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Designing an IoT-Based Smart Home Automation System with Web-Based Monitoring and Control Features

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Abstract

In recent years, the demand for smart home systems has increased due to the need for improved security, comfort, and energy efficiency. Many household activities, such as door access control, lighting management, gas leak detection, and clothes drying, are still performed manually, which may lead to safety risks and operational inefficiencies. This study presents the design and testing of an Internet of Things (IoT)-based smart home automation systems using an ESP32 microcontroller integrated with ultrasonic, LDR, MQ-2 gas, and rain sensors. The system is designed to automatically respond to real-time environmental conditions and provide remote monitoring and control through a web-based interface. Experimental results indicate that the rain sensor effectively controls the clothesline mechanism, where the servo motor closes the clothesline at analog sensor output values between 0 and 2499 under wet conditions and opens it at values equal to or above 3200 in dry conditions. The ultrasonic sensor successfully controls automatic door operation at distances of 15 cm or less, while the MQ-2 sensor reliably detects hazardous gas levels and activates an alarm system. In addition, the LDR sensor enables efficient lighting control based on ambient light intensity. The results demonstrate that the proposed system operates reliably and contributes to improved safety, convenience, and efficiency in IoT-based smart home applications.

Keywords: IoT, Smart Home, ESP32, Sensor Automation, Web-Based Monitoring

1. Introduction

Technological advances have brought about significant changes in various aspects of human life, including home management. Daily activities that were previously performed manually, such as opening doors, turning on lights, detecting gas leaks, and securing clotheslines when it rains, can now be automated through the use of the Internet of Things (IoT). Doors serve as the main access point for entering and exiting a room, and controlling access rights is an important aspect of residential security. Previous research has shown that IoT-based smart door lock systems are able to regulate access more effectively compared to conventional locking mechanisms [1].

However, in practice, most households still rely on conventional methods that are inefficient and often cause problems. Homeowners often forget to turn off lights, are late in detecting gas leaks, or experience wet clothes due to sudden rain. In addition, home security remains a major concern, as inadequate monitoring systems can increase the risk of criminal activity. A study on smart door monitoring using user identification techniques highlights that improving door security is essential to prevent unauthorized access and enhance residential safety [2].

Lighting systems in residential buildings are generally still operated manually, even though environmental conditions and human presence can be detected automatically. Research on multisensory-based smart lights shows that lighting systems can automatically turn lights on or off based on human presence or light conditions, thereby increasing energy efficiency and reducing unnecessary power consumption [3].

Environmental factors such as unpredictable weather conditions also create challenges in daily household activities. The clothes-drying process often becomes problematic due to sudden changes in weather that cannot be predicted. Previous studies on automatic clothesline systems using rain sensors and IoT technology demonstrate that such systems are capable of responding automatically to rainfall and protecting clothes from getting wet [4]. From a safety perspective, gas leaks and fire incidents in residential areas are among the most common disasters and can result in significant material losses and even casualties. Research on smart home systems designed to anticipate fires and gas leaks indicates that early detection using gas sensors can significantly reduce the risk of accidents and improve household safety [5]. The modern view of the smart home concept emphasizes the integration of various electronic devices and sensors into a single system that can operate automatically. Studies on IoT-based smart home systems explain that installing several electronic devices connected via IoT enables automatic control without continuous human intervention, thereby increasing comfort and efficiency [6].

In terms of system development, the ESP32 microcontroller has become a popular choice in IoT-based smart home prototypes thanks to its low cost, integrated Wi-Fi and Bluetooth support, and the availability of extensive open-source libraries, which facilitate system implementation and development [7]. In addition, IoT-based smart home models aim to connect all devices in the home, allowing users to monitor and control various smart devices centrally and remotely via an internet-based platform [8].

To strengthen the monitoring and system integration aspects, several studies emphasize that IoT systems integrated with web-based platforms can significantly improve the efficiency of real-time monitoring and device control. Web-based monitoring enables users to access sensor data, control devices, and receive environmental condition notifications from anywhere, thereby increasing the flexibility and reliability of smart home systems [9]. In addition to functionality and security, data communication reliability is a critical factor in IoT-based smart home systems. Previous research indicates that the use of Wi-Fi networks combined with stable communication protocols supports real-time sensor data transmission and helps maintain the overall performance of home automation systems [10].

Based on these studies, this research aims to design and build an IoT-based smart home automation system that can automatically respond to conditions in the home environment. The proposed system is designed to adjust lighting based on light intensity, detect potential gas leaks to improve safety, and control clotheslines when rain is detected. In addition, this study develops web-based monitoring that allows users to control and monitor the system manually or automatically from a distance.

