Fire Safety Monitoring System Based on Internet of Things

Andriy Palamar[a] and Mykhaylo Palamar[a]

[a] *Ternopil Ivan Puluj National Technical University, Ruska str., 56, Ternopil, 46001, Ukraine*

Abstract

The increasing concerns over fire safety have driven the development of advanced monitoring systems to enhance early detection and response capabilities. This paper presents a comprehensive study on the development and implementation of a fire safety monitoring system based on the Internet of Things. The proposed system aims to enhance fire detection, prevention, and emergency response through real-time monitoring, data analytics, and seamless integration with existing infrastructure.

A proposed fire safety monitoring system based on the Internet of Things integrates various sensors, communication technologies, and data processing techniques. The system aims to provide real-time monitoring and alerting, enabling prompt actions to prevent fire incidents and minimize potential damages.

The research findings contribute to the advancement of fire safety technologies and offer valuable insights into the potential of IoT in improving fire safety monitoring systems.

In this paper, the architecture of the fire safety monitoring system, detailing the components, their functionalities, and their interconnections is presented. The deployment of IoT devices, sensors, and communication protocols to ensure reliable and secure data transmission is discussed.

Keywords

Internet of Things, fire safety, monitoring, microcontroller, ifttt, sensor.

1. Introduction

The increasing prevalence of fire incidents and their devastating consequences highlight the critical need for advanced fire safety monitoring systems. Fire accidents can cause severe damage to property and lead to loss of life, so it is crucial to have a reliable fire safety monitoring system.

Traditional fire detection methods and means, although effective to some extent, often fall short in providing timely and accurate information for effective emergency response. In recent years, the emergence of the Internet of Things (IoT) has revolutionized the field of fire safety monitoring by offering innovative and intelligent solutions. This paper presents a comprehensive study on the development and implementation of a fire safety monitoring system based on IoT, which leverages interconnected devices, sensors, and data analytics to enhance fire detection, prevention, and emergency response.

The objective of this research is to develop a fire safety monitoring system that addresses the limitations of traditional fire detection methods. The proposed system integrates a network of intelligent sensors, wireless communication protocols, fog computing, and advanced data analytics techniques to create a robust and efficient fire safety ecosystem. The system aims to provide accurate and timely fire detection, continuous monitoring, remote accessibility, and seamless integration with emergency response mechanisms.

This paper aims to design and implementation of a cost-effective fire detection system based on IoT, which is a critical aspect of fire safety, in order to provide real-time monitoring, data analysis, and prompt alerts in the event of a fire.

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EMAIL: palamar.andrij@gmail.com (A. Palamar); palamar.m.i@gmail.com (M. Palamar).
ORCID: 0000-0003-2162-9011 (A. Palamar); 0000-0002-8255-8491 (M. Palamar).

2. Related works

Several studies have been conducted on fire safety monitoring systems, both traditional and IoT-based. Traditional fire safety monitoring systems have been widely used for many years. These systems use smoke detectors, heat detectors, and other sensors to detect fires and activate alarms.

One such study [1] introduces a network-based intelligent fire alarm system that aims to enhance fire detection and response. While the paper presents an interesting concept, there are several notable disadvantages of the proposed solution that need to be addressed. One significant drawback is the lack of detailed information on the system's scalability and deployment considerations. The authors briefly mention the use of a network-based approach but do not provide sufficient insights into the system's adaptability to different building sizes, layouts, and infrastructure configurations.

Another paper [2] proposed a fire prevention and monitoring smart system that combines multiple technologies to enhance fire safety. While the paper introduces an interesting solution, there are several drawbacks of the proposed system. One major disadvantage is the lack of detailed information regarding the system's reliability and robustness. The authors briefly mention the integration of different technologies such as IoT, cloud computing, and machine learning, but fail to provide a thorough analysis of the system's performance under various conditions and potential failure scenarios. Without comprehensive testing and evaluation, it is challenging to determine the system's effectiveness.

The authors in [3] a system for real-time early warning in building fire detection using XBee-PRO RF modules. While the paper offers an interesting approach to fire detection based on the Zigbee technology, there are several notable disadvantages of proposed system. One significant drawback is the limited discussion on the system's data accuracy and reliability. The authors mention the use of XBee-PRO modules for communication, but there is a lack of in-depth analysis regarding the potential limitations and challenges associated with wireless communication in fire detection systems.

