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Development of a Prototype Room Security Monitoring System for Early Fire Detection Using a Prototyping Method Based on Sensors and IoT

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Abstract— **Many public spaces have implemented monitoring systems to detect fires. Traditional fire monitoring relies on manual supervision, requiring personnel to conduct daily inspections, making it inefficient and time-consuming. This study aims to develop a prototype room security monitoring system designed for early fire detection. The system utilizes IoT technology and a web-based platform, allowing operators to monitor all rooms remotely. The system integrates fire detection sensors with an alarm mechanism for real-time alerts. Each room is outfitted with a flame detector sensor operated by a microcontroller (Arduino Nano), which serves as the central control for all connected devices. To transmit data from the sensors to the web-based system, the prototype uses the ESP8266 Wi-Fi module, enabling seamless communication between the sensors and the monitoring platform. The system development was carried out using the prototyping method, which involved iterative design, construction, and testing. In addition, blackbox testing was conducted to evaluate the system's functionality without examining the internal code. The results indicate that the system successfully detects fires early and sends real-time notifications to the web platform with high accuracy. The system also allows for rapid operator response through the alarm system. Based on the blackbox testing results, all key features, such as fire detection, web notifications, and alarms, functioned as specified. Thus, this prototype is deemed effective in enhancing the efficiency of room security monitoring.**

Index Terms— **Early Fire Detection, Monitoring System, IoT (Internet of Things), Prototyping, Fire Detection Sensor.**

I. Introduction

A monitoring system is a process of interaction involving various activities, such as observation, review, and periodic supervision, aimed at preventing fires [1]. Fires are often caused by the negligence of individuals in the vicinity, especially due to cigarette butts being discarded improperly [2]. Despite smoking bans, violations frequently occur, increasing fire hazards [3]. Additionally, fires can also result from poor electrical connections, which can lead to short circuits [4].

Crowded places like shopping malls, hotels, and campuses have implemented monitoring systems to detect fires [5]. This system involves monitoring each room directly, requiring physical visits to these locations every day, which can be time-consuming. Currently, the existing systems have shortcomings; when a room detects fire, the alarm sounds but does not provide information about the exact location of the fire. Furthermore, this alarm system can be manipulated, leading to false alarms without an actual fire.

This research aims to design a fire detection system based on IoT and SMS gateway using Arduino. Data transmission is performed via IoT, with Arduino connected to temperature, smoke, and flame sensors, relying on an internet connection through the SIM 900 module. This IoT-based data transmission accelerates fire information delivery, allowing for quicker access and reducing the likelihood of data manipulation. However, this system still does not provide specific details about the fire location.

IoT-based fire detection systems offer several advantages over conventional fire safety technology. Traditional technology generally uses smoke or heat sensors that only trigger a local alarm when signs of fire are detected. These systems have limitations as they do not provide specific information about the fire's exact location and only give general warnings [6]. In contrast, IoT-based systems utilize various sensors, such as flame, smoke, and temperature sensors, which are connected via the internet to detect fires more quickly and accurately. The specific location of the fire can be immediately identified, enabling a faster and more targeted response [7].

Additionally, IoT-based systems have advantages in notification and response. Conventional technology relies solely on local alarms, requiring a physical presence to follow up on fire alerts. On the other hand, IoT-based systems can send real-time notifications through various platforms, such as smartphone applications or instant messaging, to relevant personnel or building owners [8]. This allows for rapid action even when individuals are not on-site. Remote monitoring and control capabilities are also a major advantage of IoT-based systems. With internet connectivity, these systems enable real-time condition monitoring and remote activation of fire suppression devices via an online platform. This is not possible with conventional systems, which are limited to local monitoring [9].

Another advantage is flexibility in integration and scalability. IoT-based fire detection systems can easily integrate with other building management systems, such as security or HVAC (Heating, Ventilation, and Air

Conditioning) systems. These systems can also be scaled as needed, making them applicable to various types of buildings, from residential homes to large industrial facilities [10]. In contrast, conventional systems tend to be standalone and difficult to integrate with other technologies.

Despite these advantages, implementing IoT-based fire detection systems on a large scale presents several challenges. One of the main challenges is dependency on the availability and stability of internet networks. In areas with inadequate network infrastructure, real-time data transmission and notifications may be disrupted, reducing the system's effectiveness [11]. Additionally, data security concerns arise because these systems are connected to the internet, increasing the risk of cyberattacks that could compromise system integrity and reliability [12]. Therefore, data protection and cybersecurity measures must be a priority in its implementation.

