

Arduino-based intelligent fire and smoke detection system for early hazard prevention

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Article Info

Article history:

Received Jan 1, 2026

Revised Mar 31, 2026

Accepted May 12, 2026

Keywords:

Arduino

Fire detection sensor

Intelligent

Prevention

Smoke detection sensor

ABSTRACT

Fire accidents pose a serious threat to human life, property, and the environment, particularly in residential, industrial, and commercial areas. Early detection of fire and smoke is crucial to minimize damage and prevent loss of life. This paper presents the design and implementation of a low-cost, Arduino-based fire and smoke detection system that provides reliable and real-time monitoring. The proposed system integrates flame and smoke sensors to continuously observe environmental conditions and identify potential fire hazards at an early stage. An Arduino microcontroller processes sensor data and triggers audible and visual alarms when predefined threshold levels are exceeded. In addition, the system can be extended with wireless communication modules to send alert notifications to concerned authorities or users, ensuring rapid response during emergency situations. The proposed solution emphasizes simplicity, affordability, and energy efficiency, making it suitable for deployment in homes, offices, warehouses, and small-scale industries. Experimental results demonstrate the effectiveness of the system in detecting fire and smoke promptly, thereby enhancing safety and reducing the risk of severe fire-related incidents. The proposed model offers a practical and scalable approach to smart fire safety systems and can be further enhanced by integrating internet of things (IoT) and cloud-based monitoring for advanced applications.

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1. INTRODUCTION

Fire accidents are among the most critical hazards that pose serious risks to human life, infrastructure, and the environment. With rapid urbanization and increased use of electrical and electronic appliances, the probability of fire incidents in residential, commercial, and industrial areas has significantly increased. Delayed detection of fire and smoke often leads to severe loss of life and property, highlighting the need for efficient and reliable early warning systems. Traditional fire detection systems are often expensive, complex to install, and limited in scalability, making them unsuitable for small buildings and low-budget applications. Recent advancements in embedded systems and microcontroller-based technologies have enabled the development of low-cost, compact, and intelligent fire detection solutions. Among these, Arduino-based platforms have gained popularity due to their simplicity, flexibility, and ease of integration with various sensors [1]–[5].

This paper proposes an Arduino-based fire and smoke detection system designed to provide real-time monitoring and early alerts. The system employs flame and smoke sensors to continuously monitor environmental conditions and detect abnormal changes indicative of fire hazards. When the sensed values exceed predefined safety thresholds, the system activates alarm mechanisms to alert occupants promptly. The

proposed approach aims to enhance safety, reduce response time during emergencies, and offer an economical solution suitable for smart homes, offices, and industrial environments [4], [6]–[9].

The authors presents the design and implementation of an intelligent fire safety system aimed at improving public safety through early detection and efficient evacuation. The system utilizes an Arduino microcontroller integrated with MQ-series gas sensors to continuously monitor environmental conditions in real time. A novel graph theory-based algorithm is employed to dynamically determine optimal evacuation routes, ensuring safe and rapid occupant movement during fire emergencies. Upon detecting critical conditions, the system analyzes sensor data, evaluates risk levels, and activates guided evacuation procedures while avoiding hazardous zones. The architecture includes sensor deployment, data acquisition, and automated decision-making mechanisms. Simulation results demonstrate enhanced evacuation efficiency and reduced response time across various fire scenarios. Future enhancements include incorporating machine learning for predictive analysis, expanding internet of things (IoT-based) connectivity, and improving multi-sensor data fusion. The proposed system offers a scalable and adaptive solution for advanced fire safety in modern infrastructures [10], [11].