The theoretical basis of this study includes the concept of IoT and its application in automation systems, the working principles of ultrasonic sensors for distance detection, LDR sensors for light detection, MQ-2 sensors for hazardous gas detection, and rain sensors for weather monitoring. Furthermore, theories related to the ESP32 microcontroller, Wi-Fi networks, and web-based monitoring integration form an important basis for system development. Although these technologies have been applied in previous studies, this research focuses on integrating all sensors into a single system capable of operating in real-time with a high level of responsiveness.

This research is expected to provide both practical and academic benefits. Practically, the smart home system developed can improve comfort, safety, and energy efficiency in residential environments. Academically, this research contributes to the development of IoT systems, particularly in the areas of multi-sensor integration, environment-based automation, and web-based monitoring. It is hoped that the results of this research can serve as a foundation for the development of more advanced smart home automation technology in the future.

2. Methodology

2.1 Research Stages

This research method involves several important stages in the development of an IoT-based smart home system using ESP32, ultrasonic sensors, LDR, MQ-2, and rain sensors. The research stages begin with problem identification, namely observing problems in household activities such as doors that are still opened manually, lights that are often forgotten to be turned off, the potential danger of gas leaks, and clothes that easily get wet when it rains suddenly. After the problems were identified, the next step was to gather supporting theories through a literature study on Internet of Things (IoT) technology, sensor characteristics, and the working principles of the ESP32 microcontroller, as shown in Figure 1.

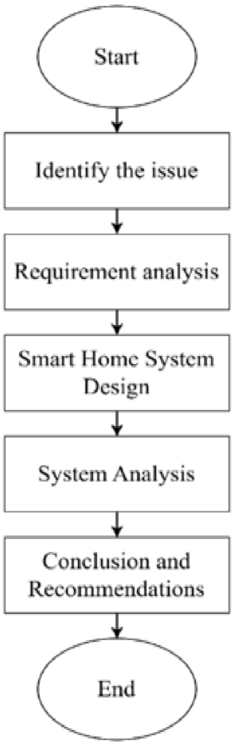

Figure 1. Research Framework Flowchart

2.2 Materials Requirements

In the process of developing this smart home system, a number of hardware devices are needed to assemble sensors, process data, and control actuators. In addition to a computer or laptop as a development device, there are other main components used in the system. The following are the hardware requirements used in Table 1:

Table 1. Hardware Requirements

No	Name	Description
1	Ultrasonic Sensor	Object distance detection
2	LDR Sensor	Intensity of incoming light
3	MQ-2 Sensor	Gas detection
4	Rain Sensor	Rain detection
5	LED (Red, Green, White)	Light source indicator
6	ESP32	Microcontroller
7	Jumper Cable	Connecting all components
8	Breadboard	Connecting component tools
9	Servo	Mechanical angle drive
10	Buzzer	As sound output

11	Battery Socket	Battery compartment
12	Battery	Power source
13	Resistor 220 ohm	Current limiter
14	Laptop	Programming

2.3 Software Requirements

Several software programs are used in the system design and implementation process, especially for microcontroller programming and web monitoring creation. The list of required software is shown in Table 2:

Table 2. Software Requirements

No	Name	Descriptions
1	Arduino IDE	Text editor
2	Wokwi	System design
3	Windows 11	Operating system
4	MySQL	Database storage
5	Visual Studio Code	Web design

2.4 Hardware Design

This circuit is an automatic system controlled by the ESP32 as the data processing center. Ultrasonic sensors are used to detect the presence of humans or approaching objects. LDR sensors are installed to read the light level in the room and determine when the lights need to be turned on. At the back of the room, there is a gas sensor that functions as a gas leak detector. For the motion mechanism, a servo is used, for example, to open automatic doors and move smart clotheslines. Additionally, a buzzer functions as an audible indicator, while red–green indicator lights show the specific status of the system. All components are connected to the ESP32 through common VCC and GND lines to ensure stable and responsive system operation, as shown in Figure 2.

