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Solar-Powered IoT-Based Home Fire Early Warning and Protection System

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ABSTRACT

This paper presents the implementation of a prototype of a fire early warning system in a residential house using temperature and smoke sensors supplied by an Internet of Things (IoT) based solar module. The 10Wp solar module serves as the energy source, connected to a 12V battery via a solar charge controller (SSC). The Arduino Uno serves as a microcontroller or controller for the proposed system model. NodeMCU functions as a wifi module for communication between the Microcontroller and Android. The system starts working with Arduino Uno and NodeMCU in an on condition and is connected to the internet. Data retrieval is carried out through testing by the MQ-2 Sensor and LM35 Sensor, respectively, to detect smoke (gas) and heat. The system then activates the buzzer, sends data on the status and level of smoke (gas) and heat to the smartphone screen and liquid crystal displays (LCDs) in the form of an alarm, and orders the PLN switch to operate, cutting off the electricity. The results of the tool test show that the proposed prototype can provide early warning notifications regarding the status and level of smoke (gas) and heat, both from the LCD and remotely from the smartphone, and is able to activate the relay and order the switch to cut off the electricity, thereby preventing a fire. The prototype system's source is supplied by solar modules independently, making it applicable in remote areas with limited electricity access- compared to the previous model, which was supplied solely by the electricity grid.

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1. INTRODUCTION

Internet of Things (IOT), a concept where various physical devices (such as sensors, gadgets, machines, or everyday objects) are connected to the internet and can communicate with each other and `exchange data without direct human intervention [1]-[5]. IoT brings about a major transformation with advantages such as efficiency, automation, and ease of access. However, data security and device compatibility remain challenges that must be addressed. With the development of technology, IoT will further strengthen its role in various sectors of life [6]-[9].

Sensors are a critical component in IoT as they act as "senses" that collect data from the physical environment [11],[12]. The data collected by sensors is then processed and used to control other devices or provide helpful information[13]-[15]. IoT sensors are the backbone of modern technology, allowing the physical world to connect with the digital world. As technology advances, sensors will become smaller, smarter, and integrated with AI for more complex solutions [16]-[18].

Fire is a disaster that can cause significant losses to life and property [19]-[23]. Based on this risk, it is necessary to develop an effective and efficient early detection system for fire prevention to protect the safety and security of users and buildings [24]-[28]. A prototype of a web-based home fire early warning system using

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the Wiznet W5500 Ethernet module has been developed in [29]. This system protocol enables users to send fire information via the internet using the IoT method, with the Wiznet Ethernet module serving as the communication medium. A fire warning system for apartment buildings using the IoT concept has been designed in [30]. This design was built using fire sensors, smoke sensors, Arduino Uno as a client and Raspberry Pi. Telemetry Modules and IoT-based early Warning Systems in the Microprocessor and Interface Laboratory have been developed in [31]. The prototype of the tool is capable of functioning as a temperature telemetry module, fire early warning system, and flood early warning system based on IoT. The prototype of a fire detection device using an Arduino-based smoke sensor and temperature sensor monitored by an SMS gateway has been implemented in [32]. The proposed system is capable of detecting the presence of smoke and an increase in room temperature, and then sends fire information remotely via an SMS Gateway to the user.

An Arduino Uno-based early warning and fire location identification information tool has been developed in [33]. The hardware used is a fire sensor, smoke sensor, temperature sensor, SMS information via a GSM module, and a global positioning system (GPS) module to read the coordinates of the fire location. An early fire warning system has also been developed in [34]. The difference is that the proposed tool lacks a GPS filter to identify the location of the fire. Research that develops early warning systems for smartphones based on temperature, humidity, MQ139, TVOC, eCO2, and total volatile organic compounds (TVOC) measured by sensor devices [35]. An innovative UAV-based Internet of Things (UIoT) system for monitoring, detecting, and suppressing forest fires in the air. For widespread use, a low-cost, low-maintenance IoT node architecture for fire detection is offered [36]. The suggested system exhibits notable benefits in terms of timeliness, accuracy, and efficiency. It uses a mix of fire and smoke sensors, a Raspberry Pi 3 B+ for data processing, and a ThingSpeak cloud platform for real-time data storage and display [37].