Initial implementation costs also pose a challenge for adopting IoT-based systems. While operational costs may be more efficient in the long run, the initial investment for hardware, software, and network infrastructure can be a barrier for some organizations or individuals [13]. Furthermore, compatibility among IoT devices remains an issue, as different devices and platforms may have varying communication standards. Standardizing communication protocols is crucial to ensure interoperability between devices within the system [14]. Lastly, maintenance and technical support are critical factors to consider. IoT systems require regular maintenance and adequate technical support to function optimally. A lack of skilled personnel in maintenance may affect the system's performance and reliability in the long term [15]. Considering these comparisons and challenges, large-scale implementation of IoT-based fire detection systems requires careful planning. Strategies must include reliable network infrastructure, strict data security policies, and continuous maintenance to ensure these systems maximize their benefits in enhancing fire safety.

Therefore, this study proposes the development of a monitoring prototype capable of detecting fires and providing detailed information about the affected room, as well as automatically spraying water at the fire location. This system uses a web platform, requiring only an operator for supervision. Equipped with an alarm notification system, this allows for quicker fire response. The rooms capable of detecting fire are those that have flame detection sensors installed. The flame detector operates with the support of a microcontroller (Arduino Nano) serving as the control center for all devices, using the ESP8266 Wi-Fi module to connect the sensors to the internet, enabling the Arduino to send sensor data to the web platform.

II. THEORITICAL BASIS AND RESEARCH METHODS

In this research, it is crucial to understand the concepts underlying the development of a room security monitoring system for early fire detection. Therefore, we will explain the relevant theoretical framework as well as the research methods employed to achieve the objectives of this study.

Theoretical Framework

1. **Monitoring System**
   A monitoring system is a method for continuously observing and evaluating a condition or process [16]. In the context of fire, this system functions to detect early signs of fire, such as smoke or increased temperature, allowing for prompt preventive actions to be taken. "IoT technology facilitates real-time data collection and remote monitoring via the internet [17].
2. **Early Fire Detection**
   Early fire detection is a crucial initial step in preventing significant losses due to fires [18]. This detection system typically employs various types of sensors, such as smoke sensors, temperature sensors, and flame sensors. These sensors operate by detecting physical changes that indicate the presence of fire. The sooner the detection occurs, the greater the likelihood of mitigating the impact.
3. **Prototyping**
   The prototyping method is an approach in system development that involves creating an initial model of the system to be built [19], [20]. This prototype is used to test the concepts and features of the system before further development takes place. In the context of this research, prototyping is utilized to develop a monitoring system that can effectively and efficiently detect fires.
4. **Black-Box Testing**
   Black-box testing is a software testing method that focuses on the functionality of the system without considering its internal structure or code [21], [22]. This method aims to ensure that the system operates according to specified requirements and can handle input correctly. In this research, black-box testing is employed to evaluate various features of the developed monitoring system.

Research Methodology

1. **Type of Research**
   This research employs an experimental research design [23], [24]. Experimental research is conducted to evaluate the effectiveness of the monitoring system in detecting fires.
2. **Prototype Development**
   The method used in this research is the prototyping method. The fire monitoring system prototype will be designed and developed in stages. Each stage of development will be evaluated and refined based on the testing results [25], [26].

3. **System Testing**
   System testing is conducted using the black-box testing method. In this testing, all features and functionalities of the system will be tested to ensure that the system operates as expected. Testing will involve providing specific inputs to the system and checking the output generated, as well as verifying whether the system can accurately detect fires and send notifications promptly.
4. **Data Collection**
   Collected data will include response time, detection accuracy, and alarm frequency. This data will be analyzed to evaluate the effectiveness of the developed monitoring system [27], [28].
5. **Results Evaluation**
   After testing is completed, the results will be evaluated to determine the strengths and weaknesses of the system. This research aims to produce recommendations for further improvements and the application of the monitoring system in a broader context.