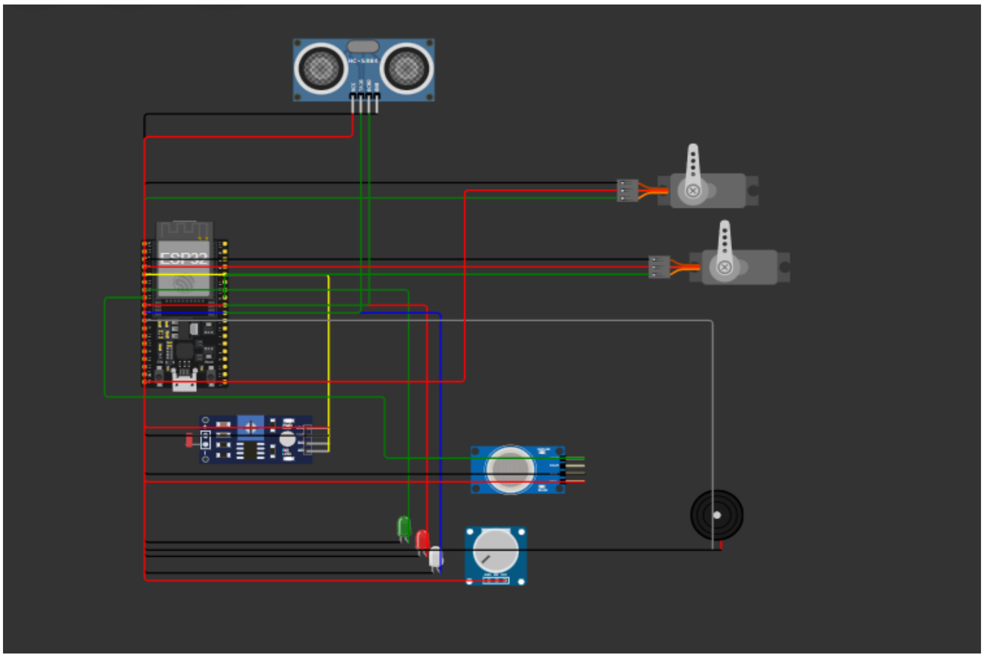

Figure 2. Hardware Design

2.5 System Block Diagram

The block diagram for the research project "Designing an IoT-Based Smart Home Monitoring System with Web-Based Control and Monitoring Features" can be seen in Figure 3.

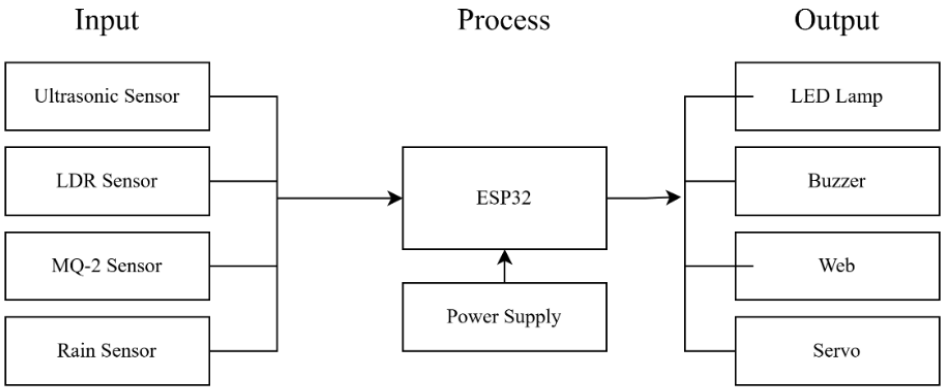

Figure 3. System Block Diagram

According to the block diagram in Figure 3, the functions of each part of the system are as follows:

1. Ultrasonic Sensor
   Ultrasonic distance sensors utilize ultrasonic sound waves to detect objects in front of them [11]. In this system, the measured distance is used as a trigger to automatically open or close the door.
2. LDR Sensor
   An LDR sensor measures light intensity, where its resistance decreases under bright conditions and increases in low-light conditions [12]. In this system, the sensor determines light or dark conditions to automatically control the lighting.
3. MQ-2 Sensor
   The MQ-2 gas sensor operates using a heated sensing element with a special layer that is sensitive to gas [13]. In this system, when gas is detected above a predefined threshold, the ESP32 activates a buzzer as a warning alarm.
4. Rain Sensor
   A raindrop sensor is used to detect the presence of rainwater [14]. In this system, when rain is detected, the sensor triggers the servo motor to automatically control the clothesline mechanism.
5. ESP32
   Acts as the processing center of the entire system. The ESP32 receives data from sensors, processes automatic logic, sends and receives data from the web, and controls actuators such as lights, servos, and buzzers.
6. Power Supply
   As a resource used to run the ESP32 along with connected sensors and actuators.
7. LED
   An LED (Light Emitting Diode) is a semiconductor device capable of emitting monochromatic light [15]. In this system, the LED functions as an indicator or main lighting unit that turns on and off automatically based on light intensity or can be controlled manually through a web-based interface.
8. Buzzer
   Functions as a warning alarm during gas leaks or certain emergency conditions.
9. Web Monitoring & Control
   Web-based monitoring facilitates users in controlling and supervising home systems remotely from any location [16]. In this study, the web platform enables real-time monitoring and allows users to manually control doors, lights, alarms, and select automatic or manual operating modes.