A vision-based indoor smoke and fire detection system is presented by [38]. Existing models based on Faster R–CNN Inception V2 and SSD MobileNet V2 models are explored and adopted. Small training and testing datasets, specifically for the indoor fire case, are used with varying pixel densities in images. Initial evaluation of the approach is done by testing both models on videos, including simulated bedrooms and living rooms as well as CCTV videos of office spaces.

An automatic early warning system with the synchronization of firefighters based on IoT has been designed in [39]. This system can detect and provide real-time temperature information to firefighters and warehouse owners. The system is able to work if there is a drastic change in temperature and smoke occurs immediately after being detected by the sensor. The performance of a gas sensor circuit for detecting smoldering and plastic fires while ensuring the rejection of a series of disturbances is presented [40]. Various fire and disturbance experiments in a validated standard fire chamber (240 m3) using PLS-DA and SVM. The prototype of the IoT-based fire detection system at Labuhanbatu University has been investigated in [41]. The system is capable of detecting fires using temperature sensors, gas sensors, and fire sensors, with a sensitivity accuracy of 90% for each sensor. The control of the fire alarm system using Arduino Uno has been observed in [42]. The proposed system is capable of detecting abnormal temperature increases and smoke and provides a warning of potential fires in the form of an alarm sound. The Deep Learning model with IoT systems to monitor, detect, and alert fire in various places like forests, apartments, industrial buildings, etc have been proposed in [43]. A pre-trained Convolutional Neural Network (CNN), namely MobileNet, is used in Deep Learning as a base model. Transfer learning is used to develop FireNet architecture for fire detection tasks.

Previous research on the prototype of the fire early detection, control, and monitoring system in residential homes has mostly still utilized PLN electricity. The weakness of this system is that it can only be applied in urban areas and cannot be implemented in remote areas with limited electricity access. The study proposes a prototype of an early warning and fire control system for residential homes, utilizing temperature and smoke sensors supplied by IoT-based solar modules. The 10 Wp solar module is the energy source connected to the battery via SCC. The Arduino Uno serves as the controller for the proposed model. NodeMCU functions as a Wifi module for communication between the microcontroller and Android. The proposed system is expected to be able to detect smoke (gas) and temperature levels as the leading indicators of fire, to be able to provide initial information on fire status to users remotely by the buzzer to the smartphone using Kodular-android application and LCD screens and to be able to activate the relay to order the home switch to cut off the flow of electricity. The paper is structured into four sections. Section 3 discusses the description and flow materials of the proposed research method. Section 4 reveals the simulation results and discussion containing the results of the tool implementation, the results of the solar module and battery voltage testing, the results of the software design, the solar module and battery voltage testing, the smoke sensor testing, the temperature sensor testing, the relay breaker and buzzer testing, and the LCD testing. Finally, the conclusions and limitations are disclosed in Section 4.

2. METHOD

2.1. Proposed Model

Figure 1 illustrates the prototype design of a fire early warning system for a residential house, utilizing temperature and smoke sensors powered by a solar module based on the Internet of Things (IoT) concept. The 10 Wp solar module is the primary power source of the proposed model. The 12V battery functions as a storage for energy generated by the solar module. SCC functions to control the charging and discharging process between the solar module and the battery. Arduino Uno functions as a microcontroller or controller of all the processes of the proposed system model. NodeMCU functions as a wifi module for communication between the microcontroller and Android. The buzzer module serves as an output device for the sensor, producing sound. The MQ-2 sensor functions as an input device to detect smoke or gas.

The LM35 sensor is an input device used to detect high temperatures. RTC is a component that records the time when the sensor detects an event. The 16 x 2 LCD module serves as an output, displaying the tool's work results on a written screen to help users view the status. The alarm activates the bell when the sensor detects smoke and heat, indicating the presence of a fire. The 5 V relay module functions as a PLN electricity switch breaker that automatically works when the smoke and heat sensors detect.

