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Design and Construction of an ESP32-Based IoT Fire Alarm System to Differentiate Cigarette Smoke and Fire

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Abstract -This research aims to design and implement an Internet of Things (IoT)-based fire detection system using an ESP32 microcontroller. This system integrates a DHT22 sensor (temperature), an MQ-2 sensor (smoke/gas), and an IR Flame sensor (fire) to improve detection accuracy. In addition, the system is equipped with simple intelligent logic that is able to distinguish between cigarette smoke and fire smoke to minimize false alarms. Sensor data is processed in real-time by the ESP32 and used to activate a buzzer as a local alarm and send notifications via Telegram. Tests were conducted in three conditions, namely normal conditions, cigarette smoke, and fire. The results of the study show that the system is able to detect fires well and differentiate between cigarette smoke and fire based on a combination of sensor parameters. The system is also able to provide notifications quickly and responsively. This research provides an IoT-based security system solution that is effective, inexpensive, and easy to develop.

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I. INTRODUCTION

A. *Background*

Fires in buildings and residential areas are currently on the rise, making them the second most common disaster after floods. Some of the most common causes of fires in buildings and residential areas include fuel shortages, electrical short circuits, household appliances such as stoves (gas or electric), wall lamps or candles, cigarettes, mosquito coils, burning trash, and fireworks or firecrackers.[1] With the high number of fire accidents, every home must be safe and prepared for fire. However, many people still ignore safety aspects, especially in the event of a fire. The only solution is to extinguish the blaze as it grows with whatever means are available. The lack of monitoring equipment that can detect fires can lead to fires.[2] Homes left unattended by their owners are not immune to workplace accidents or hazards, one of which is fire. This dangerous aspect requires homeowners to have a work safety system in place. Urban fires typically involve short circuits in electrical wiring or equipment, gas leaks in LPG pipes, or human negligence, such as forgetting to turn off the stove or burning trash, which can cause a fire. Fires that are not handled quickly will certainly cause significant losses, both in terms of lives and property. This is caused by a number of factors, including delays in receiving information from firefighters and the absence of the home or building owner at the scene.[3] Smart devices are essential in both private and public residences to alert us to fires, which pose a significant risk to human life. Advances in telecommunications and technology can have a significant impact on daily life. The increasing number of modern and sophisticated inventions is evidence of this, and human demand for technology continues to rise.[4]

B. *formulation of the problem*

1. How do you design an IoT-based fire detection system using ESP32 and multiple sensors (MQ-2, *IR Flame,* and DHT22)?
2. How do you accurately classify cigarette smoke and fire using multi-sensor data?
3. How does the system perform in detecting fires and providing real-time notifications?

C. *research purposes*

1. Design and build an IoT-based fire detection system using ESP32 and MQ-2, IR Flame, and DHT22 sensors.

2. Develop a simple method to differentiate between cigarette smoke and fire based on multi-sensor data.
3. Test the system's performance in detecting fires and sending real-time notifications.