2. CIRCUIT CONNECTION DESCRIPTION

The proposed fire and smoke detection system show in Figure 1. This is built using an Arduino microcontroller interfaced with a gas sensor, LED, and buzzer to provide early warning indications. All components are powered through a regulated 5 V supply provided by the breadboard power supply module. The MQ-2 gas sensor is used to detect smoke and combustible gases. The VCC pin of the MQ-2 sensor is connected to the 5 V output of the power supply, and the GND pin is connected to the common ground. The analog output (A0) of the MQ-2 sensor is connected to the analog input pin A0 of the Arduino, enabling continuous monitoring of gas concentration levels. A LED is connected to one of the digital output pins of the Arduino through a current-limiting resistor. This LED serves as a visual alert and glows when smoke or gas concentration exceeds the preset threshold value. A buzzer is connected to another digital output pin of the Arduino and the ground. The buzzer produces an audible alarm when the system detects the presence of smoke or fire, ensuring immediate attention. All grounds of the components are interconnected to maintain a common reference. The Arduino continuously processes sensor data and activates the LED and buzzer when abnormal conditions are detected, thereby providing a reliable and effective fire and smoke alert mechanism [12]–[15].

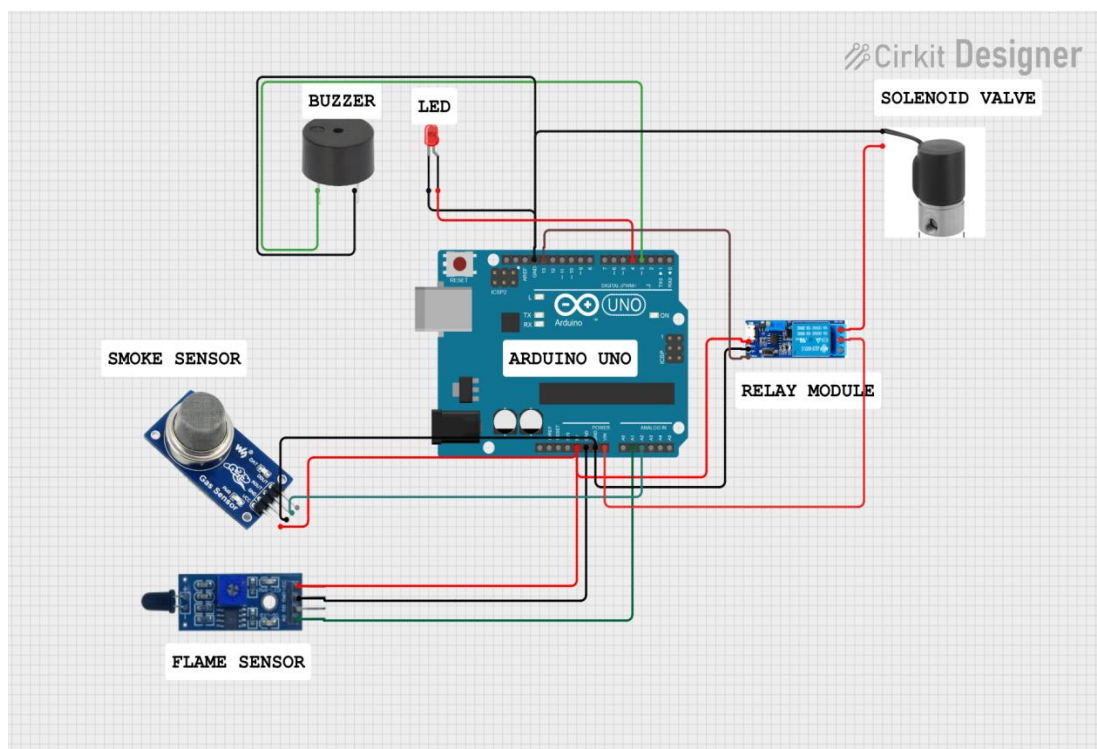


Figure 1. Fire and smoke detection system

Table 1 shows the list of hardware components used in the implementation of the Arduino-based fire and smoke detection system. Jumper wires are utilized to establish electrical connections between the Arduino, sensors, and output devices. The Grove MQ-2 gas sensor serves as the primary sensing element for detecting smoke and combustible gases such as LPG, methane, and hydrogen. A solder-able mini breadboard is used for compact and reliable circuit assembly. The LED provides visual indication during alert conditions, while the buzzer generates an audible warning to ensure immediate attention. A regulated 5 V breadboard power supply module is employed to power all the components, ensuring stable and efficient operation of the system [16]–[20].