Literature Review: Comparison of Fire Detection Technologies and IoT Advances in Fire Safety

1. Fire Detection Technologies

Various fire detection methods have been developed using sensor-based approaches, image analysis, and artificial intelligence. The main technologies in fire detection include:

- **Smoke Sensors**: These sensors use photoelectric or ionization principles to detect smoke particles generated by combustion. This technology is widely used in conventional detection systems due to its reliability in detecting early-stage fires [29].
- **Temperature Sensors**: These sensors detect significant temperature increases in a room. Commonly used temperature sensors include thermocouples and thermistors, which enable fire detection with a quick response to abnormal temperature spikes [30].
- **Flame Sensors**: Operating by detecting specific light spectra emitted by flames, such as ultraviolet (UV) or infrared (IR) light. These sensors are effective in detecting fully developed fires but are less sensitive to early-stage fires [31]..

2. Comparison of Fire Detection Technologies

Table 1. Comparison of Fire Detection Technologies

Detection Technology	Advantages	Disadvantages
Smoke Sensors	Sensitive to early-stage fire smoke	May generate false alarms from non-fire smoke [29]
Temperature Sensors	Unaffected by smoke or dust	Slow response to fires that do not rapidly increase temperature [30]
Flame Sensors	Direct detection of flames	Less effective for early-stage fires [31]

3. IoT Advances in Fire Safety

The Internet of Things (IoT) has significantly improved fire safety by enabling real-time data collection, remote monitoring, and automated response. Key innovations in IoT-based fire safety include:

- **Connected Detection Systems**: Smoke, temperature, and flame sensors can be integrated into IoT networks to send real-time alerts to mobile devices or monitoring center s[32].
- **Data-Driven Prediction and Analysis**: Utilizing big data and AI to analyze fire trends, predict potential fires, and optimize prevention strategies [33].
- **Integration with Smart Buildings**: IoT technology allows fire detection to be connected to ventilation systems, alarms, and sprinklers for automatic response to minimize fire impact [34].
- **Emergency Communication Systems**: Using IoT to automatically provide evacuation instructions via mobile applications, text messages, or smart speakers to reduce panic and improve evacuation efficiency [35].

4. Challenges of IOT Fire Detection

Advancements in IoT-based fire detection technology have enhanced efficiency and speed in detecting and responding to fires. However, challenges remain, such as battery life limitations in IoT devices, data security, and relatively high implementation costs. Therefore, the development of more efficient and affordable systems remains a key focus in improving global fire safety.

III. Research Stages

Research Methodology

In the experimental phase of the room security monitoring system prototype for fire detection, the following stages are used:

1. Hardware Design

The hardware design starts with:

a. Connecting the ESP8266 module to the Arduino,
b. Connecting the Arduino to the network using the ESP8266.

2. Software Design

The software design starts with:

a. Writing the Arduino code,
b. Creating the web interface,
c. Connecting the web and Arduino.

3. Prototype Design

The prototype design starts with:

a. Designing the placement,
b. Conducting hardware testing,
c. Conducting software testing.

4. Device Testing

Device testing starts with:

a. Testing the sensors against room conditions,
b. Testing the Arduino against the network,
c. Testing the web against the device.

Tools and Materials

To create a well-functioning room monitoring system, the tools and materials used in this research are as follows:

1. Arduino Nano module (Arduino software as IDE)
2. ESP8266 Wi-Fi module
3. Flame Detector
4. Transformer
5. Motor Washer
6. Laptop
7. Supporting electronic devices
8. Sublime Text software (used for web programming).

Prototype Design

The prototype design for the room security monitoring system for fire detection in this research consists of software design, hardware design, and prototype design that mutually support each other as a medium in the creation of this system.

1. Software Design

The software design for the room security monitoring system for fire detection uses two programming software:

a. Arduino IDE:

In this research, the software "Arduino 1.8.1" is used to create the program for the device so that it can function as expected.

b. Sublime Text:

In this research, the software "Sublime Text 2" is used for web programming in the monitoring system.

2. **Hardware Design:**

The hardware design of the room security monitoring system for fire detection consists of several components:

a. Wi-Fi Network:

Functions as the main processor of the monitoring system to ensure data can be sent to the web.

b. ESP8266 Module:

Functions to connect the Arduino microcontroller board to the network.

c. Arduino Nano:

Functions as the control center for all devices. The Arduino receives data from all sensors and then sends it to the web with the help of the Wi-Fi module to connect to the network.

d. Flame Detector:

Functions to detect the presence of fire in the room.

e. Laptop

Functions to monitor the rooms equipped with detection sensors.

f. Motor Washer Modul:

Functions to automatically release water when a fire occurs.