II JOURNAL PAPER PREPARATION

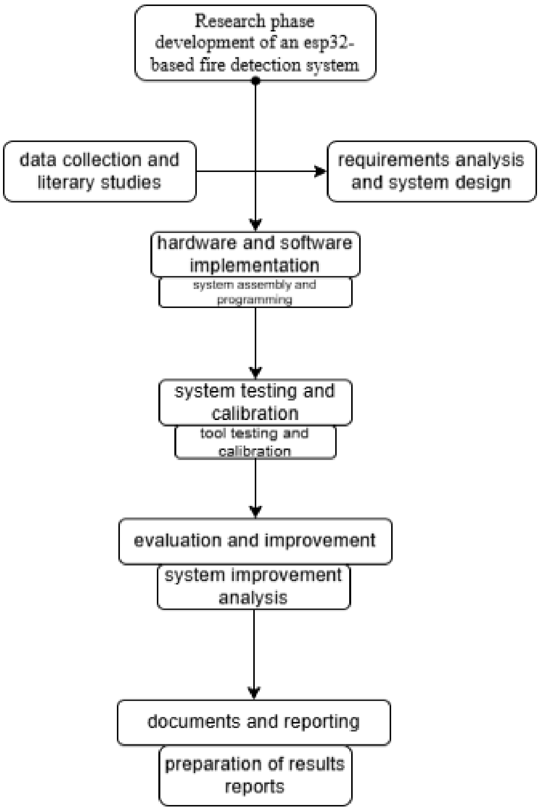


Figure 1 Research Flow

A. Explanation of the Research Flow

The research flow begins with data collection and literature review, which involves examining various references related to fire detection systems, sensor technology, and the Internet of Things concept used in the system. This stage aims to establish a theoretical basis to support the device design. The next stage is requirements analysis and system design, which involves identifying the hardware and software requirements to be used. This stage determines the use of several sensors, such as the DHT22 temperature and humidity sensor for temperature detection, the MQ-2 gas sensor module for smoke detection, and the IR flame sensor module for fire detection. After the system design is complete, the research continues with the hardware and software implementation phase. This phase involves assembling all hardware components and programming the microcontroller so that the sensors can read data and the system can send notifications over the internet. Next, system testing and calibration are conducted to determine the device's performance. Testing is carried out by simulating several conditions, such as normal conditions, cigarette smoke, and fire conditions, to ensure the system can effectively distinguish between each condition. The next stage is system evaluation and improvement, which is carried out by analyzing the test results. If errors or inconsistencies are found in the system, repairs are made to both the hardware and software. The final stage is documentation and reporting, where the entire research process, test results, and [4]research conducted.

B. Hardware implementation

The ESP32 is the successor to the ESP8266, offering several improvements across the board. It not only supports WiFi connectivity but also Bluetooth Low Energy, making the ESP32 even more versatile.[5], [6] [7]How the DHT22 sensor works, the semiconductor material in the temperature and humidity sensor reads the temperature and humidity values, then the data is sent to the Wemos in digital form simultaneously, the data transmission time between temperature and humidity data is very short, namely less than 40ms, so the reading will look like it is simultaneous.[8] [9], [10]The MQ-2 smoke gas sensor can be directly adjusted for sensitivity by rotating its trimmer. This sensor is commonly used to detect gas leaks in both homes and industry.[11], [12] This sensor detects the concentration of flammable gases in the air, and its output is read as an analog voltage. Gas leaks increase the sensor's conductivity, and the higher the gas concentration, the higher the sensor's conductivity.[3] [13]A power supply is an electronic circuit that functions as a converter of AC (alternating current) to DC (direct current).[14] The LM2596 Step-Down Module is a module that uses the LM2596 IC as its main component. The LM2596 IC is an integrated circuit that functions as a step-down DC converter or voltage reducer with a maximum current of 2A.[15] The buzzer in this detection device design acts as an audible alarm that provides an audible warning. The buzzer module is equipped with a piezo buzzer component connected to a digital output on the microcontroller.