10. Servo
    A servo motor is an actuator equipped with an integrated control system [17]. In this system, the servo motor functions to automatically open and close doors and to drive the clothesline mechanism when rain is detected.

2.6 System Flowchart

The workflow of the ESP32-based smart home system begins with the initialization of all components, including ultrasonic sensors, LDR sensors, MQ-2 gas sensors, rain sensors, servos, LEDs, buzzers, and web communication modules. Once initialization is complete, the system enters automatic monitoring mode. The ultrasonic sensor is used to detect objects in front of the door; if the distance is less than 15 cm, the system opens the door using the servo, turns on the green LED, and activates the buzzer, while if no objects are detected, the door remains closed.

Next, the system reads light intensity through an LDR. If the light value is low, the LED lights turn on automatically for illumination. The system then checks for gas safety using the MQ-2 sensor; if the gas level exceeds the safe limit, a buzzer is activated as a warning. In the clothesline control section, a rain sensor automatically retracts the clothesline when rainwater is detected.

In addition to automatic mode, a manual control feature can be accessed via the web. When manual mode is activated, all automatic sensors are deactivated and users can control the devices directly through the web. After each monitoring or control process is carried out, the data is sent to the web so that users can monitor the condition of their homes in real time. The system continuously repeats this process as long as the device is active, as shown in Figure 4.