The design of the hardware created by the researcher corresponds to the design illustrated in Figure 1.

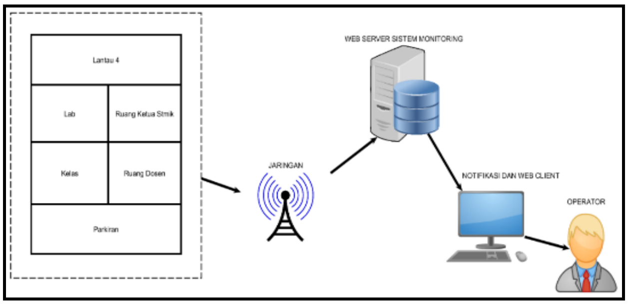

Fig. 1. Hardware Design

System Design Analysis

The system design analysis for the room security monitoring system for fire detection in this research consists of a prototype block diagram and a flowchart, which aim to illustrate how a system is constructed or planned for better understanding.

1. **Prototype Block Diagram**

The first process occurs at the input block, where the sensor sends data to the Arduino. The second process takes place in the process block, where the data from the input block is processed by the microcontroller processing system (Arduino). The Arduino receives sensor data, and before sending the sensor data to the web, it must be connected to the local network (Wi-Fi). To connect the device, the ESP8266 Wi-Fi module is required. The third process occurs at the output block, where the web receives data in the form of fire information, and the web will display an alarm notification and the status of "fire occurred" on the web interface when a fire occurs. Additionally, the device will automatically release water when a fire occurs (when the sensor values meet the specified thresholds) as generated by the process block from the input block.
The block diagram is divided into two parts: a general block diagram and a specific system design, which can be seen in Figure 2.

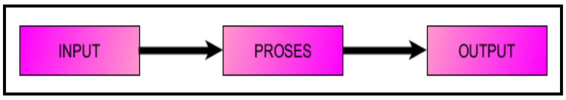

Fig. 2. Hardware Design

Based on the general block diagram of the device, the specific electronic block diagram to be created can be seen in Figure 3.

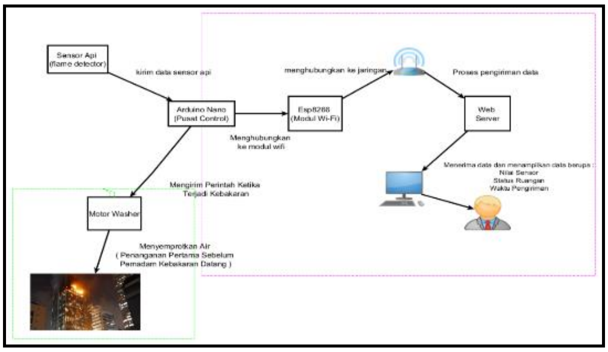

Fig. 3. the specific electronic block diagram

2. **Flowchart**

The flowchart is used to easily understand the flow of the system to be developed. It is also used to resolve issues encountered during programming of the system. Below is the flowchart for the room security monitoring system for fire detection.

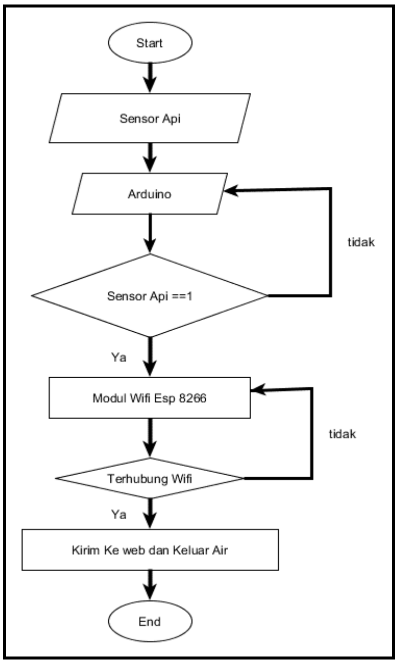

Fig. 4. Flowchart Diagram

IV. Research Result

Results of the Fire Safety Room Monitoring System Prototype

The prototype uses a frame made of 8 mm plywood, forming a design of three rooms designed to resemble **inside a building**. Of the three rooms, two are equipped with sensors, and one room is used to store all necessary components. This prototype will send the data received by the Arduino from the sensors, and the laptop will display it on the website, allowing the operator to know the status inside the room. The design of the fire safety room monitoring system prototype can be seen in Figure 5.