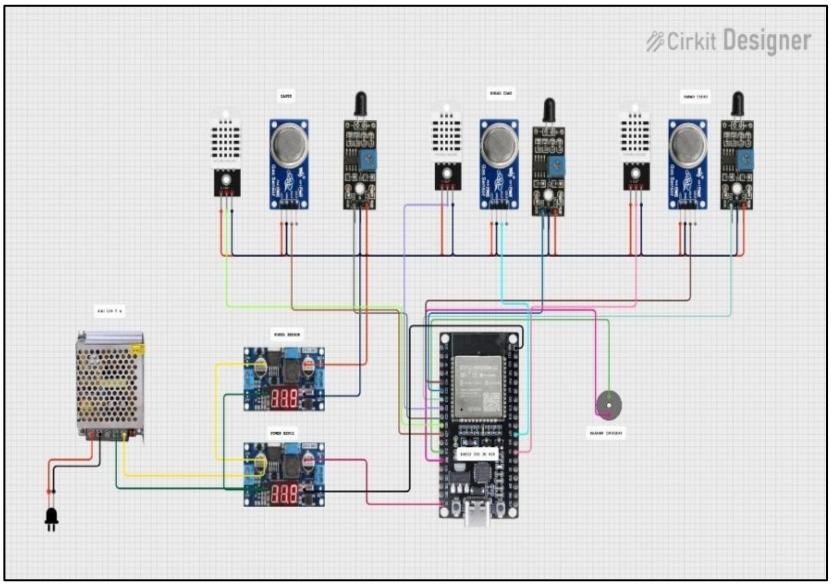


Figure 2 Tool Chain

The system is designed to ensure all components receive a stable voltage supply so they can operate optimally without interruption.The MQ-2 sensor in the circuit detects smoke and gas in the air. This sensor has a high sensitivity to various types of smoke, including cigarette smoke and smoke from combustion. The MQ-2 sensor is connected to the ESP32 analog pin to read changes in voltage that indicate the level of smoke concentration in the environment.

The flame sensor directly detects the presence of flames. This sensor is connected to the ESP32 digital pin. When fire is detected, the sensor sends a specific logic signal to the microcontroller. Flame detection is the primary indicator in determining fire conditions.

The DHT22 sensor is used to read the ambient temperature. This sensor is crucial because a significant increase in temperature is one of the early indicators of a fire. The DHT22 sensor is connected to the ESP32 digital pin to periodically read temperature data.

In addition to the sensor, the circuit is also equipped with a buzzer that functions as a local alarm. The buzzer will activate automatically when the system detects a fire based on a combination of sensor readings. This alarm aims to provide an immediate warning to the room's occupants.

C. Sofware implementation

Functional testing is conducted to ensure that each component operates according to specifications and performs its intended function. This testing is conducted in stages, starting with testing each sensor individually and working up to testing the entire system.The purpose of this testing is to determine:

- The sensor's ability to read environmental conditions.
- The system's response to changing conditions.
- The accuracy of the classification between cigarette smoke and fire.

• The ESP32's stability in processing data.

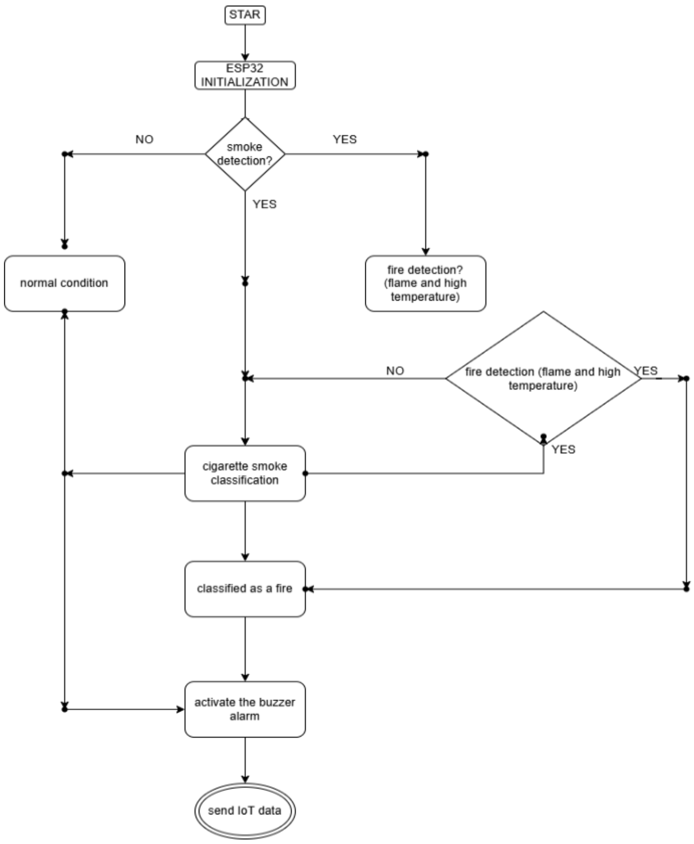


Figure 3 Software Flowchart

D. Data Acquisition & Testing Method

The research results show that the designed system performs as intended. The integration of three primary sensors provides more accurate detection capabilities than a single detection system. The system not only detects fires but is also able to distinguish between cigarette smoke, thus reducing false alarms common with conventional systems.