In recent years, the development of Internet of Things (IoT) technology [4] has led to the emergence of IoT-based fire safety monitoring systems. The paper [5] presents a comprehensive study on utilizing the IIoT for fire risk assessment. The authors delve into the use of electronic sensors and propose a solution for monitoring fire risks in industrial settings. While the paper offers valuable insights into the application of IIoT for fire risk assessment, there are certain limitations to the proposed solution that have to be addressed. The paper proposes to use GPS technology to transfer alarm information about fire case. This solution has several inherent limitations when applied to fire monitoring systems, like signal interference and delay, indoor coverage, etc.

The research [6] outlines an interesting approach to fire detection using a combination of wireless sensor networks and machine vision. The proposed system leverages wireless sensor networks to collect data from various environmental sensors to detect potential fire incidents. Additionally, machine vision techniques are employed to analyze video feeds and detect visual cues associated with fires. However, there are a few limitations that should be addressed. The authors primarily discuss the system's design and implementation aspects without providing sufficient experimental results or validation using a diverse range of fire incidents.

In [7] a novel approach to fire detection using an AI-based framework has been described. The paper presents an in-depth analysis of the proposed system, which combines multiple AI techniques such as fuzzy logic, deep learning, and rule-based reasoning. This multifunctional framework enables the system to adapt to different fire scenarios and enhance the reliability of fire detection.

Research published in [8] introduces an innovative approach to fire detection by leveraging convolutional neural networks and long short-term memory networks. The integration of these two deep learning techniques offers a comprehensive solution for fire detection. The authors aim to develop a multistage system capable of real-time fire detection, which is crucial for timely response and mitigation. However, one potential limitation of the paper is the lack of discussion on the computational requirements and resource constraints associated with implementing the proposed system.

Overall, these studies demonstrate the potential of IoT-based fire safety monitoring systems in improving fire safety and reducing the damage caused by fires. However, further research is needed to optimize the design of such systems and address challenges such as scalability, cost-effectiveness, and the ability of fire safety remote monitoring in real-time.

3. System structure

The authors of the paper propose a fire safety monitoring system based on the IoT. The rapid development of the IoT has led to its application in various fields [9, 10]. Traditional fire monitoring systems have limitations in terms of data collection and processing. The IoT offers immense potential for revolutionizing fire safety monitoring systems. By interconnecting various smart devices, sensors, and actuators, IoT enables real-time data collection, analysis, and remote monitoring of critical parameters such as temperature, smoke, gas levels, etc [11]. These interconnected systems provide enhanced situational awareness, allowing for early fire detection, prompt response, and improved decision-making. The proposed system architecture for fire safety monitoring based on the IoT concept is shown in Figure 1.