Figure 2 illustrates the flowchart of a fire early warning system in a residential house, utilizing temperature and smoke sensors powered by an IoT-based solar module. The system starts when the Arduino Uno and NodeMCU are powered on and connected to the Wi-Fi internet signal. Furthermore, the sensor retrieves data by detecting the presence of smoke and heat. The system will then activate the buzzer, send data from the smoke and heat status detection results to the mobile phone and LCD screens, and instruct the PLN switch to cut off the electricity supply to the house.

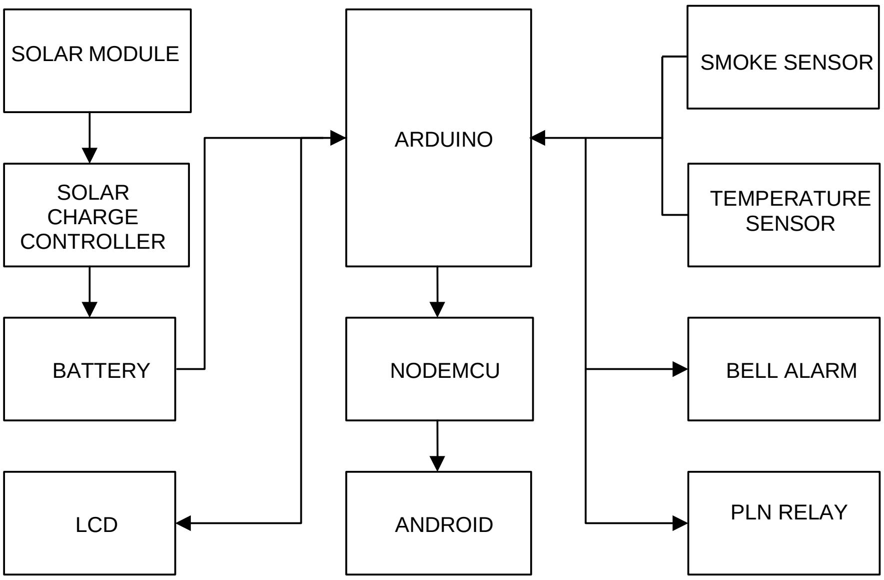


Figure 1. Prototype Design of Fire Early Warning System in Residential Houses

2.2. Battery Voltage Validity Test

Battery voltage testing employs two methods: using a multimeter and an LCD. To determine the measurement accuracy and performance of the prototype tool, the results of the multimeter measurements must be compared with the results of the LCD measurements. The results of the comparison of measurement data between multimeter testing and LCD measurements produce a difference in the percentage error of the battery voltage value, which is formulated in the following Equation (1):

$$Error\ (\%) = \frac{Multimeter\ Measurement - LCD\ Measurement}{Multimeter\ Measurement} \times 100\% \quad (1)$$

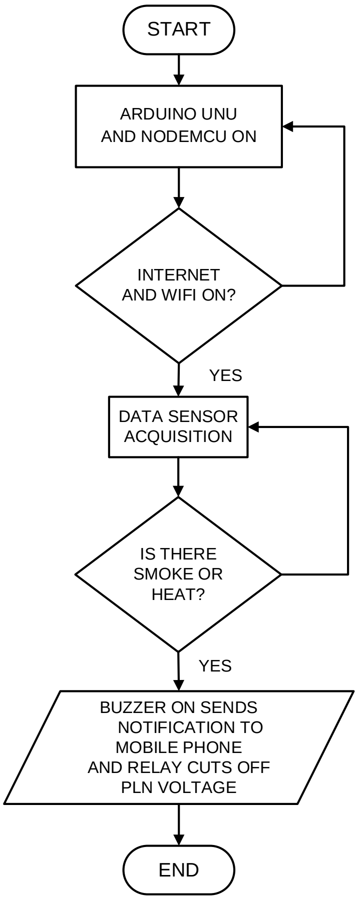


Figure 2. Flowchart of Fire Early Warning System in Residential Houses

3. RESULTS AND DISCUSSION

3.1. Tool Implementation

Figure 3 illustrates the hardware design of the prototype monitor and control system for the railway crossing using ATS. The numbering in the figure indicates the parts used in the equipment. The parts i.e. (1) 10 Wp Solar Module, (2) 12 V Battery, (3) Solar Charge Controller, (4) Arduino Uno, (5) NodeMCU, (6) Buzzer Module, (7) MQ-2 Smoke Sensor, (8) LM 35 Temperature Sensor, (9) RTC, (10) 16 x 2 LCD, and (11) 5 V Relay Module.