Table 1. Hardware components

| No. | Component name | Specification/description | Quantity |
|-----|--------------------------------|---------------------------------------------|----------|
| 1 | Jumper wires (generic) | Male-to-male/male-to-female | 1 set |
| 2 | Grove – gas sensor (MQ-2) | Smoke, LPG, methane, and hydrogen detection | 1 |
| 3 | Solder-able breadboard (mini) | SparkFun mini prototype board | 1 |
| 4 | LED (generic) | Visual indication (red) | 1 |
| 5 | Buzzer | Audible alert device | 1 |
| 6 | Breadboard power supply module | 5 V output | 1 |

3. RESULTS AND DISCUSSION

The performance of the proposed Arduino-based fire and smoke detection system was evaluated under different environmental conditions to verify its reliability and effectiveness. The system operates in three distinct modes based on sensor readings and predefined threshold values. These modes ensure accurate detection and timely alerts for safe evacuation.

3.1. Smoke alert evacuated mode

Smoke alert evacuated condition shown in Figure 2. When smoke concentration exceeds the first threshold limit but no direct flame is detected, the system enters the Smoke Alert Evacuated Mode. In this condition, the LED is activated, and the buzzer produces an intermittent alarm to warn occupants about potential danger. This early warning allows sufficient time for evacuation and preventive action before the situation escalates. The results demonstrate that the system can detect smoke at an early stage, significantly improving safety and response time.

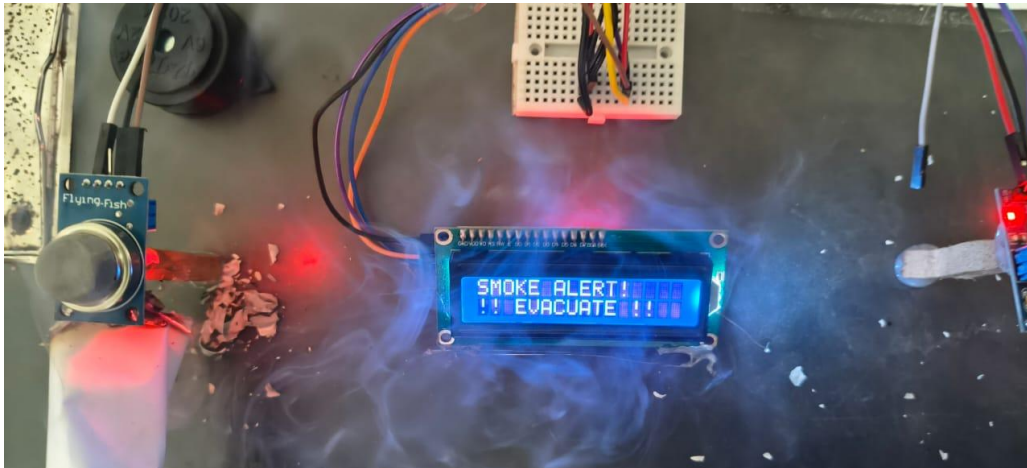


Figure 2. Smoke alert evacuated condition

3.2. Fire alert evacuated condition

Fire alert evacuated condition shown in Figure 3. When the sensor readings cross the critical threshold, indicating the presence of fire or high gas concentration, the system switches to the fire alert evacuated mode. In this mode, the LED glows continuously, and the buzzer generates a continuous alarm signal to indicate a severe hazard. This immediate and strong alert ensures rapid evacuation and emergency response. Experimental observations confirm the system's effectiveness in detecting fire conditions promptly and reliably.