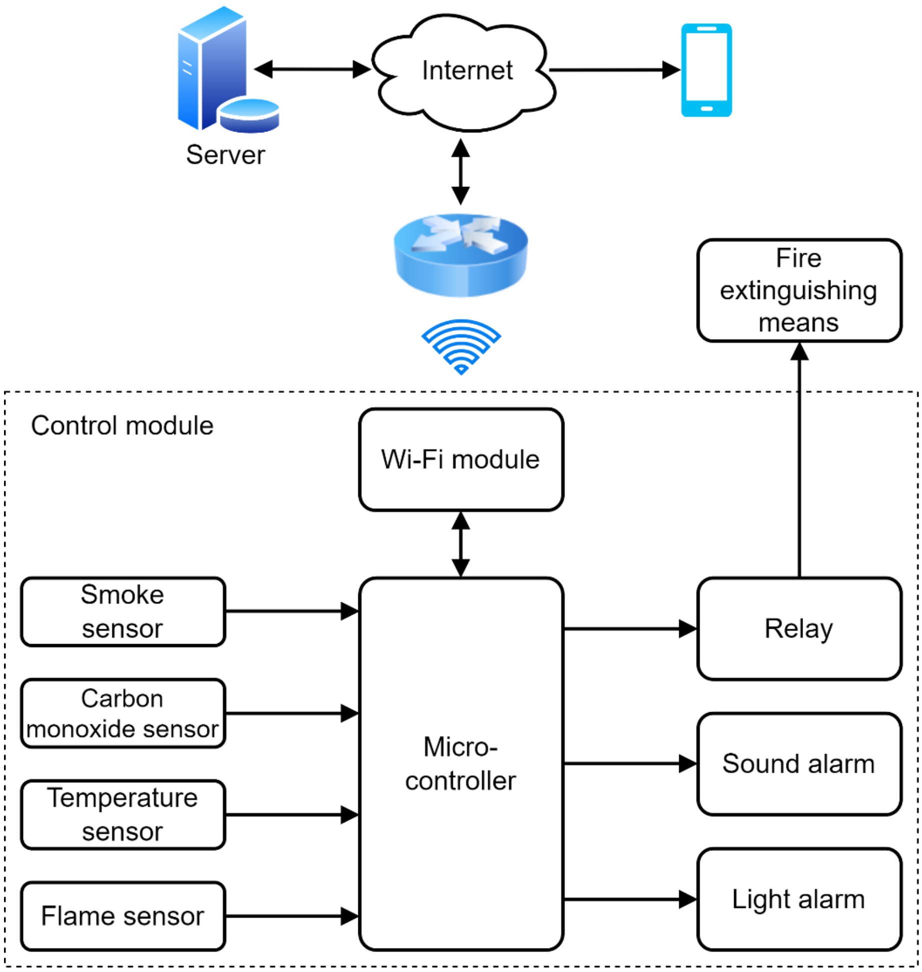

Figure 1: Fire safety monitoring system architecture

The following functional elements were used in the system:

- smoke sensor;
- carbon monoxide sensor;
- temperature sensor;
- flame sensor;
- microcontroller;
- Wi-Fi module;
- relay;
- fire extinguishing means;
- light alarm;
- sound alarm.

4. System implementation

4.1. Hardware prototype

The control module structural diagram of the fire safety monitoring system is shown in Figure 2.

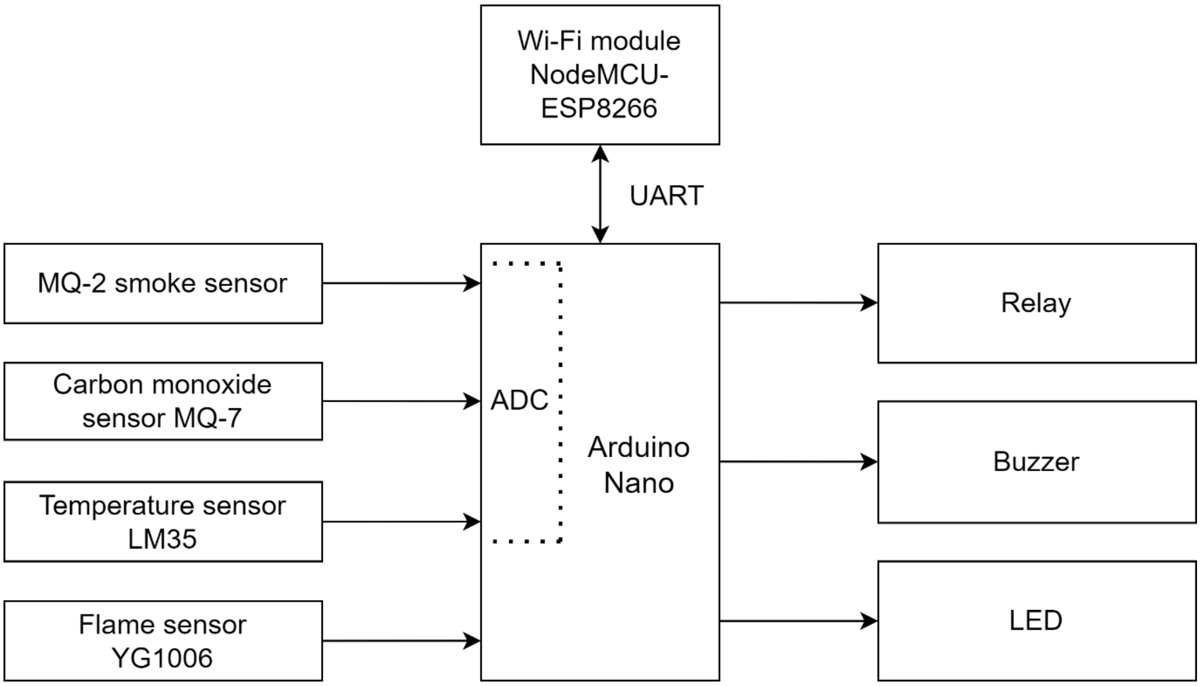

Figure 2: Structural diagram of the control module for the fire safety monitoring system

The diagram includes the following components: Arduino Nano module, NodeMCU Wi-Fi module, MQ-2 smoke sensor, MQ-7 carbon monoxide sensor, LM35 temperature sensor, YG1006 flame sensor, relay module, buzzer, LED.