Figure 3. Prototype of IoT-Based Solar Powered Home Fire Early Warning System

3.2. Software Design Results

This study utilizes software in the form of an App Inventor application. In this inventor application, there is an application called Kodular. The software display can be viewed on the smartphone screen, where the results are shown in Figure 4. On the smartphone screen, users can view the display of the smoke content level (gas) and the temperature level of the detection results from the two sensors, each displayed in ppm and degrees Celsius. The smartphone is also equipped with a reset button to help users if they need to re-measure with the same or a different gas (smoke). Users can also view the test history, which includes the date and time the sensor detected smoke (or gas) and the corresponding temperature.

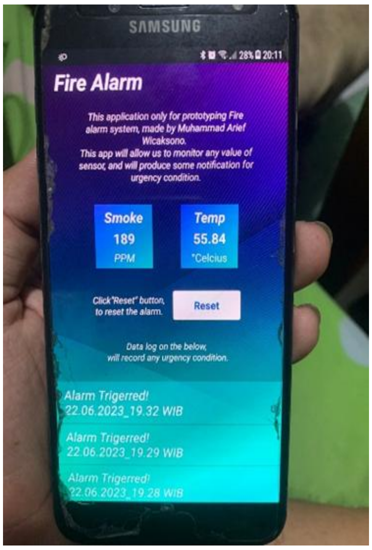
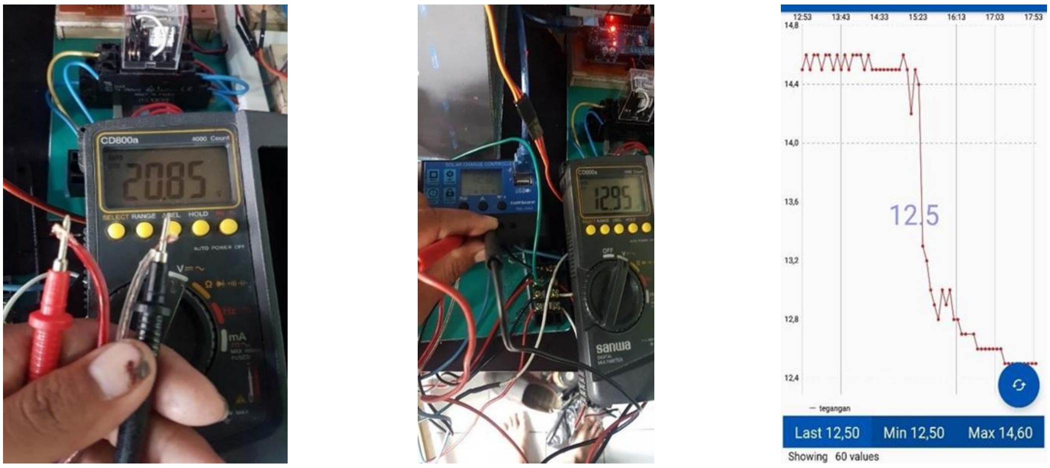


Figure 4. Android Application Display on Smartphone Screen

3.3. Solar Module and Battery Voltage Testing

Figure 5a shows the measurement of the output voltage value of the solar module. Testing the output voltage of the solar module is necessary because it affects and influences the performance of the SCC. The procedure for testing the output voltage on the solar module includes: (1) Placing the solar module in the correct position so that it is exposed to sunlight, (2) adjusting the selector position on the multimeter to measure DC voltage, and (3) locking the black probe cable (COM) on the multimeter to the ground cable (GND) and connecting the red probe cable (V) to the (+) cable of the solar module. The battery voltage test aims to determine the output voltage of the battery connected to the solar module and SCC. Battery voltage testing is conducted from 09:00 to 17:00 WIB. Figure 5b shows the measurement of the battery output voltage. Figure 5c shows a graph of the measured battery output voltage value.