III RESULTS AND DISCUSSION

This subchapter presents the research results from the design, implementation, and testing of an ESP32-based IoT Fire Alarm system. These results were used to evaluate the system's overall performance, including hardware, software, and integration between components. They also assessed the system's ability to detect fires early and differentiate between cigarette smoke and fire.The system consists of an ESP32 microcontroller, an MQ-2 sensor, a flame sensor, a DHT22 sensor, a buzzer, and a WiFi connection, all working together to monitor environmental conditions in real time. Based on the test results, the system was able to classify conditions into three categories: normal, cigarette smoke, and fire, based on a combination of sensor readings.

1. Sensor Functional Testing

Functional testing is performed to ensure that each component operates according to specifications and performs its intended purpose. This testing is carried out in stages, starting with testing each sensor individually and working up to testing the entire system.

a) MQ-2 Sensor Testing

No	Condition	Sensor Valeu	Description
1	No smoke	Stable low	Valid
2	Cigarette smoke	Increased	Valid
3	Combustion smoke	Increased High	Valid

The MQ-2 sensor was tested under three conditions: smokeless, cigarette smoke, and combustion smoke. In the smokeless condition, the sensor displayed low and stable readings, representing normal environmental conditions. When exposed to cigarette smoke, the readings increased, indicating the sensor was capable of detecting moderate concentrations of smoke. Meanwhile, in the presence of combustion smoke, the readings were higher than in cigarette smoke, indicating a higher smoke concentration and a potential indication of a fire.Overall, the test results demonstrate that the MQ-2 sensor responds well to changes in smoke levels and is effective as a smoke detector in an ESP32-based fire alarm system.

b) Flame Sensor Testing

No	Parameter	Value	Description
1	Stable	5V	working voltage
2	response to fire	fast	accurate
3	Detection distance	±20–100 cm	Stable

Flame sensor testing was conducted to evaluate its performance in detecting fire based on its working voltage, response, and detection distance. The sensor operated at 5V and showed stable working conditions. In the response test, the sensor was able to detect fire quickly and accurately when the fire source was within range. In addition, the results of the distance test showed that the sensor could detect fire at a range of ±20–100 cm, depending on the intensity of the flame. Overall, the flame sensor has stable performance, fast response, and suitable detection range so it is effective for use as a fire detector in an ESP32-based fire alarm system.

c) DHT22 Sensor Testing

No	Condition	Temperature	Readable Description
1	Normal room	27–30°C	Valid
2	Near heat source	35–45°C	Valid
3	Fire simulation	>50°C	Valid

The DHT22 sensor was tested to evaluate its ability to detect temperature changes under various environmental conditions. Under normal conditions, the sensor showed stable readings in the range of 27–30°C. When brought close to a heat source, the detected temperature increased to around 35–45°C, indicating a good response to temperature changes. In a fire simulation, the sensor recorded temperatures above 30°C, indicating high heat conditions.Overall, the DHT22 sensor is capable of accurately detecting temperature changes from normal conditions to extreme heat, making it suitable for use as a supporting parameter in an ESP32-based fire detection system.

d) Buzzer Testing

Buzzer testing demonstrated that the alarm system operated according to its designed detection logic. Under normal conditions and in the presence of cigarette smoke, the buzzer was off because no fire indicator was detected, thus preventing false alarms. Conversely, under fire conditions, the buzzer activated in response to the combination of fire, dense smoke, and high temperature detection.Overall, the test results showed that the buzzer functioned properly and only activated under hazardous conditions, improving system accuracy and minimizing false detections.

e) Overall Sensor System Testing

Testing of the entire sensor system demonstrated that the integrated MQ-2, flame, and DHT22 sensors accurately determined environmental conditions. Under normal conditions, the system detected no smoke, fire, or high temperatures, thus classifying it as safe, with the buzzer turned off. Under cigarette smoke conditions, the system detected only smoke without any fire or elevated temperature, thus still not activating the buzzer. Meanwhile, under fire conditions, all three parameters (smoke, fire, and high temperature) were detected simultaneously, prompting the system to activate the buzzer as an alarm.Overall, the test results demonstrated that the system accurately classified environmental conditions and only activated the alarm in the event of a fire, thereby increasing system reliability and minimizing false alarms.

f) Integrated System Testing

Condition 1 – Fire

The system declares a fire if:

• Fire is detected
• Smoke is detected
• High temperature

```
MQ2: 4095 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 3788 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 3300 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 2937 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
Sensor 1: 1227 - API TERDETEKSI!
Sensor 1: 1072 - API TERDETEKSI!
Sensor 1: 1988 - API TERDETEKSI!
Sensor 1: 2288 - API TERDETEKSI!
```

The system logic is designed based on a combination of three main parameters: fire, smoke, and temperature detection. The system will classify a condition as a fire if the flame sensor detects fire, the MQ-2 sensor detects smoke, and the DHT22 sensor indicates a high temperature simultaneously. The combination of these three parameters forms the basis for decision-making because it represents a realistic combustion condition.When these conditions are met, the ESP32 microcontroller will activate a buzzer as a local alarm and send a warning notification via Telegram as a response to the emergency.

System action:

• Buzzer active

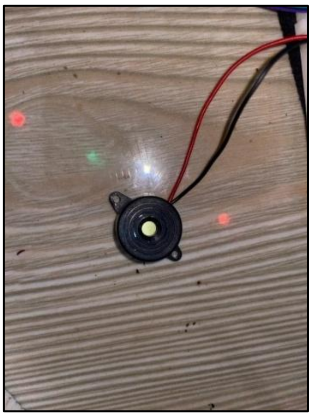


Figure 4 Buzzer

• Telegram notification sent

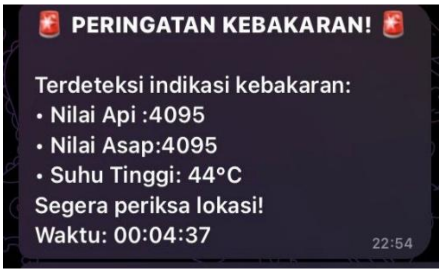


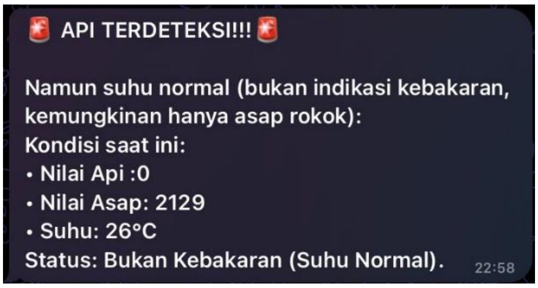
Figure 5 Telegram notification sent

• Sensor data is displayed in the serial monitor

```
📊 DATA SENSOR:
Fire: NO | Smoke: YES 💨 | Temp High: YES 🌡️ | Alarm: OFF 🟢
----------------------
Sensor 1: 4095 - API TERDETEKSI!
Sensor 2: 4095 - API TERDETEKSI! MQ2: 4095 - ASAP TERDETEKSI!
Suhu: 44.10°C - SUHU TINGGI!
✅ Notifikasi KEBAKARAN Telegram terkirim

📊 DATA SENSOR:
Fire: YES 🔥 | Smoke: YES 💨 | Temp High: YES 🌡️ | Alarm: ON 🔴
----------------------
MQ2: 4095 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 3788 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 3300 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
MQ2: 2937 - ASAP TERDETEKSI!
Suhu: 43.90°C - SUHU TINGGI!
```

Condition 2 – (Not a Fire)
The system declares a non-fire if:
• Smoke is detected
• Flame is not detected
• Temperature is normal
Program Logic:
When the system detects smoke but no flames or high temperatures, the situation is categorized as a non-fire. Smoke detected by the MQ2 sensor can originate from other sources, such as cigarette smoke, cooking steam, or cooking gas, which do not produce flames. In this situation, the flame sensor does not detect a fire source, and the DHT22 sensor indicates the room temperature is still within normal limits. This combination of parameters indicates that a fire has not occurred, so the system simply considers it an environmental disturbance or a normal activity producing a small amount of smoke. This logic is used to reduce false fire detections and prevent continuous alarms from sounding in non-hazardous conditions.
System action:
• Buzzer not activated.
• Smoke alert notification sent via Telegram.



