Design and Construction of a Safe Deposit Box with an Internal Environmental Condition Monitoring System

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Abstract

This study examines the creation of a secure deposit box system that integrates environmental monitoring and security functionalities with Internet of Things (IoT) technology. The system is designed to improve the protection of stored items by maintaining suitable internal conditions while preventing unauthorized access. An ESP32 microcontroller is employed as the core processing unit to manage sensor inputs and control system responses. Internal temperature and humidity are monitored using a DHT22 sensor, allowing the system to observe environmental changes that may affect sensitive items. Human movement is detected using a PIR sensor, while a magnetic reed switch is used to identify door opening events. To support security functions, the system is equipped with a door lock solenoid that serves as an automatic locking mechanism and a buzzer that provides an audible alert when suspicious activity or forced access is detected. All sensor readings and system statuses are presented through a web-based dashboard, which enables users to monitor conditions and security events in real time via a local network connection. System evaluation was carried out to assess the reliability of sensor readings, the responsiveness of actuators, and overall system performance. The findings demonstrate that the system functions reliably, providing precise environmental measurements, dependable motion and door status detection, and prompt alarm activation. In conclusion, the established safe deposit box system provides a pragmatic and efficient option for safeguarding expensive assets necessitating regulated environmental conditions, with potential for enhancement through cloud-based monitoring and alerting functionalities.

Keywords: Internet of Things (IoT), Smart Safe Deposit Box, Environmental Monitoring, ESP32 Microcontroller, Security System

1. Introduction

Sensitive items such as medications, important documents, and valuable assets require not only physical security but also stable environmental conditions to preserve their quality and integrity. Medications are highly sensitive products, particularly to environmental changes, especially temperature and humidity. The instability of both parameters can accelerate the degradation of the active ingredient, thereby reducing its effectiveness and potentially cause side effects. Some studies show that many medications must be stored within a specific temperature range to maintain their stability, thus requiring storage containers capable of continuously maintaining and monitoring environmental conditions [1]. With the development of Internet of Things (IoT) technology, sensor-based monitoring is now one of the effective solutions for ensuring that drug quality is maintained. Intelligent building automation systems are one of the most researched areas, driven by the high demand for economical systems designed to provide controlled and reliable environments. In addition, the development of such systems increases efficiency and addresses not only economic concerns but also moral and environmental issues [2]. Research on IoT-based environmental monitoring systems also

confirms that real-time temperature and humidity monitoring significantly improves the effectiveness of storage condition supervision compared to conventional manual methods [3].

In daily practice, storing medication at home or in small healthcare facilities is still done using ordinary boxes or cabinets that do not have automatic monitoring. The absence of temperature and humidity sensors means users are unaware when environmental conditions change to a point that could endanger the stability of the medication. Additionally, the risk of unauthorized access—for example, by children or other parties—remains quite high because storage boxes are generally not equipped with active security features. Some studies explain that using traditional keys has drawbacks because they are easily forced open, thus not providing optimal protection for stored items [4]. Certain instances demonstrate that unsupervised physical access may result in both the abuse and destruction of drugs. This scenario highlights the necessity for a drug storage system that is both secure and proficient in real-time detection of threats and environmental conditions. Research on intelligent security systems reveals that integrating door sensors and motion detectors can strengthen protection against unwanted access by offering early warning measures [5].

Extensive research has been undertaken on temperature and humidity monitoring via digital sensors, especially concerning food storage, sensitive storage environments, and IoT-based monitoring systems. Numerous studies demonstrate that employing sensors such as DHT11 and DHT22 facilitates robust and responsive environmental monitoring, rendering them appropriate for applications necessitating temperature stability [6]. Other studies emphasize that integrating environmental sensors with microcontrollers and web-based monitoring platforms allows continuous observation and supports preventive actions before environmental conditions reach critical thresholds [7]. Other research has also implemented PIR sensors to detect suspicious activity and reed switches to determine door status, proving that integrating these sensors can enhance physical security in storage systems [8]. Additionally, the use of microcontrollers like the ESP32 is widespread because they support Wi-Fi and have sufficient processing power to run web-based monitoring systems [9].

Based on these issues, this research aims to design and implement an IoT-based safe deposit box equipped with real-time environmental monitoring and security mechanisms, which can be applied to the storage of sensitive items such as medications and other valuable assets. The system is also equipped with a web-based dashboard that allows users to monitor internal environmental conditions and security status directly from various devices. Recent studies on IoT-based monitoring systems in healthcare facilities demonstrate that integrated environmental monitoring solutions are able to operate in a stable and responsive manner, supporting faster and more accurate decision-making processes [10].

