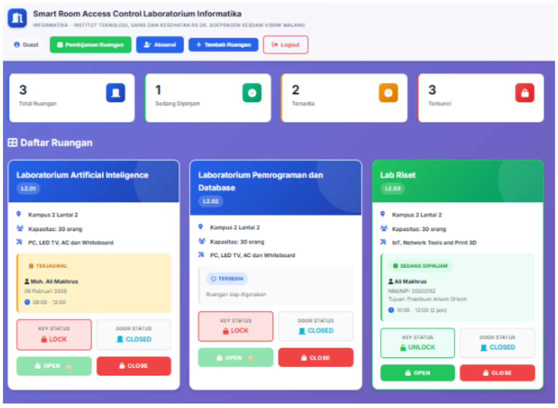

Figure 14. Monitoring and Activity History

4.12. Overall Implementation of Tools

The device is designed to be integrated directly into the door structure. In this system, a swing door made of a combination of wood and glass serves as the test object. The main devices, namely the ESP32, relay module, and buzzer, are assembled in a protective box (enclosure) and installed at the top of the door frame to protect the circuit and facilitate installation management.

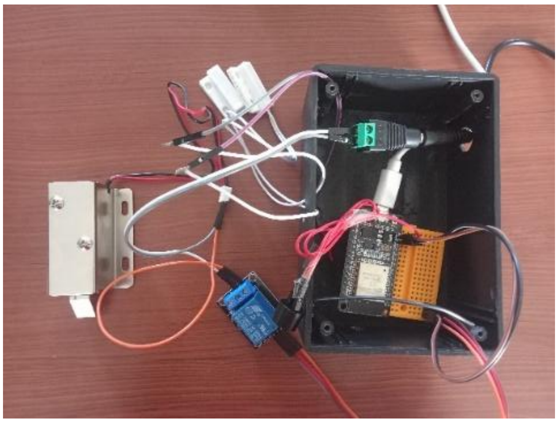
Figure 15. Series Before Installation

The solenoid door lock is permanently installed on the upper door frame and connected to the relay module, with a 12V adapter as a power source. The reed switch sensor is installed with the sensor and the magnet on the door leaf and frame respectively, so that it can accurately detect whether the door is closed or open. The placement of the enclosure adjacent to the solenoid also considers the ease of maintenance and reconfiguration of the device. Figure 15 shows the prototype circuit before it is installed on the door.

Figure 16 shows the implementation of the system on the door, where all devices have been properly installed and integrated, making the system ready for IoT based automatic door control.


Figure 16. Series After Installation

4.13. Analysis and Testing

System testing is conducted to ensure that all components and key functions of the IoT-based laboratory door access control system meet the design requirements. This system is designed to support an integrated laboratory door control process, ranging from door status detection, electronic door locking and unlocking, local notifications, to remote monitoring and control via a web interface using the HTTP and MQTT protocol. Testing was conducted in stages on each system component, as shown in Table 1, to ensure that each device functions as expected and supports the overall performance of the system.

Tabel 1. Device Test Result

No.	Components	Expected Functionality	Test Results
1	ESP32	Connect to Wi-Fi and can send/receive data	Successful (✓)
2	Reed Switch	Detects changes in door position and sends signals to ESP32	Successful (✓)
3	Buzzer	Provides an audible warning when the door is open	Successful (✓)
4	1 Channel Relay	Connecr current to the solenoid when commanded via the web	Successful (✓)
5	Selecoid Door Loack	Open the door automatically when receiving electrical current	Successful (✓)
6	Website	Sends commands and display door status in real-time	Successful (✓)

Based on the test results, it can be concluded that all system components work as expected. The ESP32 successfully connected to the Wi-Fi network and conducted two-way communication with the web interface using the HTTP request–response or Publish-Subscribe MQTT mechanism. The reed switch sensor was able to successfully detect the door status, while the buzzer served as a local notification when the door opening command was executed. The relay module can be controlled via the web to activate the solenoid to lock/unlock the door, allowing the door to be accessed electronically.

In addition, the web interface is capable of displaying the door status in real-time and sending remote control commands, which can only be executed when the user has completed the room booking process. These results indicate that the integration between hardware, software, and the room rental system functions correctly and supports the effective implementation of an IoT-based laboratory door access control system.

5. CONCLUSION AND RECOMMENDATIONS

This study successfully designed and implemented an Internet of Things (IoT)-based laboratory door access control system using the ESP32 microcontroller. The proposed system is capable of controlling and monitoring laboratory doors automatically and in real time through an internet connection using the HTTP communication protocol and MQTT communication protocol. Experimental results show that all system components, including the reed switch sensor, relay module, solenoid door lock, buzzer, and web-based interface, function as designed and are well integrated. The system provides better security and efficiency access control mechanism compared to conventional locking methods and enables remote monitoring and control of laboratory access. Therefore, the proposed system is feasible to be applied in higher education laboratory environments to enhance security and access management. For future work, the system can be further developed by integrating user authentication mechanisms, scheduling features, and more secure communication protocols to improve reliability and scalability.

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