(a) (b) (c)

Figure 5. (a) Measurement of solar module output voltage, b) Measurement of battery output voltage, c) Graph of battery output voltage measurement results

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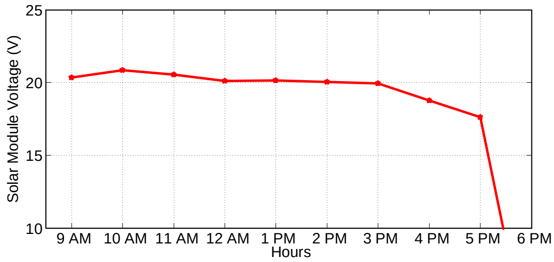
Tables 1 and 2 each display the results of testing the output voltage of the solar module from 9:00 AM to 5:00 PM. Figures 6a and 6b show the performance of solar module output voltage, battery output voltage, and SCC voltage, respectively.

Table 1. Testing the Output Voltage of Solar Modules

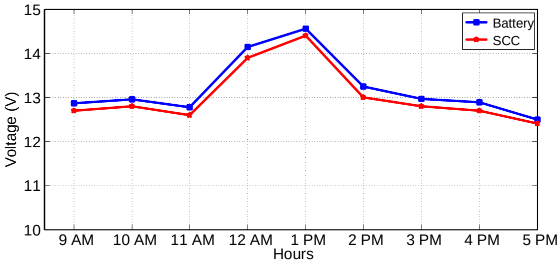
No.	Hours	Output Voltage (V)
1	9 AM	20.34
2	10 AM	20.85
3	11 AM	20.54
4	12 AM	20.10
5	1 PM	20.14
6	2 PM	20.03
7	3 PM	19.95
8	4 PM	18.77
9	5 PM	17.62
10	6 PM	0.57

Table 2. Battery Output Voltage Testing

No.	Hours	Voltage Battery (V)	Solar Charger Control Voltage (V)	Error (%)	Battery Current (A)
1	9 AM	12.86	12.7	1.25	0.17
2	10 AM	12.95	12.8	1.15	0.17
3	11 AM	12.78	12.6	1.40	0.15
4	12 AM	14.14	13.9	1.69	0.19
5	1 PM	14.56	14.4	1.09	0.13
6	2 PM	13.25	13.0	1.93	0.19
7	3 PM	12.97	12.8	1.31	0.17
8	4 PM	12.89	12.7	1.47	0.16
9	5 PM	12.50	12.4	0.80	0.19
Average Error				1.21	



(a)



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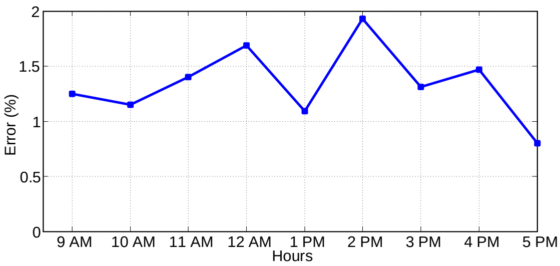


(c)

Figure 6. (a) Output Voltage of Solar Modules, b) Comparison of Battery Output Voltage and Solar Charge Controller Voltage, (c) Error Measurement between Battery Output and Solar Charge Controller Voltage

Table 1 and Figure 6a show that the highest output voltage of the solar module occurred at 10:00 AM at 20.85 V and the smallest output voltage was achieved at 5:45 PM at 0.57 V. Table 2 and Figure 6b show that the highest battery voltage of the multimeter is achieved at 13:00 at 14.56 V and the lowest battery voltage is achieved at 17:00 at 12.50 V. Table 2 also shows that the highest battery voltage read by the LCD is achieved at 13:00 at 14.4 V and the lowest battery voltage is achieved at 17:00 at 12.40 V. Figure 6c shows the error measurement between battery output and SCC voltage resulting from Equation 1 for each hour from 9 AM-5 PM. It shows a deviation measuring the average output voltage of the battery between using a multimeter and reading the LCD screen. Then, its results met the requirements because they were able to produce an average error of 1.21%.