Recent research has shown that IoT-based environmental monitoring systems integrated with web-based platforms provide significant advantages in terms of real-time supervision, data visualization, and user accessibility. Aher et al. developed an IoT-based environmental monitoring system that utilizes sensors, microcontrollers, and a web dashboard to display real-time and historical environmental data stored in a database, enabling efficient remote monitoring and timely response to abnormal conditions [11].

Previous studies indicate that the IoT strategy is successful in monitoring temperature, humidity, and the security of storage rooms or containers. Nevertheless, the majority of research continues to concentrate on a singular facet, such as environmental monitoring or security alarm systems, without integrating both into a cohesive solution. Moreover, certain studies lack a web interface that facilitates effective cross-device monitoring. This research addresses the gap by incorporating environmental monitoring, physical threat detection, automated locking, and a web dashboard into a cohesive and user-friendly safe deposit box system applicable to sensitive items, including medications, while enabling real-time supervision and timely response to abnormal environmental and security conditions. In addition, the proposed system is designed

to improve accessibility and usability by allowing users to monitor system status through standard web-enabled devices without requiring specialized software.

2. Methodology

The research methodology was formulated utilizing a systems engineering approach, with each phase executed consecutively, from problem identification to the evaluation of testing outcomes. This methodology was chosen because it can provide a systematic way to design, build, and test the performance of Internet of Things (IoT) systems. The stages of this process encompass requirements analysis, system design, implementation, and testing. Each phase is designed to ensure that the medication storage box operates safely, responsively, and accurately in monitoring environmental conditions and detecting potential safety risks.

2.1 Needs Analysis

A needs analysis was conducted to identify the key features that drug storage containers should have. Several prior studies have demonstrated that real-time monitoring of temperature and humidity is essential, as environmental conditions markedly influence drug quality and stability [12]. Additionally, security features such as motion detection using PIR and door opening detection using reed switches are required, as implemented in research on IoT-based room security systems [8]. From a hardware perspective, the system requires an ESP32, a DHT11 sensor, a PIR sensor, a reed switch, a servo, a buzzer, and a web dashboard for data visualization, consistent with the general approach in IoT monitoring research [9].

a. Tools

The tools used to assemble, program, test, and support the development include:
- Laptop
- USB to micro-USB cable
- Hot glue gun
- Screwdriver
- Digital multimeter

b. Materials

The electronic components and physical materials used in the proposed system are:
- ESP32 Development Board
- DHT22 temperature and humidity sensor
- HC-SR501 PIR motion sensor
- Reed Switch MC-38 (Magnetic Door Sensor)
- Door lock solenoid
- Buzzer
- Jumper cables
- Medicine storage box

c. System Design

This system utilizes the Internet of Things (IoT) framework to facilitate communication and data exchange concerning environmental conditions. This technique enables devices to gather information from their environment, communicate data via the internet, and receive instructions or feedback, hence facilitating more intelligent and responsive decision-making processes [13].

The system design stage aims to provide a comprehensive overview of the sensor system for medicine storage with data acquisition and to describe the relationships among the components involved in the IoT-based drug storage box for monitoring and security purposes. This stage

explains the overall system workflow, starting with the system for storing medicine from data acquisition by sensors, data processing by the microcontroller, actuator control for the medicine storage mechanism, and information presentation through a web-based interface. To clarify the system architecture and operational flow, the design is illustrated using a block diagram and a flowchart, as presented in the following subsections.