As a result of comparative analysis of existing microcontroller-based platforms on the market for implementing a fire safety monitoring system, the Arduino Nano module was chosen. It is a miniature fully functional device based on the Atmega328 microcontroller, adapted for use with prototype boards. It is characterized by an 8-bit data bus, an improved RISC architecture, and several low-power modes. The presence of a built-in six-channel ten-bit ADC makes this microcontroller a good tool for working with analog sensors that will be used in the designed system.

Despite its compact size, the module contains a large number of pins that allow for sensors connecting. Therefore, due to its compact size, available digital and analog inputs, low cost, and convenient programming process, the Arduino Nano platform was chosen as the main control module for the fire safety monitoring system.

A smoke sensor is an important component in fire safety monitoring systems. For the designed system, a smoke sensor module based on the gas analyzer MQ-2 was chosen. It allows measuring the concentration of hydrogen, smoke (which appears during combustion), hydrocarbon gases in the air, including methane, propane, and butane. This sensor can be used to detect areas of smoke and leaks of industrial gases. The MQ-2 sensor generates an analog signal, the magnitude of which is proportional to the concentration of gases to which the gas analyzer is sensitive.

To measure the carbon monoxide concentration level in the air the MQ-7 sensor was chosen in the designed system. The operation principle of the sensor is based on the change in resistance of a thin layer of tin dioxide (SnO_2) upon contact with carbon monoxide molecules. The sensitive element of the MQ-7 sensor includes a ceramic tube and a layer of tin dioxide deposited on it. Inside this tube, there is a heating element that increases the temperature of the sensitive layer to a value at which it will react to a particular type of gas.

Temperature measurement in this system will be carried out using the LM35 sensor module. LM35 is a precision integrated temperature sensor characterized by high accuracy and a wide measurement range. Another advantage of the LM35 sensor is its low output resistance and the possibility of precise calibration. The current consumption of this sensor is very low, approximately 60 µA. The LM35 sensor has good linearity and conversion accuracy. The guaranteed measurement accuracy is 0.5 °C. However, this value may vary depending on the measurement range. Maximum accuracy of ±0.25 °C is achieved when used in room conditions. The minimum measurement accuracy can be ±0.75 °C when operating in the widest temperature range from -55 °C to +150 °C.

An infrared YG1006 flame sensor was chosen to detect the fire sources. The operation principle of this sensor is based on the ability of a highly sensitive NPN silicon phototransistor to detect light flow sources in the wavelength range of 760 nm – 1100 nm.

To implement remote monitoring in the designed system, the NodeMCU module based on the ESP8266MOD microcontroller was chosen. It allows easy connection of the device to a local network or the Internet. It enables sending and receiving information remotely via an Internet connection. The ESP8266MOD microcontroller contains an integrated Wi-Fi transmitter, which allows for wireless network connection using the TCP/IP protocol. To support the Wi-Fi stack in this microcontroller, a Tensilica microchip is used. The ESP8266 operates at a frequency of 80 MHz. The electrical schematic diagram of the control module for the fire safety monitoring system is shown in Figure 3.