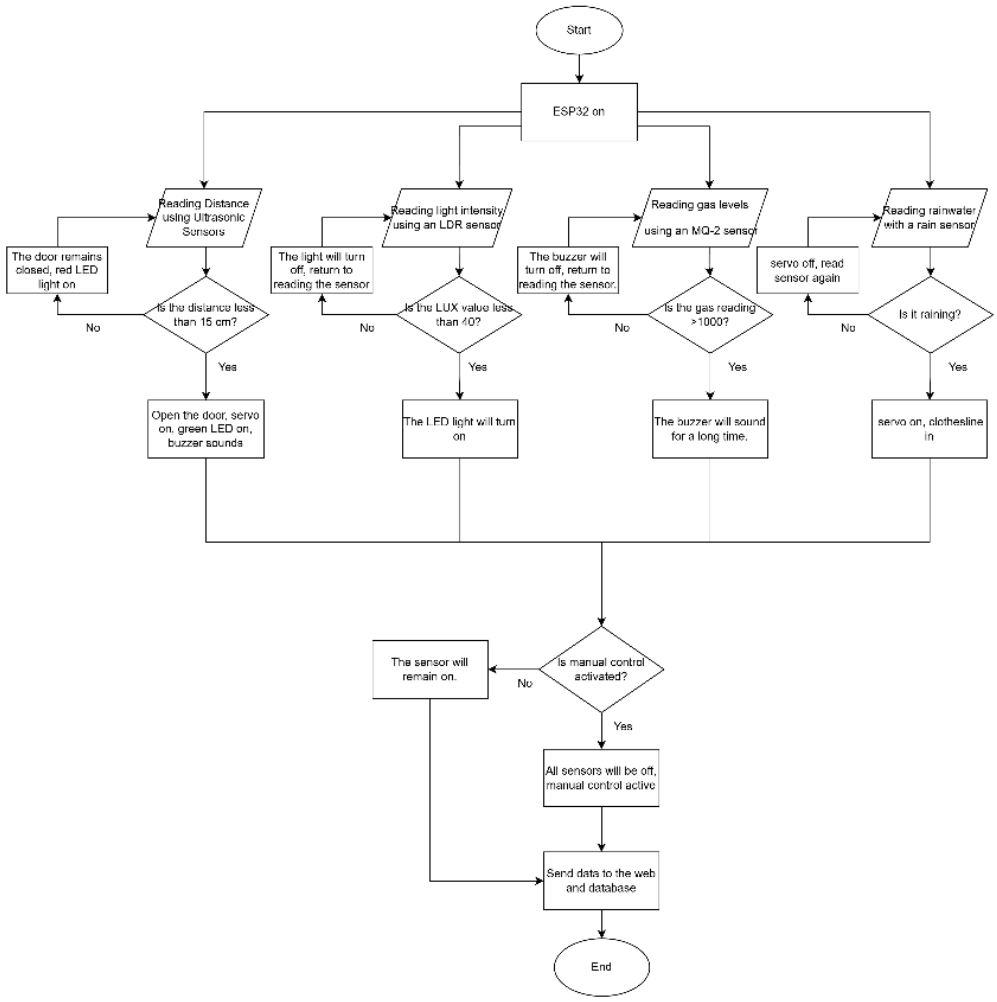

Figure 4. System Flowchart

3. Results and Discussion

3.1 Tool Design Results

The result of this tool design is an automated system that utilizes several sensors to enhance comfort and safety in the home. An ultrasonic sensor is used to detect human presence; when someone is present, the indicator light turns green, and when no one is present, the light turns red. A servo is used to open the door automatically, and a buzzer sounds to indicate when the door is open. In the back area, a gas sensor is installed to detect gas leaks. This system also features a smart clothesline, where a servo automatically raises or lowers the clothesline according to predetermined conditions. The purpose of this device is to improve security, simplify daily activities, and help save energy because all devices only operate when needed, as shown in Figures 5 and 6.

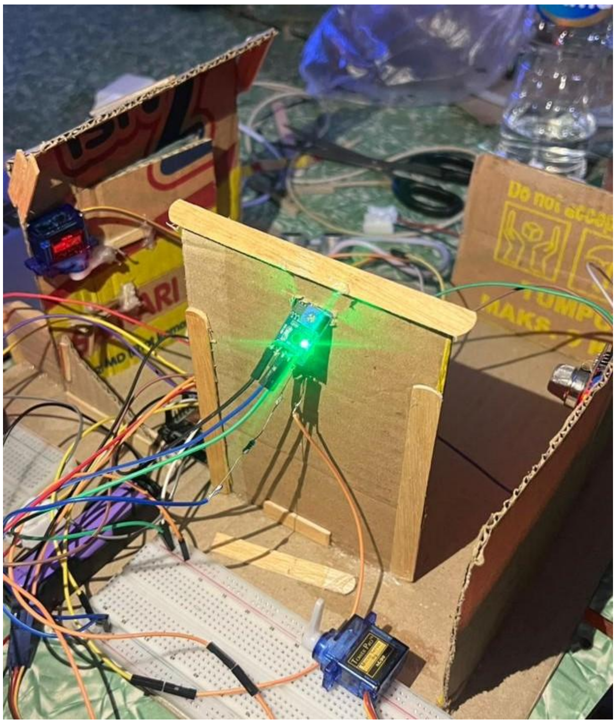

Figure 5. Tool Design Results

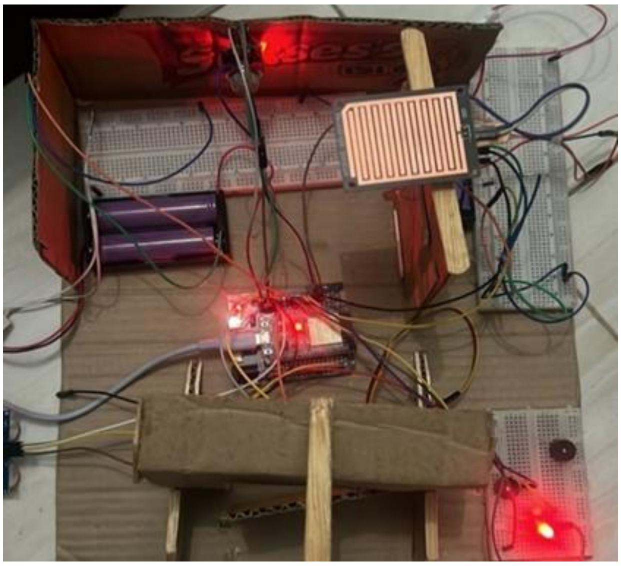

Figure 6. Tool Design Results

3.2 System Web Display

1. Login Page Display

Displays the login page, which serves as the starting point before users can access the Smart Home System. This page contains a login form with username and password fields. The purpose of this page is to maintain system security so that only users with accounts can view sensor data and control devices. The login display is simple and easy to use, allowing users to log into the system quickly without complicated processes, as shown in Figure 7.