2.2 Block Diagram

A block diagram is a graphical representation used to explain the working process of a system by dividing it into input, process, and output components. This box-shaped diagram is commonly applied to describe the operational structure of tools, circuits, or installations [14]. The block diagram of the ESP32-based control system is presented in Figure 1.
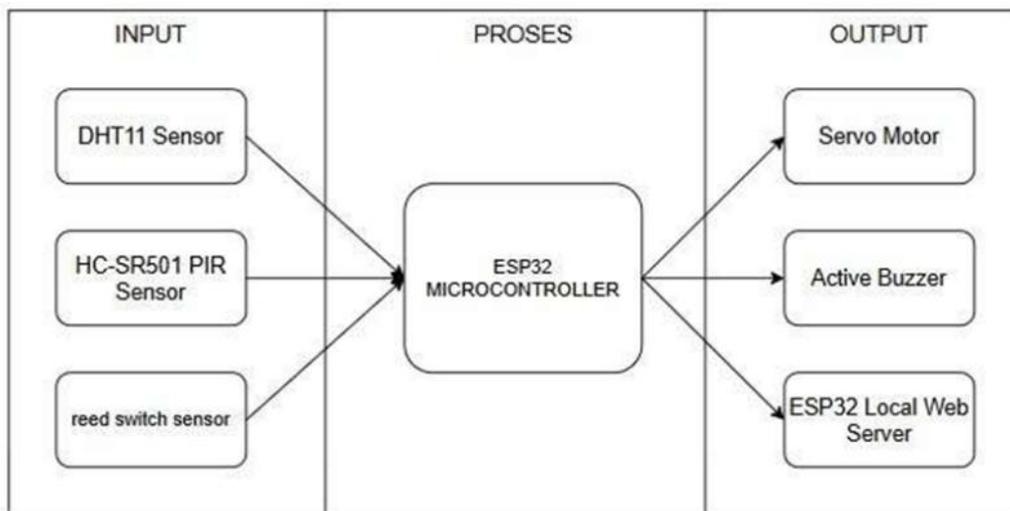

Figure 1. Block Diagram of the ESP32-based Control System

As shown in Figure 1, the IoT-based medicine storage box system consists of three main sections: input, process, and output. The DHT11/DHT22 sensor, HC-SR501 PIR sensor, and magnetic reed switch act as input devices that provide environmental and security condition data to the ESP32 microcontroller. The ESP32 interprets incoming data and produces outputs, including solenoid or servo motor activation for locking, buzzer activation for alarm indication, and data transmission to a local web server for real-time monitoring. This setup illustrates that all system components function cohesively to facilitate both environmental monitoring and security operations for the medicine cabinet.

2.3 Flowchart

A flowchart is a method used to visually describe problem-solving steps and data flow using standardized and easily understood symbols. The primary purpose of a flowchart is to simplify complex processes so that system logic and procedures can be clearly interpreted [15]. Figure 2 illustrates the operational logic of the SmartSafe system in the form of a flowchart, outlining the sequential processes and decision-making flow.
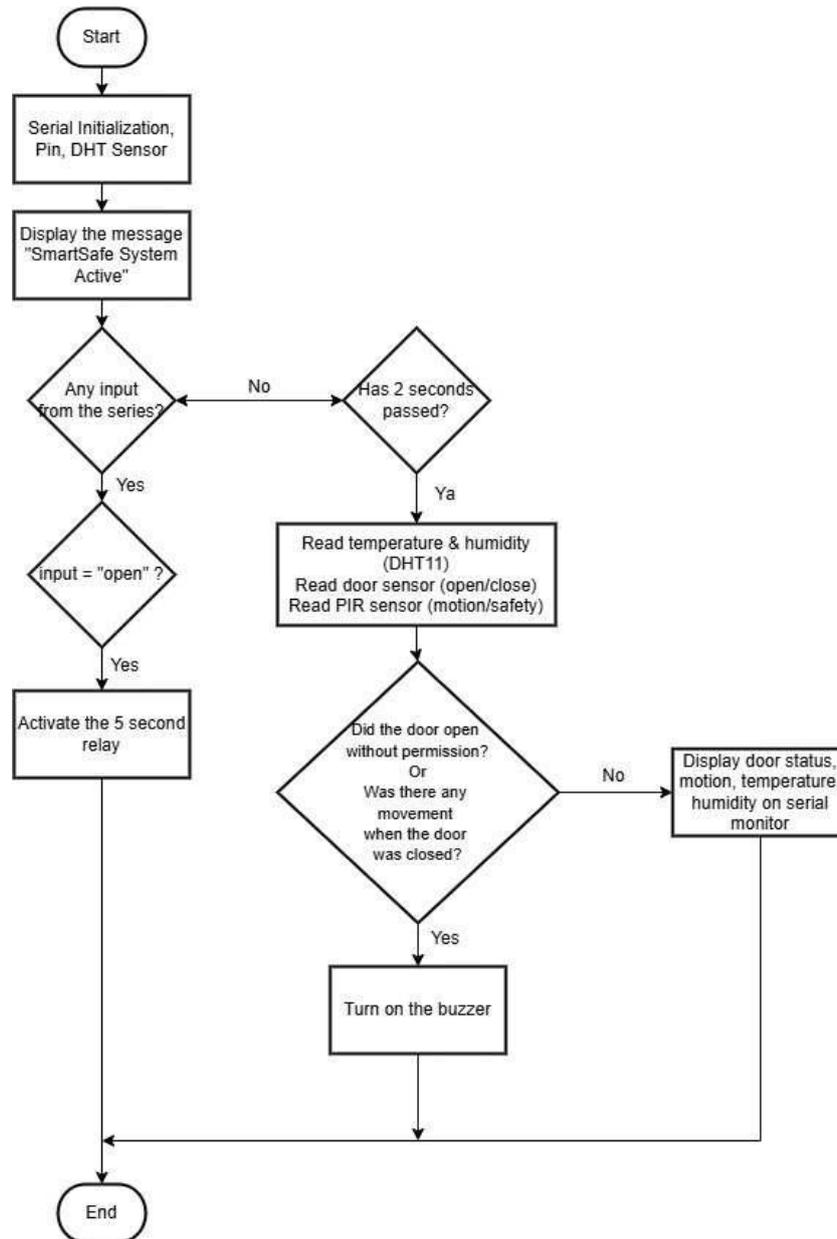
Figure 2. Flowchart of the SmartSafe System Operational Logic