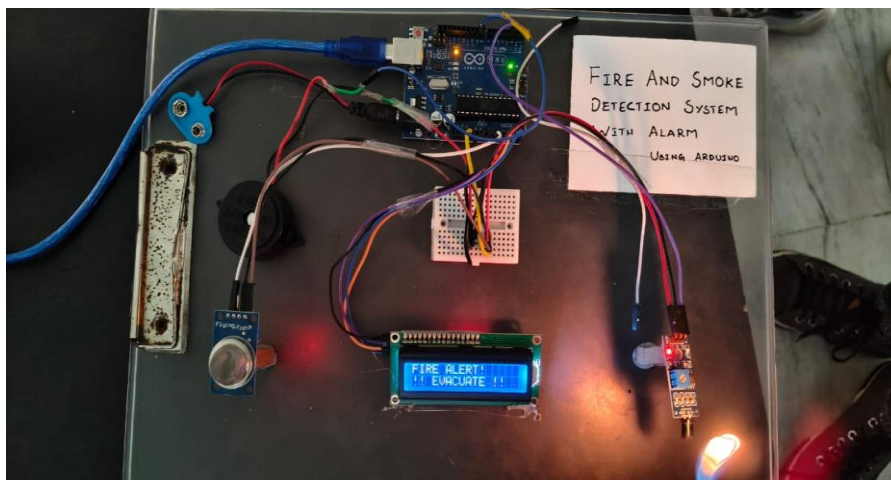


Figure 3. Fire alert evacuated condition

3.3. Normal condition

Figure 4 shows the normal condition. Under normal environmental conditions, when no smoke or fire is present, the MQ-2 sensor output remains below the predefined threshold level. In this mode, the system operates in a standby state. Both the LED and buzzer remain OFF, indicating a safe environment. The system continuously monitors the surroundings and maintains readiness for any abnormal condition. This mode confirms stable operation and avoids false alarms.

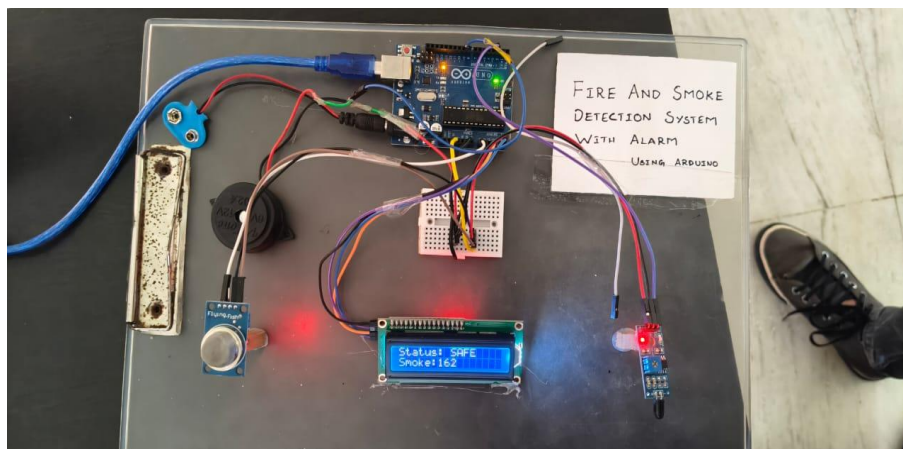


Figure 4. Normal condition

4. CONCLUSION

The developed Arduino-based fire and smoke detection system provides an effective, low-cost, and reliable solution for early fire hazard detection. By integrating flame and smoke sensors with a microcontroller, the system ensures continuous environmental monitoring and rapid response through audible and visual alerts. Its simple design and energy-efficient operation make it highly suitable for a wide range of applications, including residential buildings, offices, warehouses, and small-scale industries. The experimental results confirm that the system can promptly detect fire and smoke conditions, thereby reducing potential risks to human life and property. Furthermore, the capability to incorporate wireless communication modules enhances its functionality by enabling real-time alert notifications to users and authorities, improving emergency response times.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

| Name of Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest to disclose.

DATA AVAILABILITY

The data availability is not applicable to this paper as no new data were created or analyzed in this study.




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