3.4. Smoke Sensor Testing

The MQ-2 sensor test aims to determine the sensor's sensitivity to smoke or gases that can cause a fire. Figure 7a shows the test using the MQ-2 sensor. In this test, the gas is represented by benzene gas from a lighter, and the smoke is represented by cigarette smoke. Figure 7b and Figure 7c show the results of the MQ-2 sensor test on lighter gas and cigarette smoke, respectively.

(a) (b) (c)

Figure 7. (a) Testing using the MQ-2 Sensor, (b) Results of testing the sensor on lighter gas, (c) Results of testing the sensor on cigarette smoke

After testing the MQ-2 Sensor on lighter gas and smoke, the sensor's sensitivity to the two test objects was determined, and the results are presented in Table 3 below.

Table 3. Results of testing the MQ-2 sensor on lighter gas and cigarette smoke

No.	Test Materials	Alarm Time (Sec)
1	Benzene Gas Lighter	3
2	Cigarette Smoke	4

The test results in Table 3 show that the MQ-2 Sensor is able to detect lighter gas in 3 seconds faster than cigarette smoke, which takes 4 seconds. Thus, the MQ-2 Sensor has better test sensitivity to lighter gas than cigarette smoke.

3.5. Temperature Sensor Testing

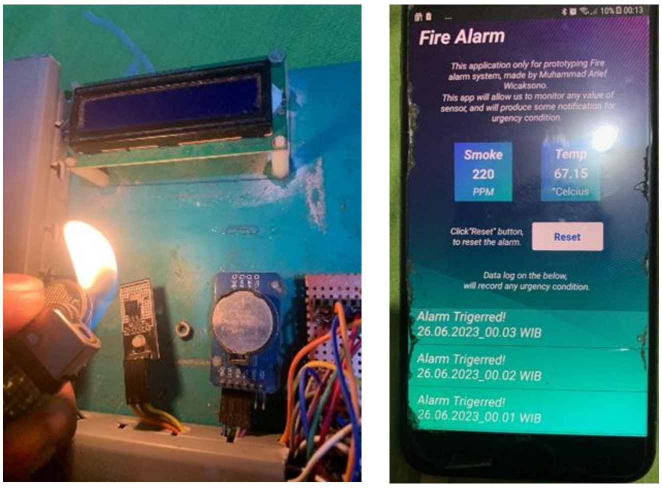
The LM35 Sensor test aims to determine the sensor's sensitivity to heat, which is one of the causes of fire. Temperature testing is conducted at three different positions along the match source distance. Figures 8a and 8b, respectively, show the testing process and the results of temperature testing using the LM35 Sensor.

After testing the hot temperature of the match using the LM35 sensor, the results of the LM35 Sensor sensitivity test, based on the distance of the fire source, are presented in Table 4.

Table 4. Results of LM35 Sensor Testing

No	Distance of fire or heat (cm)	Alarm time (sec)
1	2	2
2	5	5
3	12	10

The results of the heat test, conducted using the LM 35 sensor and a match flame, show that at distances of 2 cm, 5 cm, and 12 cm, the prototype can sound the fire alarm in 2 seconds, 5 seconds, and 10 seconds, respectively. Thus, the closer the heat source, the more sensitive the LM35 sensor is, as it can respond faster to the origin of the heat source compared to heat sources that are further away.