As illustrated in Figure 2, the IoT-based medicine storage box operates through a structured sequence of processes. The system begins with the initialization of serial communication, pin configuration, and activation of the DHT sensor. After the system displays a notification indicating that the device is active, the ESP32 waits for serial input to allow manual unlocking. When an "open" command is received, the relay is activated for five seconds to unlock the latch.

The system autonomously monitors temperature, humidity, door status, and motion data at two-second intervals without operator input. The gathered sensor data are subsequently evaluated to identify anomalous conditions, such as unlawful door openings or motion sensed while the door remains closed. If any suspicious condition is identified, the buzzer is activated as an alarm. When no threat is detected, the system only displays the current environmental and security status on the serial monitor. This flowchart confirms that the system is capable of performing automatic monitoring and security control while still supporting manual operation via serial input.

2.4 System Implamantation

In the system implementation phase, the proposed design was transformed into a workable prototype by integrating an ESP32 microcontroller with a DHT22 sensor, an HC-SR501 PIR sensor, a magnetic reed switch, and output components including a servo motor and a buzzer for alarm signaling. Software development was executed utilizing the Arduino IDE, which managed sensor data collecting, relay and servo control, and alarm activation according to established security parameters.

A local web server on the ESP32 was established to present monitoring data on a dashboard interface, encompassing real-time temperature, humidity, door status, and motion detection information. The primary dashboard screen additionally provides a concise overview of the gadget and its capabilities. All components were amalgamated and assessed under diverse circumstances to appraise system responsiveness. The findings demonstrate that the solenoid/servo locking mechanism and buzzer functioned well, and the dashboard precisely exhibited the monitored data.

2.5 System Testing

To guarantee the system's reliable operation under various usage settings, several in-depth assessment tests were performed on each principal component and system feature. This testing step assessed both functional performance and system stability during a specified operational duration. One of the principal evaluation methodologies employed was reliability testing, which concentrates on evaluating system durability and consistency throughout extended usage.

The reliability testing parameters included:

a) stability of temperature and humidity readings within specified time intervals;
b) consistency of door status and motion detection;
c) responsiveness of the servo motor and buzzer when a security threat is detected; and
d) stability of the ESP32 connection and IoT data transmission throughout the testing period.

Previous studies emphasize that sensor accuracy and network stability are critical factors in the success of IoT-based systems. Therefore, continuous testing was conducted to ensure that no significant errors, delays, or data losses occurred during system operation.

3. Results and Discussion

3.1 Results of System Implementation

a. Hardware Implementation

The hardware implementation entailed the integration of all system components focused on the ESP32 microcontroller, which functions as the principal control unit. The DHT11 sensor was installed in the medicine storage box to continuously monitor temperature and humidity levels. A PIR sensor was mounted in a suitable location to detect human presence in the storage room. The door state was checked using a magnetic reed switch affixed to the cabinet door.