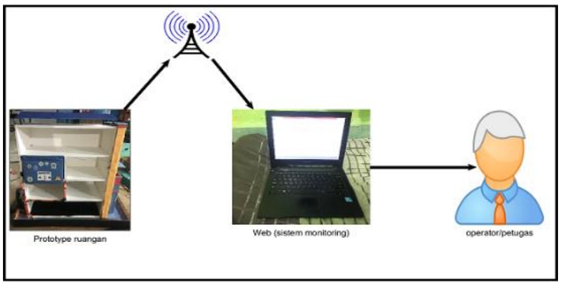

Fig. 5. design of the fire safety room monitoring system prototype

Results of the Website Display

The website design is divided into two parts:

1. **Results of the Home Page Display**

The home page of the fire safety room monitoring system website is the first page that appears when this website is accessed. On the left side of the page, there is an explanation of the system created, and on the right side, there are menu features to access the monitoring system.

Fig. 6. **Home Page Display**

2. **Results of the Monitoring System Display**

The design of the monitoring system page is for monitoring the rooms equipped with sensors.

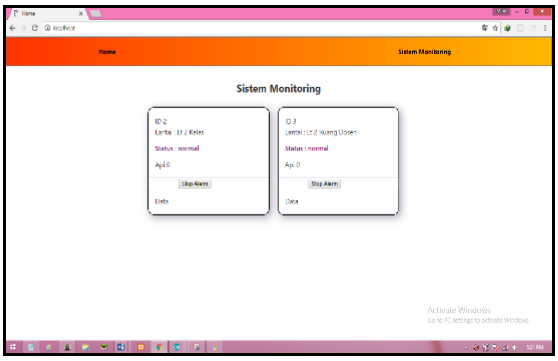

Fig. 7. Monitoring System Display

Prototype Testing

In this prototype testing, the researcher uses a fire object for fire simulation. The object tested can be seen in Figure 8.

Fig. 8. Object Tested

1. Sensor Testing Against Room Conditions

Fire sensor testing is conducted in each prototype room where sensors are installed. The first test is performed in Room 1 (lecturer's room), and the second test is performed in Room 2 (classroom). Below is Figure 9, which identifies and describes each fire sensor in this prototype fire safety room monitoring system test.

Fig. 9. Room Conditions

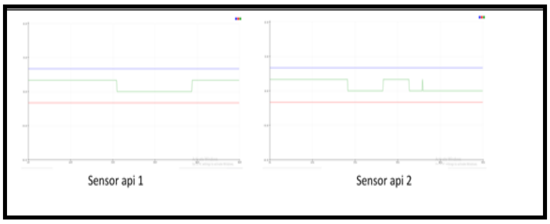

Fig. 10. Graph of sensor reading results

a. Sensor testing of room conditions 1

In the first test of the fire sensor, the value obtained when the device is first turned on is fire sensor = 0. The data from the fire sensor is 1/0. The fire sensor will detect when a fire occurs, as shown in Table 1.

Table 1. Sensor testing of room conditions 1

No	FLAME SENSOR VALUE	Status	Sent Status	Success Status
1	0	x	send it to the website	1
2	1	√	send it to the website and splash water	1

Table 1. Sensor testing of room conditions 1

No	FLAME SENSOR VALUE	Status	Sent Status	Success Status
1	0	x	send it to the website	1
2	1	√	send it to the website and splash water	1

Description:

Sensor Reading Status:
X Not Detected
√ Detected

Fire Sensor:
0 No fire
1 Fire present

Success Status:
1 Success
0 Failed

It is known that the trials conducted were done twice, resulting in a success status of two times.

Success Percentage:
= Success/(Total Tests) x 100%
= 2/2 x 100% = 100%
The success percentage of the sensor testing against room 1 conditions is 100%.

b. Sensor testing of room conditions 2

The second test is similar to the first, differing only in the room. The value obtained when the device is first turned on is fire sensor = 0, with the fire sensor data being 1/0. The results of the sensor readings using the provided object can be seen in Table 2.