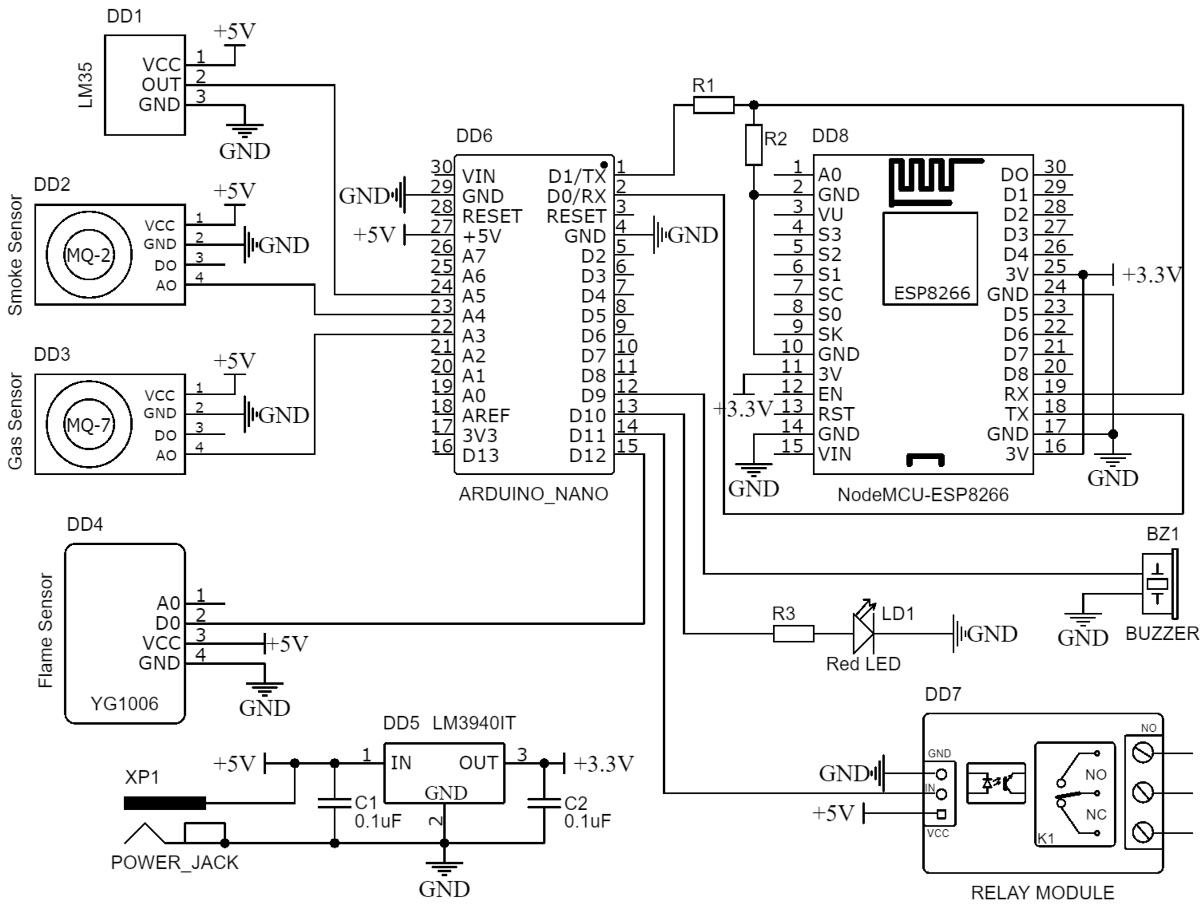

Figure 3: Circuit diagram of the control module for the fire safety monitoring system

The circuit is powered by a +5 V voltage source, which is supplied from a standard power supply via connector XP1. This voltage level is supplied to the Arduino Nano module, labeled DD6 on the diagram, and to the sensors. The NodeMCU module, labeled as U8, requires a +3.3 V power supply for proper operation. Therefore, the LM3940IT regulator is included in the circuit to convert the +5 V voltage to +3.3 V. The capacitors C1 and C2 with a capacitance of 0.1 µF, placed in the input and output circuit of the DD5 regulator, provide filtering of the power supply voltage.

The outputs of the temperature sensors LM35, smoke sensor MQ-2, and carbon monoxide sensor MQ-7, labeled DD1, DD2, and DD3 respectively on the diagram, are connected to the analog inputs of the Arduino Nano board: A5, A4, and A3. The digital output of the flame sensor YG1006, labeled as DD4 on the diagram, is connected to the D12 input of the DD6 module.

Data exchange between the Arduino Nano and the NodeMCU ESP8266 modules is implemented using the UART interface. For this purpose, pin TX of the DD6 module is connected to pin RX of the DD8 board. Because the DD6 and DD8 components use different voltage values, a voltage divider circuit using resistors R1 with a nominal value of 1 kΩ and R2 with a nominal value of 2 kΩ is used to connect the second UART interface line.

The piezoelectric buzzer BZ1, which is intended for generating an alarm sound signal, is connected to the digital output D9 of module DD6. The red LED LD1, connected through a 330 Ω resistor R3, is connected to the digital output D10 of the Arduino Nano board. The relay module, denoted as DD7 on the diagram, is connected to the digital output D11 of module DD6.