A servo motor was implemented to function as the automatic locking mechanism, enabling the door to open or close in response to control commands issued by the ESP32. To enhance security, a buzzer was included as an audible alert system that activates when unauthorized access or unusual activity is detected. All hardware components were interconnected using jumper wires and powered with a stable supply, resulting in an integrated system that supports environmental monitoring while improving storage security. The electronic circuit schematic and wiring configuration of the implemented system are illustrated in Figure 3.
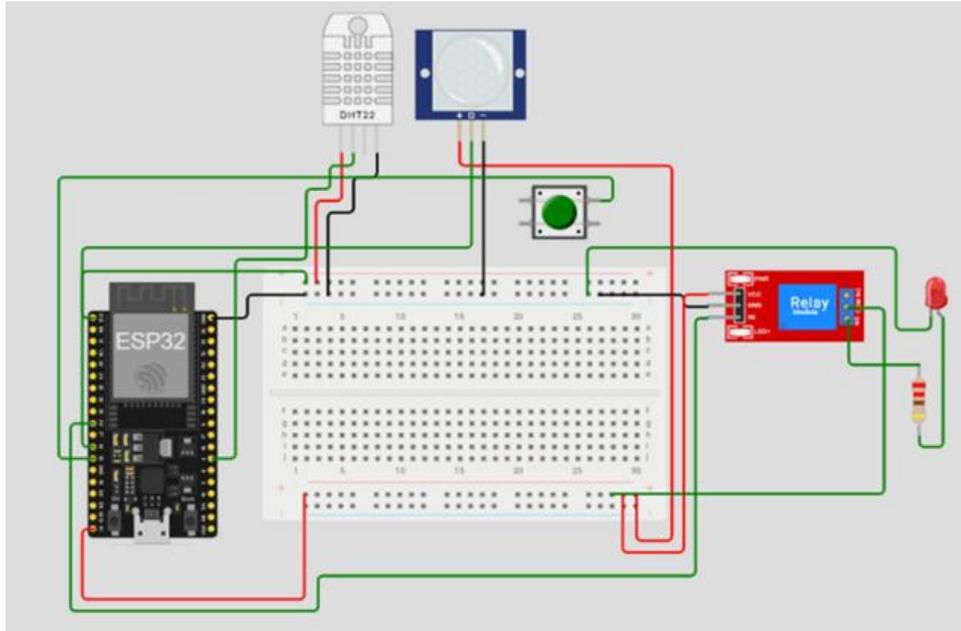
Figure 3. Electronic Circuit Schematic and Wiring Diagram

b. Software Implementation

The software implementation results are presented through a web-based interface hosted on the ESP32 local web server. The interface consists of several main pages, namely Home, Dashboard, Methods, About Me, and Contact Us.

The homepage offers a comprehensive overview of the SmartSafe system, its developmental goals, and the significance of secure and monitored medication storage. The Dashboard site presents real-time sensor data, encompassing temperature, humidity, door status, and motion detection, allowing users to precisely monitor environmental and security conditions. The Methods page delineates the data processing and decision-making logic employed on sensor readings prior to visualization. The About Me page provides a summary of the hardware components utilized in the system, including the ESP32, DHT11 sensor, PIR sensor, magnetic reed switch, servo motor, and buzzer. The Contact Us page offers contact details for technical help and conversation. The visual appearance of each web interface page is shown in Figures 4–8.
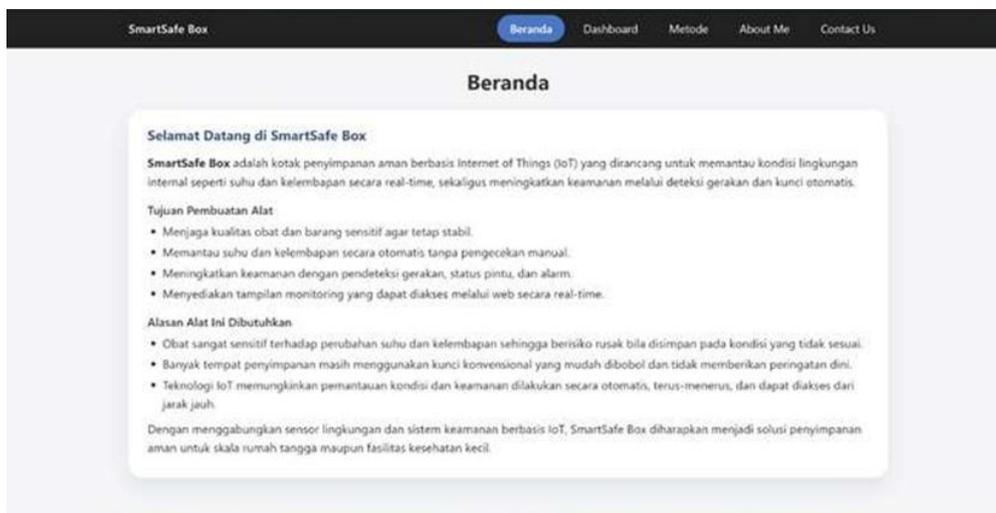