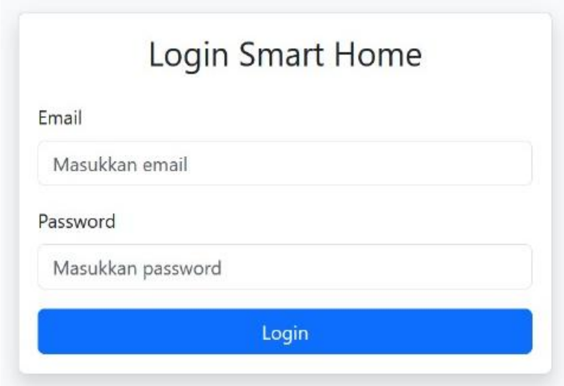

Figure 7. Login Page Display

2. Home Page Display

This is the Home Page or main Dashboard display. On this page, users can see a summary of the overall condition of their home, such as door status, lighting conditions, gas safety levels, and weather information from rain sensors. This Dashboard is designed so that users can monitor the condition of their home in a single view without having to open other menus. This display serves as a quick information center, which is very helpful for daily monitoring in Figure 8.

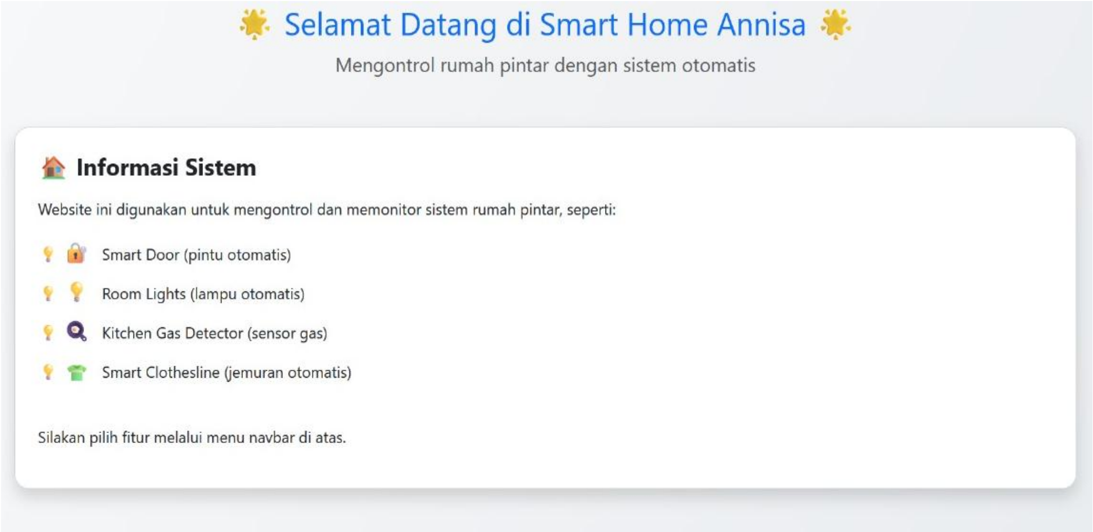

Figure 8. Home Page Display

3. Development Team Display

Displays the developer page, which contains information about the system development team. This section usually displays the name of developers, their positions or role, and additional information such as photos or contact details. This page serves as the official identity of the system developers and can be used as a reference if users need technical assistance or want to further develop the system in Figure 9.

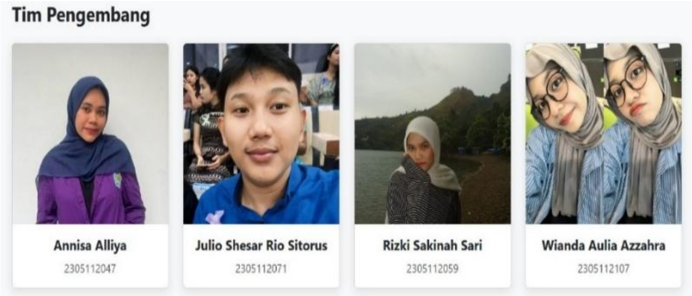

Figure 9. Development Team Display

4. History Display

Shows the report page display. This page presents historical data from every sensor activity and connected device, such as when the lights were turned on, when the door was opened, gas detection data, and automatic clothes drying activities. All data is recorded in the history so that users can view data at any time. The history page provides transparency regarding home activities and serves as a monitoring documentation tool in Figure 10.