4.2. Software implementation

To develop software for the microcontroller, which serves as the core of the Arduino Nano platform, the programming language Processing was used in this project. It is based on a simplified version of the C/C++ languages with additional libraries added. The Arduino IDE was chosen for writing the code. It is a cross-platform application created in Java. It includes an editor for writing code with a corresponding compiler, as well as a module for uploading the firmware to the microcontroller.

The algorithm of operation for the Atmega328 microcontroller program of the Arduino Nano module includes the following stages.

1. The software libraries including, and global variables and constants declaring.
2. Configuration of the UART interface for data exchange with the Wi-Fi module.
3. Initialization of the input and output digital and analog pins of the microcontroller.
4. Polling the ADC channel to which the LM35 temperature sensor is connected and converting the measured value into Celsius degrees.
5. Comparing the obtained room temperature value with the threshold value specified as a constant at the beginning of the program. If the value exceeds the norm, a procedure is called, which performs a series of actions to notify about the high risk of fire. If the temperature value is within the norm, the analysis proceeds to the next step.
6. Reading the ADC channel to which the MQ-2 smoke sensor is connected and converting the measured value into parts per million (ppm).
7. Comparing the obtained smoke concentration value in the room with the threshold value specified as a constant in the program code. If the value exceeds the norm, a procedure is called, which performs a series of actions to notify about the high risk of fire. If the smoke value is within the norm, the analysis proceeds to the next step.
8. Reading the ADC channel to which the MQ-7 carbon monoxide sensor is connected and converting the measured value into ppm.
9. Comparing the obtained carbon monoxide concentration value with the threshold value specified as a constant at the beginning of the program. If the value exceeds the norm, a procedure is called, which performs a series of actions to notify about the high risk of fire. If the carbon monoxide value is within the norm, the analysis proceeds to the next step.
10. Reading the microcontroller digital input to which the YG1006 flame sensor is connected.
11. If the flame sensor is in normal state, a procedure is called, which performs a series of actions: generating digital signals on the microcontroller outputs to turn off the sound alarm and the red LED; switching the relay module contacts to the off state for the fire extinguishing devices connected to it; generating and sending a message through the UART interface to the Wi-Fi module with information about the normal fire situation in the room).
12. If the flame sensor indicates the presence of fire, the program calls a procedure, which performs a series of actions: generating a signal on the digital outputs of the microcontroller to activate the piezoelectric speaker for audible fire warning and periodically blinks the red LED for visual notification; switching the relay module contacts to the on state for the fire extinguishing devices

connected to it; generating and sending a message through the UART interface to the Wi-Fi module with information about the occurrence of a fire situation in the room.

To receive remote notifications about the fire safety status, the IFTTT service was chosen, which allows creating specific triggers and corresponding conditions to ensure task execution on compatible devices. A task in the IFTTT service, called a "Recipe," consists of two components: a "Trigger" and an "Action". The trigger represents a certain condition that, when met, triggers the corresponding action. In other words, the "action" is performed when the "trigger" is activated, following the "If This, Then That" principle. A source code listing of the function, which is responsible for sending data to the IFTTT service using an HTTP POST request, is shown in Figure 4.

```
void sendDataToIFTTT() {
  // Prepare the data to be sent to IFTTT
  String eventData = "value1=" + String(temperature) +
                     "&value2=" + String(smokeValue) +
                     "&value3=" + String(carbonMonoxideValue) +
                     "&value4=" + String(flameValue);

  // Send HTTP POST request to IFTTT webhook
  WiFiClient client;
  HTTPClient http;
  // Your Domain name with URL path or IP address with path
  http.begin(client, iftttWebhookURL);
  // Specify content-type header
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  // Send HTTP POST request
  int httpResponseCode = http.POST(eventData);
  // Free resources
  http.end();

  Serial.print("HTTP Response Code: ");
  Serial.println(httpResponseCode);

  delay(3000); // Wait for 3 seconds before sending the next data
}
```

Figure 4: A source code listing of the function sendDataToIFTTT()

In the case of the designed remote fire safety monitoring system, the NodeMCU Wi-Fi module will be used as the channel within the IFTTT platform, and the action will involve sending notifications to the user's smartphone. To check the functionality of the system, the official mobile application of the IFTTT service was installed.

5. Experimental results and discussion

Once the hardware and software components were developed, they were integrated to form the complete fire safety monitoring system prototype. The sensors were connected to the microcontroller, and the firmware code was uploaded to enable data collection and transmission.