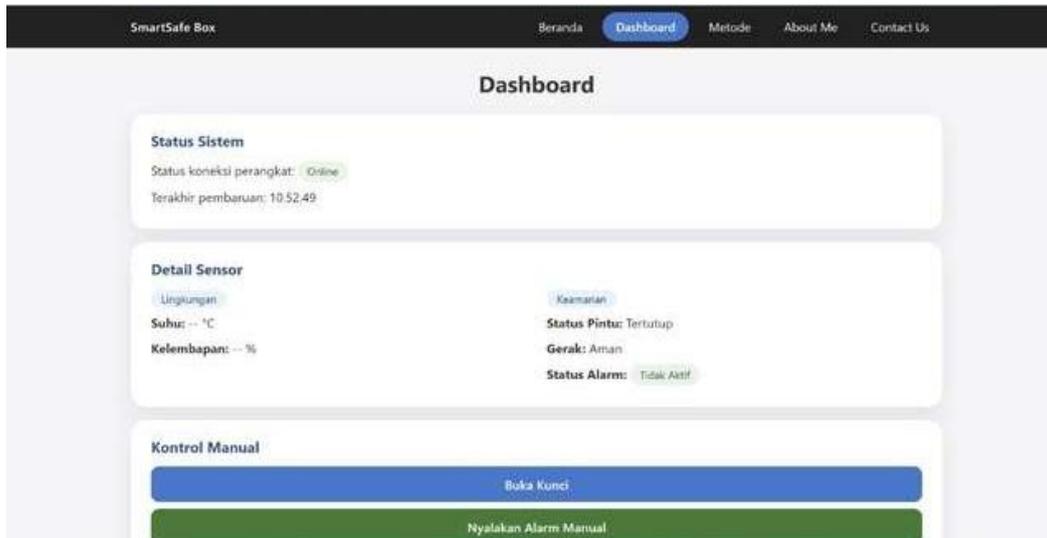**Figure 4.** Home Page Interface of the SmartSafe Web Application

Figure 5. Real-Time Monitoring Dashboard for Environmental and Security Conditions
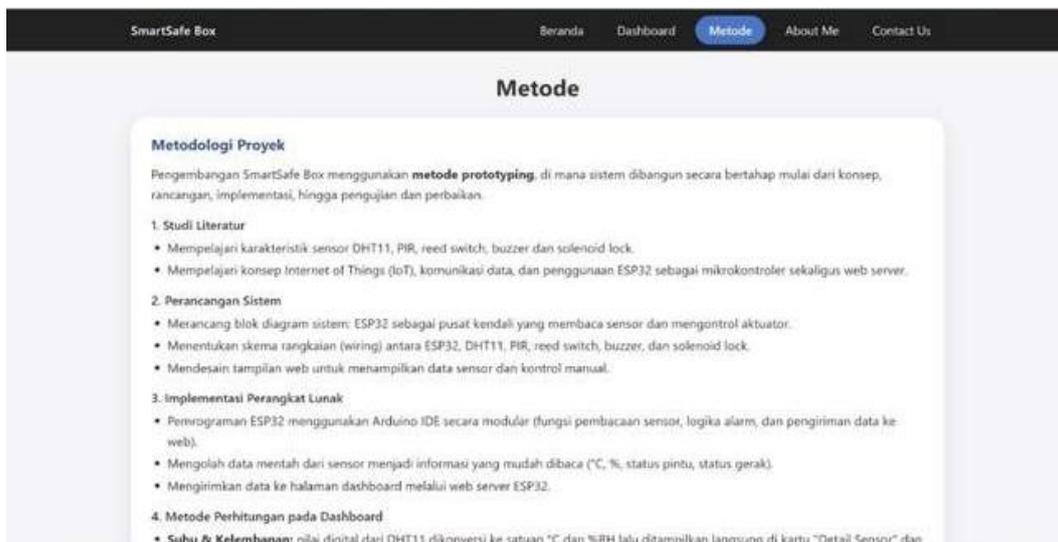