History Data Sensor (Realtime)

No	Sensor	Nilai	Status	Waktu
1	LDR (Cahaya)	0	Lampu OFF	18.51.56
2	Rain (Hujan)	4095	Tertutup	18.51.56
3	Gas	170	✓ AMAN	18.51.56
4	Pintu (Jarak)	8 cm	Terbuka	18.51.56

Figure 10. History Display

5. Sensor Monitoring Display

This image above shows the design of the Smart Home system Dashboard, which is used to monitor and control various Smart Home features. This Dashboard has several main control menus, namely Smart Door, Room Lights, Kitchen Gas Sensor, and Smart Clothes. Each feature is equipped with the latest status information such as door closed, lights on, gas safe, and clothes closed so that users can immediately know the condition of their home.

Each feature also has a manual and manual stop button (as well as a Reset button for the gas sensor) that allows users to activate or deactivate the device directly as needed.

The purpose of this Dashboard display is to provide integrated control; enhance device efficiency by ensuring that devices are only turned on when needed. This Dashboard is the main control center that makes it easy for residents to manage the Smart Home system practically and effectively in Figure 11.

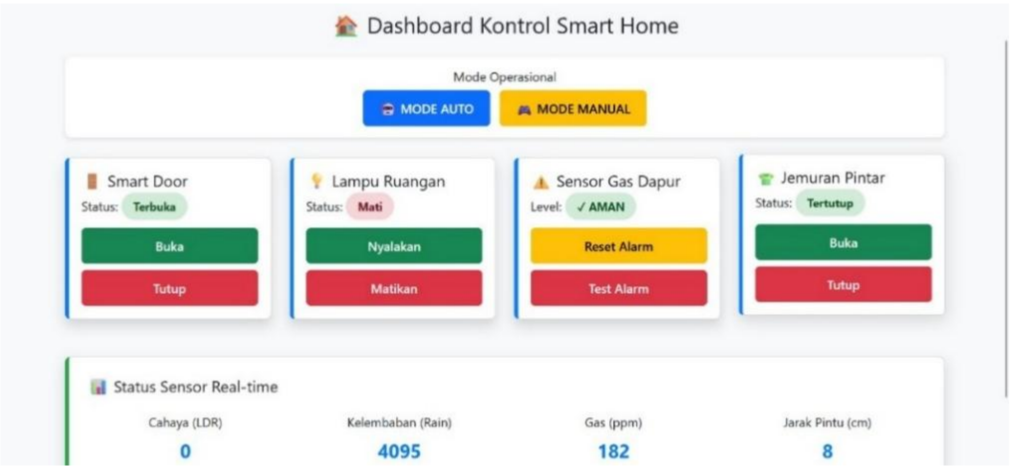

Figure 11. Monitoring Sensor Display

3.3 System Database

This System Database functions to save all data required by the Smart Home application, including data used for login and data sent via the contact form. The image shows that within the Database named web_login, there are two main tables, namely proses_kontak and user. The proses_kontak table is used to store data from the contact page, which consists of the columns name, email, and message. Every time a user sends a message through the form, the data is automatically stored and can be viewed in this table.

Meanwhile, the user table is used to save login account data, such as the username and password used to log into the system. This table ensures that only registered users can access the Smart Home Dashboard. With these two tables, the Database is able to manage the system needs in an integrated manner, namely login security and storage of messages from users in Figure 12.