A series of testing procedures were conducted to evaluate the functionality, accuracy, and reliability of the prototype. This involved simulating various fire-related scenarios and assessing the system's response in terms of data collection, processing, and notification generation. The prototype was also tested for its compatibility with the IFTTT service, ensuring successful communication and seamless integration.

If the data obtained from the sensors exceeds the permissible norm, the notification process will start, which includes: flashing of the red LED; turning on the siren; sending a notification to the owner's smartphone using the IFTTT service. Figure 5 shows an incoming VoIP call in the IFTTT application caused by an alarm signal generated by the control module of the designed fire safety monitoring system.

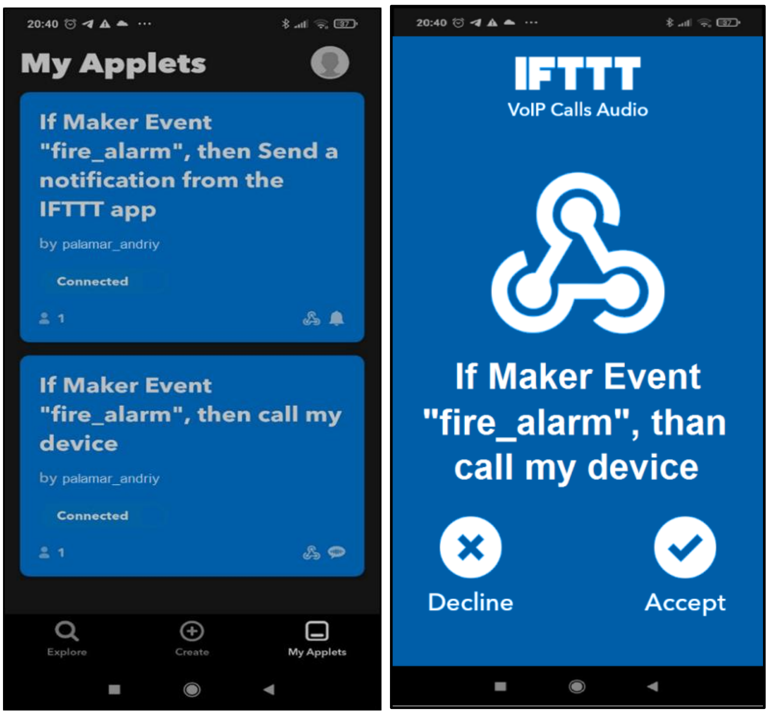

Figure 5: An incoming VoIP call using the mobile application of the IFTTT service as a result of a fire alarm

The results obtained from the system's operation demonstrated its successful functioning in monitoring fire safety parameters in real-time. The system effectively collected data from various sensors, including temperature, smoke, carbon monoxide, and flame sensor, enabling continuous monitoring of the environment for potential fire hazards.

Upon the detection of abnormal readings or hazardous conditions, the system promptly triggered appropriate actions, such as generating alarms, activating fire suppression systems, and sending notifications to relevant parties. The integration of the IFTTT framework facilitated the remote monitoring and notification process, ensuring that users received timely alerts on their smartphones.

Through extensive testing and evaluation, the system demonstrated high reliability and accuracy in detecting fire-related events. The response time of the system was within acceptable limits, enabling rapid intervention and mitigation measures to prevent fire incidents from escalating.

The results confirm the successful implementation of the fire safety monitoring system based on the Internet of Things. The system exhibited robust performance in detecting and alerting about fire hazards, providing an efficient and reliable solution for enhancing fire safety in various environments.

6. Conclusions

In this paper, the design and implementation of a fire safety monitoring system based on IoT was presented. The system uses sensors to detect temperature, smoke, carbon monoxide and flame that indicate the occurrence of a fire, and can provide real-time monitoring, data analysis, and prompt alerts to relevant personnel.

The study shows that an IoT-based fire safety monitoring system has several advantages over traditional fire monitoring systems, including the ability to collect and process large amounts of data, integrate with other devices, and take prompt action in the event of a fire. However, there are also challenges to implementing such a system, including the need for a reliable network connection, potential security risks, and the need for specialized skills to manage the system.

The scientific novelty of this research lies in the integration of IoT technologies, fog computing methods and wireless communication to develop a comprehensive and advanced fire safety monitoring system. Overall, an IoT-based fire safety monitoring system has great potential to improve fire safety and reduce the damage caused by fires.

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