Figure 6. Methods Page of the SmartSafe Web Interface

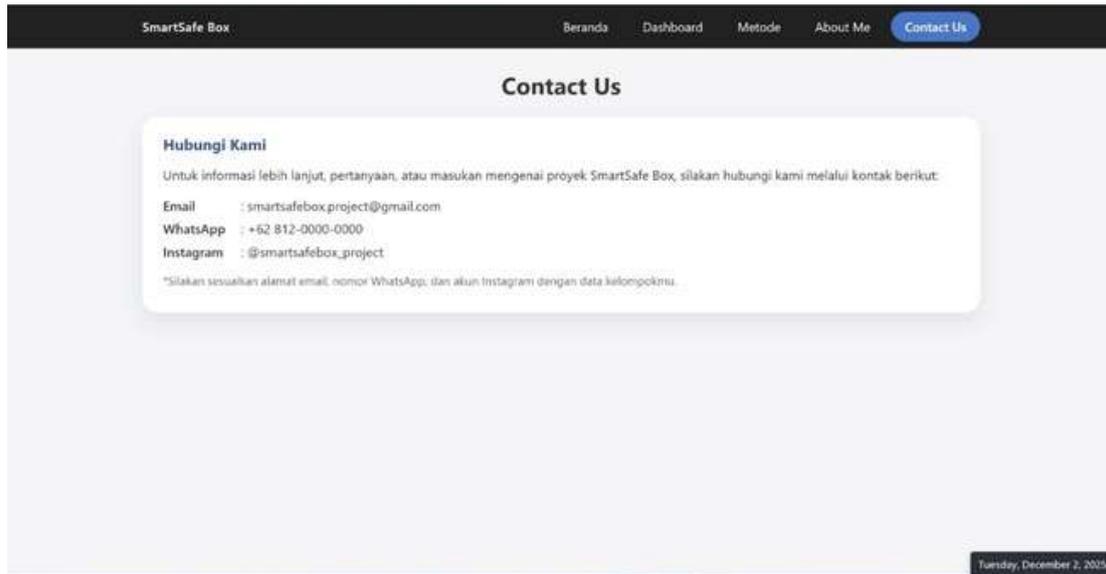**Figure 7.** About Me Page of the SmartSafe Web Interface

Figure 8. Contact Us Page of the SmartSafe Web Interface

The software implementation demonstrates that sensor data are successfully processed and displayed in real time, and the structured web interface allows users to easily understand and operate the system.

3.2 Performance Testing Results

Functional and performance testing were conducted to verify that all system components—from environmental sensors to security modules—operate according to the defined control logic. Testing was conducted at six observation locations that reflect authentic operational circumstances of the drug storage box. The assessed parameters comprised temperature, humidity, door status, motion detection, servo response, and alarm activation. The results of functional testing are summarized in Table 1.

Table 1. System Functional Testing Results

No	Time (Second)	Temperature (°C)	Humidity (%)	Servo Status	Motion Status	Alarm Condition
1	0	29.5	61.0	Closed	Safe	Inactive
2	2	29.7	60.8	Closed	Safe	Inactive
3	8	30.1	61.5	Open	Safe	Active (Door Open Without Permission)
4	12	30.0	61.3	Closed	Movement Detected!	Active (Suspicious Movement)
5	18	29.8	60.9	Closed	Safe	Inactive
6	20	29.6	61.2	Closed	Safe	Inactive

Table 1 illustrates that the system exhibits steady environmental monitoring performance, with temperature and humidity data consistently maintained within a defined range; hence, it works well but is not as accurate as higher-end sensors, and the system currently requires a local network connection, which limits access from far away, affirming the reliability of the DHT11 sensor. The security systems operate effectively: the alarm activates upon unauthorized door access and upon motion detection while the door is closed. Upon resolving the results of putting the system into action and testing, it shows that the SmartSafe system effectively combines environmental monitoring and security features into one abnormal situation; thereby, the system autonomously reverts to a secure state.