Table 2. Sensor testing of room conditions 2

No	flame sensor value	Status	Sent Status	Success Status
1	0	x	send it to the website	1
2	1	√	send it to the website and splash water	1

Description:

Sensor Reading Status:
X Not Detected
√ Detected

Fire Sensor:
0 No fire
1 Fire present

Success Status:
1 Success
0 Failed

It is known that the trials conducted were done twice, resulting in a success status of two times.
Success Percentage:
= Success/(Total Tests) x 100%
= 2/2 x 100% = 100%
The success percentage of the sensor testing against room 2 conditions is 100%.

2. **Arduino Testing Against the Network**
Arduino network testing is conducted using the Arduino. First, the Arduino is connected to the ESP8266 Wi-Fi module, after which the Arduino is connected to the network to send sensor data to the website. Below are the results of programming tests using the Arduino microcontroller, as seen in Figure 11.

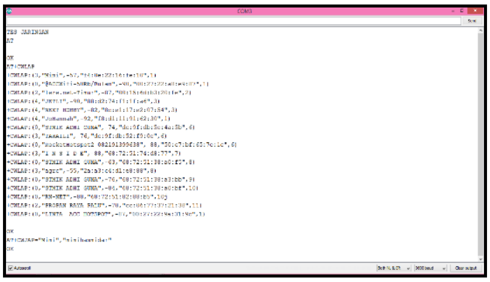

Fig. 11. the process of connecting to the network

The following table (Table 3) shows the testing of Arduino to connect to the network using the ESP8266 Wi-Fi module.

Table 3. Sensor Testing to Network

No	Connected to modul WiFi	Network Status	Sent Status	Success Status
1	X	X	Not Sent	1
2	√	X	Not Sent	1
3	√	X	Sent	1

Description:
Connected Modul Wifi:
X Not Detected
√ Detected

Network Status:
X Not Detected
√ Detected

Success Status:
1 Success
0 Failed

It is known that the trials conducted were done twice, resulting in a success status of two times.

Success Percentage:
= Success/(Total Tests) x 100%
= 3/3 x 100% = 100%
The success percentage of the sensor testing to network is 100%.

Website Testing Against the Device
Testing is conducted in rooms that have fire sensors installed. Below are the tests conducted on the fire safety room monitoring system prototype, as seen in Figures 12 and Figures 13.

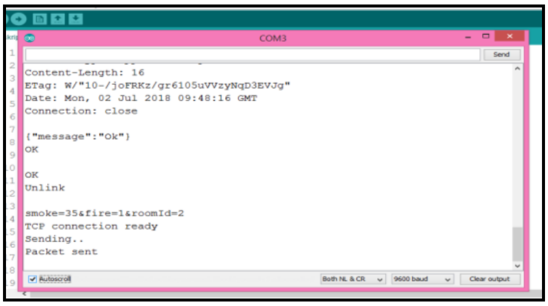

Fig. 12. Process of sending data from Arduino to the website

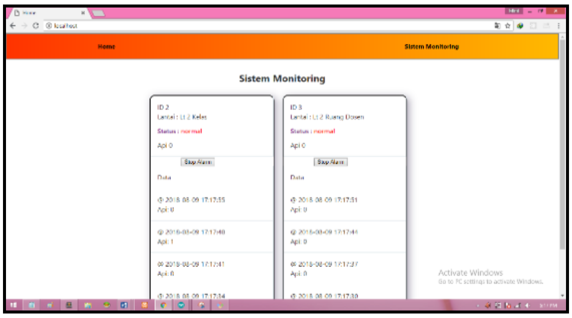

Fig. 13. Process of sending data from Website to the Arduino

Website testing against the device is performed in rooms equipped with sensors, and testing is conducted randomly. The tests are performed with predetermined objects. When the fire sensor detects a value of = 1, it means there is a fire, and if the value is = 0, there is no fire. The possibility of detecting a fire can be seen in Table 4.

Table 4. Sensor Testing to Network

No	Value of Flame Sensor	Website Indicator	Tools Indicator	Room	Success Status
1	0	Normal	X	Room 1	1
2	0	Normal	X	Room 2	1
3	1	Burnt	√	Room 3	1
4	1	Burnt	√	Room 4	1

Description:

Value Of Flame Sensor:
0 Not Detected
1 Detected

Website Indicator:
Normal
Burnt

Tools Indicator:
X Not Spraying Water
√ Spraying Water

Success Status:
1 Success
0 Failed

Final Results of the Fire Safety Room Monitoring System Prototype Testing

Testing is conducted under several sensor conditions and with several objects prepared by the researcher. In this testing, 10 running trials are performed. The final test results are displayed in Table 5.