• Sensor data remains displayed on the Serial Monitor as a means of monitoring room conditions.

```
Fire: NO | Smoke: YES 💨 | Temp High: NO | Alarm: OFF 🟢
----------------------
MQ2: 2725 - ASAP TERDETEKSI!
MQ2: 2610 - ASAP TERDETEKSI!
MQ2: 2501 - ASAP TERDETEKSI!
MQ2: 2379 - ASAP TERDETEKSI!
Fire: YES 🔥 | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
----------------------
Sensor 2: 3971 - API TERDETEKSI!
Sensor 1: 1074 - API TERDETEKSI!
Sensor 2: 4095 - API TERDETEKSI!
Sensor 1: 2250 - API TERDETEKSI!
Sensor 2: 3747 - API TERDETEKSI
```

Condition 3 – Normal Condition
The system is considered normal if:
• No fire is detected
• No smoke is detected
• The temperature is normal (no high temperature rise occurs)
Program logic:
When the system detects no smoke from the MQ2 sensor, no flames are detected by the flame sensor, and the temperature measured by the DHT22 sensor is within the normal range, the condition is classified as normal. In this situation, the environment is considered safe because there are no early indications of a potential fire or cigarette smoke disturbance.This combination of parameters indicates that there is no combustion activity, no significant smoke particles in the air, and no increase in room temperature.

Therefore, the system does not need to initiate a warning or activate an alarm. This logic serves as a baseline in the monitoring system, so that any changes can be compared to this normal state.The existence of a normal state is crucial in an IoT-based fire detection system because it serves as the primary reference in the classification process. By maintaining a normal state when there are no indications of danger, the system can operate stably, avoid false alarms, and ensure that alarms are only activated in situations that pose a real risk.

System action:

• The buzzer or alarm is turned OFF.

• The system displays "Normal" on the Serial Monitor to indicate that the room is safe.

```
📊 DATA SENSOR:
Fire: NO | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
----------------------

📊 DATA SENSOR:
Fire: NO | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
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📊 DATA SENSOR:
Fire: NO | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
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📊 DATA SENSOR:
Fire: NO | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
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📊 DATA SENSOR:
Fire: NO | Smoke: NO | Temp High: NO | Alarm: OFF 🟢
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```

• The system returns to the process of continuously reading sensors to detect possible changes in environmental conditions.

Based on the design, construction, and testing of the device, titled "Design and Construction of an ESP32-Based IoT Fire Alarm System for Differentiating Cigarette Smoke and Fire," the following conclusions can be drawn:

1. An ESP32-based fire detection system was successfully designed and implemented by integrating an MQ-2 sensor as a smoke detector, a flame sensor as a fire detector, and a DHT22 sensor as a temperature detector.
2. The system is able to differentiate environmental conditions into three main categories: normal, cigarette smoke, and fire, based on the combined readings of the three sensors.
3. The MQ-2 sensor can effectively detect changes in smoke levels, indicated by low values when smoke is absent, increasing when exposed to cigarette smoke, and increasing significantly when smoke is present.
4. The DHT22 sensor can stably detect temperature changes, ranging from normal room temperature to high temperatures in a simulated fire, making it suitable for use as a supporting parameter for fire detection.
5. The flame sensor demonstrates a fast and accurate response in detecting fire with a detection range of approximately 20–100 cm.
6. The buzzer as an alarm operates according to the system's logic, namely:

• Inactive under normal conditions

• Inactive under conditions of cigarette smoke

• Active under conditions of fire

7. Based on the results of testing the entire system, the device is capable of providing accurate early warnings in the event of a fire and minimizing false alarms due to cigarette smoke.

Thus, the designed system can function well as an intelligent and reliable early fire detection tool.

Some suggestions for future system development are as follows:

1. The system can be expanded by adding more sensor points to expand the fire detection range, especially for homes with multiple rooms.
2. Using sensors with a higher sensitivity level can improve accuracy in distinguishing cigarette smoke from fire smoke.

3. The system can be combined with automatic extinguishing devices such as water pumps or sprinklers to not only detect but also take initial action to extinguish fires.
4. Testing on a larger scale and in different environmental conditions is needed to obtain more diverse data and improve system reliability.
With further development, it is hoped that this tool can become a more optimal solution for preventing and reducing the risk of fire in homes and buildings.

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