Visual evidence of system operation during performance testing is presented in **Figure 9**, which shows the real-time monitoring dashboard alongside the hardware prototype. The displayed warning messages on the dashboard correspond directly to abnormal conditions detected during testing, confirming consistency between sensor readings, system logic, and user interface feedback.
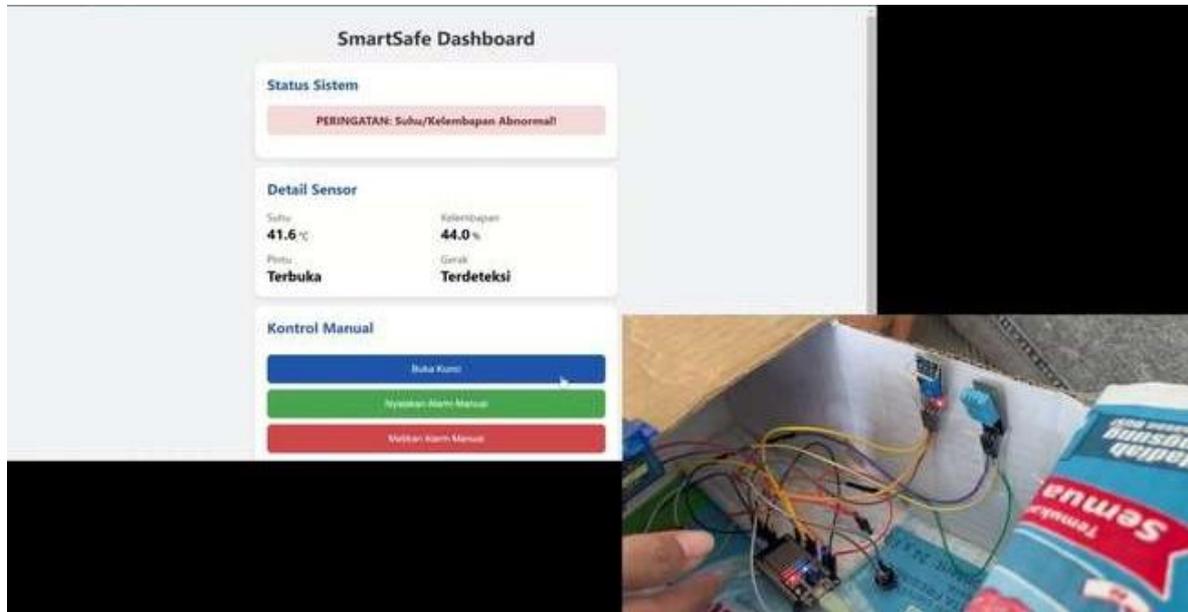
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Figure 9. Real-Time Operation of the SmartSafe System During Performance Testing

3.3 Discussion

The outcomes of system implementation and testing demonstrate that the proposed SmartSafe system successfully amalgamates environmental monitoring and security features into a unified IoT-based platform. The hardware arrangement exhibits dependable sensor readings and actuator reactions, whereas the software interface offers easy real-time monitoring and system transparency.

The performance testing findings validate that the system can precisely identify unauthorized access and environmental alterations, which is essential for medical storage applications. The proposed system provides superior safety compared to traditional storage boxes lacking monitoring or security elements by integrating automatic locking, alarm activation, and continuous environmental oversight.

Nonetheless, numerous restrictions were recognized. The DHT11 sensor delivers satisfactory performance but exhibits inferior precision relative to premium sensors, and the system presently depends on a local network connection, constraining distant access. Future improvements could include connecting to the cloud, sending mobile alerts, using more accurate sensors, and managing access for multiple users to make the system more scalable and user-friendly in healthcare environments.

4. Conclusion

Based on the results of the design, implementation, and testing that have been carried out, it can be concluded that the Safe Storage Box system with Internal Environmental Condition Monitoring based on IoT has been successfully built and functions according to the research objectives. This system is capable of real-time temperature and humidity monitoring using a

DHT22 sensor, as well as detecting physical security threats thru a PIR sensor and magnetic reed switch. The implementation of servos and buzzers enables an automatic locking mechanism as well as an alarm when unsafe conditions are detected, such as unauthorized door opening or suspicious movements.

Functional testing shows that all components work according to the designed logic, the alarm is only active under threat conditions, and the system returns to stability after normal conditions. Reliability testing shows that sensor data readings are consistent over the operational period, while usability test results indicate that the web dashboard display is easily accessible and informative for users.

Thus, the prototype created has met the requirements of a safe, responsive drug storage system capable of continuous environmental monitoring. This system has the potential for further development with internet-based notification features, cloud data storage, and a more compact physical device design for industrial and household use.

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