Table 4. Sensor Testing to Network

No	Data Delivery Status / minute	Room	Website Status	Success Status
1	Sent	Room 1	Received Sensor Data	1
2	Sent	Room 1	Received Sensor Data	1
3	Sent	Room 1	Received Sensor Data	1
4	Sent	Room 1	Received Sensor Data	1
5	Sent	Room 1	Received Sensor Data	1
6	Sent	Room 2	Received Sensor Data	1
7	Sent	Room 2	Received Sensor Data	1
8	Sent	Room 2	Received Sensor Data	1
9	Sent	Room 2	Received Sensor Data	1
10	Sent	Room 2	Received Sensor Data	1

Description:

Data Delivery Status:
Not Sent
Sent

Website Status:
Not Received
Received

Success Status:
1 Success
0 Failed

Based on the test results in Table 5, the success rate is 100%, and the failure rate is attributed to unstable network connections. Due to the unstable network, the sensor data could not be sent to the website at that time; however, if a fire occurred, the device would still spray water in the room where the fire took place. It is known that the trials conducted were done 10 times, resulting in a success status of ten times.

Success Percentage
= Success/(Total Tests) x 100%
= 10/10 x 100%
= **100%**

The success percentage of the fire safety room monitoring system is 100%.

Additional Insights

Based on the testing results of the fire safety room monitoring system prototype, the system demonstrated a 100% success rate in transmitting sensor data to the network, with failures only occurring due to unstable network connections. However, even when the network was unstable, the device could still spray water in the event of a fire, ensuring that it functions according to its primary purpose.

Long-Term Reliability The long-term reliability of the system depends on several key factors:

1. Quality of Sensors and Electronic Components: The sensors used must be highly durable against extreme environmental conditions such as heat and smoke.
2. Network Stability: Since the system relies on data transmission to a website, a stable network or an alternative local data storage solution is required in case of connection loss.
3. Power Supply: The system should have a backup power source such as a battery or UPS to ensure functionality during power outages.
4. Resistance to External Interference: The device must be designed to withstand physical interference or environmental factors that could affect its performance.

Maintenance Requirements To maintain system effectiveness, several maintenance steps are necessary:

1. Regular Sensor Calibration: Sensors should be calibrated to ensure the accuracy of smoke and temperature detection.
2. Inspection of the Water Sprinkler System: Nozzles and pipeline routes should be checked to ensure there are no blockages or leaks.
3. Software Updates: The system should be updated to enhance data security and improve monitoring algorithm performance.
4. Network Connectivity Checks: Internet

connectivity should be periodically monitored to ensure data transmission and reception work smoothly.

Integration with Existing Fire Safety Systems For the system to be integrated with existing fire safety mechanisms, several aspects must be considered:

1. Compatibility with Fire Alarm Systems: The system should be able to communicate with conventional fire alarms to enhance response effectiveness.
2. Integration with Automatic Fire Suppression Systems: If feasible, the system should be able to activate other fire suppression devices such as gas or foam-based sprinklers.
3. Synchronization with Control Centers: The system should be able to transmit data to a monitoring center to enable swift action during fire incidents.
4. Regulations and Standardization: The system must comply with applicable fire safety standards to ensure widespread implementation across different environments.

By addressing these factors, this fire safety room monitoring system has great potential to be a reliable and effective solution for improving safety in various settings.

V. Conclusion and future work

The conclusion of this research indicates that the prototype of the room fire safety monitoring system has been successfully designed and tested, achieving a 100% success rate in detecting fires and transmitting data via the network. Testing conducted in two rooms equipped with sensors demonstrated a quick and accurate response to fire conditions, while tests on the hardware and network confirmed the system's stability and reliability. The results show that this system is effective in providing protection against fires within rooms and enhancing user awareness of the room's safety status through an informative website display. The implementation of this system is expected to be a significant solution for improving building safety in the future.

Future work will focus on integrating additional features, such as real-time notifications via mobile applications, incorporating advanced machine learning algorithms for better fire detection accuracy, and expanding the system to monitor other environmental factors like smoke and carbon monoxide levels. Furthermore, efforts will be made to enhance the user interface of the website for improved accessibility and usability, ensuring a more robust and comprehensive fire safety monitoring solution.

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