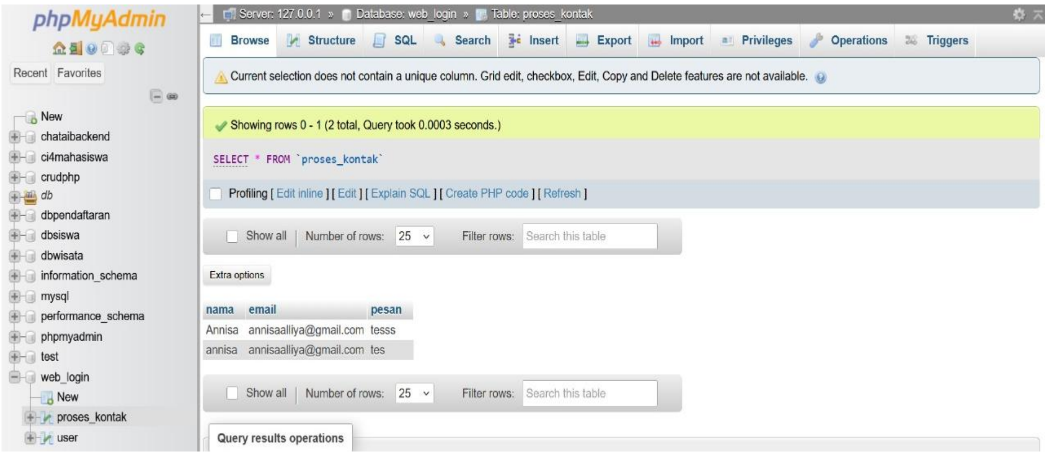

Figure 12. System Database

3.4 Testing Results

Table 3 presents the experimental results of the rain sensor used in the automatic clothesline system. The table shows the relationship between analog rain sensor values, detected weather conditions, and the corresponding servo motor actions. When the rain sensor detects low analog values between 0 and 1499, indicating very wet conditions, the clothesline remains closed to ensure safety. In the range of 2500 to 3199, corresponding to damp or drizzle conditions, the system maintains the previous servo position to prevent sudden or unnecessary movement. When the sensor value reaches 3200 or higher, indicating dry conditions, the servo motor opens the clothesline at a 0° angle, allowing normal drying operations in Table 3.

Table 3. Rain Sensor Results

Rain Sensor			
Rain Value (Analog)	**Weather Status**	**Servo Clothesline Action**	**Description**
0 - 1499	Rain (Very Wet)	CLOSE (90°)	The sensor is exposed to a lot of water
1500 - 2499	Wet	CLOSE (90°)	It's still safe to close
2500 - 3199	Damp/Drizzle	Maintain previous position	Not open or close suddenly
≥ 3200	Dry	OPEN (0°)	No water

Table 4 summarizes the testing results of the ultrasonic sensor used for automatic door control. The system is configured to open the door when an object is detected at a distance of 15 cm or less, which triggers the servo motor to rotate to 90°, activates the green LED, and produces a short buzzer sound as an access indicator. Conversely, when the detected distance exceeds 15 cm, the door remains closed, the servo motor returns to the 0° position, the red LED is activated, and the buzzer is turned off.

Table 4. Ultrasonic Sensor Results

Readable Distance (cm)	Door Status	System Action
≤ 15 cm	OPEN	Servo 90°, green LED ON, short beep
14-10 cm	OPEN	Servo 90°, green LED ON, short beep
10-7 cm	OPEN	Servo 90°, green LED ON, short beep
7-3 cm	OPEN	Servo 90°, green LED ON, short beep
3-2 cm	OPEN	Servo 90°, green LED ON, short beep
1 cm	OPEN	Servo 90°, green LED ON, short beep
16 cm	CLOSE	Servo 0°, red LED ON, buzzer off
17-20 cm	CLOSE	Servo 0°, red LED ON, buzzer off
20-25 cm	CLOSE	Servo 0°, red LED ON, buzzer off
25-30 cm	CLOSE	Servo 0°, red LED ON, buzzer off
30-35 cm	CLOSE	Servo 0°, red LED ON, buzzer off

Table 5 presents the testing results of the MQ-2 gas sensor used for gas leak detection in the proposed smart home system. When gas is detected, the system categorizes the condition as dangerous and activates a long buzzer sound as a warning indicator. In contrast, when no gas is detected, the system identifies the condition as safe and deactivates the buzzer.

Table 5. MQ-2 Sensor Results

Sensor Reading	Status	System Action
Gas detected	DANGER	Long buzzer sound
No gas detected	SAFE	Buzzer Off

Table 6 presents the testing results of the LDR sensor used for automatic lighting control in the proposed smart home system. When sufficient light intensity is detected, the system turns the LED off to prevent unnecessary energy consumption. Conversely, in the absence of light intensity, the LED is automatically turned on to provide illumination.

Table 6. LDR Sensor Results

Sensor Reading	Status	System Action
The presence of light intensity	LED OFF	The LED light is not on
Absence of light intensity	LED ON	The LED light is on

4. Conclusion

This study successfully designed and built an Internet of Things-based Smart Home System using an ESP32 microcontroller integrated with several sensors, namely ultrasonic sensors, LDR sensors, MQ-2 sensors, and rain sensors. The resulting system is capable of working automatically to respond to real-time environmental conditions in the home. The door can open automatically when an object is detected in front of the ultrasonic sensor, the lights turn on and off based on the light intensity from the LDR sensor, gas leaks can be detected by the MQ-2 sensor, and the clothesline can move automatically when rain is detected.

In addition to working in automatic mode, this system is also provided with a manual control feature via a web display. The web monitoring feature allows users to access sensor information, control devices, and view activity history remotely. The web interface provides flexibility and improves efficiency in the home, while also serving as a relevant solution for modern home automation needs and a foundation for developing more complex systems in the future.

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