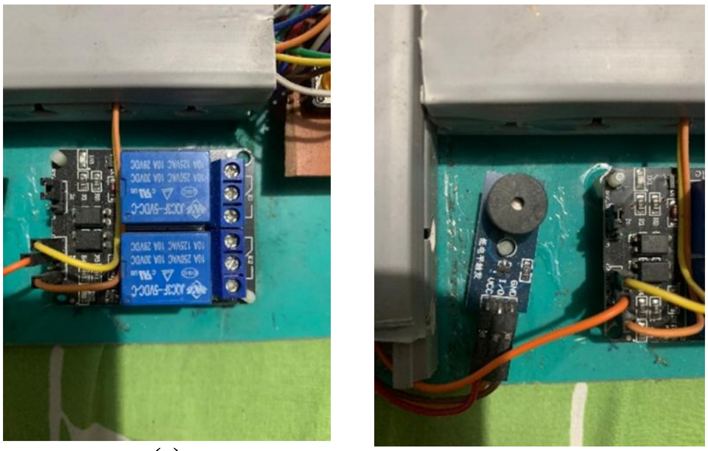


(a) (b)

Figure 8 (a) Match temperature test using the LM35 sensor, (b) Results of testing temperature values at three different match source distance positions

3.6. Breaker Relay and Buzzer Testing

The test of the relay breaker module aims to determine the sensitivity of the smoke sensor and temperature sensor by utilizing the relay. Both sensors must be able to command the relay to cut off the electricity in the house if smoke and heat, as indicators of the fire's cause, appear. The test of the buzzer module aims to detect the sensitivity of the output from the smoke or heat sensors, which triggers the buzzer to sound a warning beep. This notification is essential for the occupants of the house to check the electrical control panel immediately. Figure 9a and Figure 9b each show the test of the working mechanism of the relay breaker and buzzer.



(a) (b)

Figure 9. Test of the working mechanism of (a) the breaker relay and (b) the buzzer

The results of the relay breaker test show that when both sensors detect smoke and heat sources, the relay immediately orders the CB contact to cut off the electricity supply to the house. The results of the buzzer test also show that both sensors can function and trigger the buzzer to sound a warning or beep as a sign or fire alarm.

3.7. LCD Testing

LCD functions as a monitor or indicator of the prototype device. LCDs the device in a standby condition until the smoke (gas) and temperature detection alarms appear. In addition to being accessible via smartphone, the alarm condition can also be viewed via the LCD screen. From the LCD screen, users can also monitor the smoke (gas) and temperature levels when the alarm sounds. Figures 10a, 10b, and 10c illustrate the LCDs under the following conditions: standby, smoke detection (gas), and temperature detection.

(a) (b) (C)

Figure 10. LCD screen display in tool mode conditions: (a) Standby, (b) Detecting smoke (gas), and (c) Detecting temperature

The test results show that the LCD screen is able to display and provide information (alarm) in the form of detection and levels of smoke (gas) and temperature as early indicators of a fire in a house.

4. CONCLUSION AND LIMITATION

The authors have implemented a prototype of an early warning system and fire control system in a residential house using temperature and smoke sensors supplied by IoT-based solar modules. The 10 Wp solar module serves as the energy source and is connected to the battery via the SSC. The Arduino Uno serves as a system controller, while the NodeMCU acts as a Wi-Fi module for communication between the Microcontroller and Android. The system utilizes the MQ-2 Sensor and LQ35 Sensor, respectively, to detect smoke (gas) and heat, which are the primary indicators of the fire's cause. The prototype is capable of detecting smoke (gas) and temperature levels and sends notification results to users remotely via their smartphones and LCD screens. The system also provides early information on fire hazards through a buzzer that emits a warning sound (beep). Furthermore, the system can activate the safety relay and order the house switch to immediately cut off the electricity. Thus, the prototype is capable of preventing fires early by detecting, monitoring, and remotely cutting off electricity at home from a smartphone, validated by an LCD as part of the IoT device.

Firefighters often arrive late at the scene of a fire. The delay in officers ultimately causes the fire to last longer, resulting in more significant loss of life and property. The primary cause is that officers often receive the fire message relatively late, and they also struggle to locate the coordinates and determine the closest route to the fire location. The integration of the research prototype with a GPS can be proposed as future work to help firefighters overcome these obstacles.

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