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# DESIGN AND IMPLEMENTATION OF AN ARDUINO-BASED FIRE AND SMOKE DETECTION SYSTEM FOR EARLY HAZARD DETECTION

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# DESIGN AND IMPLEMENTATION OF AN ARDUINO-BASED FIRE AND SMOKE DETECTION SYSTEM FOR EARLY HAZARD DETECTION

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*ABSTRACT: This paper presents the design and implementation of a cost-effective Fire and Smoke Detection System using Arduino aimed at enhancing safety in residential, commercial, and small-scale industrial environments. Fire hazards pose a significant risk to life and property, necessitating the development of reliable early detection systems. The proposed system employs an MQ-2 smoke sensor and a temperature sensor (LM35/DHT11) to continuously monitor environmental conditions. These sensors detect variations in smoke concentration and temperature, converting them into electrical signals that are processed by an Arduino-based microcontroller. The microcontroller compares real-time sensor data with predefined threshold values and activates alert mechanisms such as a buzzer and LED indicators when abnormal conditions are detected. The system is designed to ensure rapid response, high sensitivity, and operational reliability while maintaining low cost and ease of implementation. Experimental testing, including smoke and heat analysis, demonstrates effective performance in detecting fire-related hazards with minimal delay. Furthermore, the modular architecture of the system allows future enhancements such as IoT integration for remote monitoring and automated emergency response. This work highlights the importance of embedded systems in safety applications and provides a practical solution for early fire detection.*

*KEYWORDS: Fire Detection System, Smoke Sensor (MQ-2), Arduino, Temperature Sensor (LM35/DHT11), Embedded Systems, Safety Engineering, IoT, Hazard Detection, Alarm System, Sensor-Based Monitoring*

## 1. INTRODUCTION

Fire hazards remain one of the most critical safety concerns in residential, commercial, and industrial environments. Rapid urbanization, increased reliance on electrical systems, and the widespread use of combustible materials have significantly elevated the risk of fire incidents. These incidents often result in severe consequences, including loss of human life, property damage, and environmental degradation. Therefore, the development of efficient, reliable, and cost-effective fire detection systems has become a crucial area of research in safety engineering.

Traditional fire detection methods primarily rely on manual observation or standalone alarm systems, which are often limited by delayed response times and lack of real-time monitoring. Such systems may fail to provide early warnings, allowing fire to spread uncontrollably before preventive actions can be taken. In contrast, modern fire detection systems utilize sensor-based

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technologies integrated with embedded systems to enable continuous monitoring and rapid response.

This research focuses on the design and implementation of a **Fire and Smoke Detection System using Arduino**, which combines smoke and temperature sensing mechanisms to detect fire hazards at an early stage. The system employs an MQ-2 smoke sensor to identify combustible gases and smoke particles, along with a temperature sensor (LM35/DHT11) to monitor thermal variations. These sensors generate electrical signals that are processed by an Arduino microcontroller, which activates alarm systems such as buzzers and LEDs when predefined thresholds are exceeded.

The proposed system emphasizes **low cost, simplicity, real-time monitoring, and reliability**, making it suitable for widespread deployment in homes, offices, and small industries. Additionally, the modular architecture enables future integration with Internet of Things (IoT) technologies for remote monitoring and automated emergency response.

The development of fire detection systems has evolved significantly over the years, transitioning from conventional alarm systems to intelligent sensor-based and IoT-enabled solutions. Several researchers have contributed to this domain, focusing on improving detection accuracy, response time, and system reliability.

Early fire detection systems were primarily based on **heat and smoke detectors**, which operated independently and triggered alarms when specific thresholds were exceeded. According to standards such as those defined by the National Fire Protection Association (NFPA), these systems form the foundation of fire safety infrastructure. However, conventional detectors often suffer from limitations such as false alarms, lack of adaptability, and inability to provide remote alerts.

With the advancement of embedded systems, researchers began integrating **microcontrollers** with sensors to develop more efficient fire detection systems. Arduino-based systems have gained significant popularity due to their simplicity, flexibility, and cost-effectiveness. Studies have shown that combining multiple sensors, such as smoke and temperature sensors, improves detection accuracy compared to single-sensor systems.

The MQ-2 gas sensor has been widely used in fire detection applications due to its high sensitivity to gases such as LPG, methane, and smoke. Research indicates that the MQ-2 sensor operates on the principle of resistance variation in the presence of gas particles, making it suitable for early-stage fire detection. Similarly, temperature sensors like LM35 and DHT11 are commonly employed to detect abnormal rises in temperature, which serve as strong indicators of fire hazards.

Recent research trends have focused on integrating fire detection systems with **Internet of Things (IoT)** platforms. IoT-enabled systems allow real-time monitoring and remote alerts through mobile applications or cloud-based services. These systems enhance safety by enabling users to respond quickly, even when they are not physically present at the location. However, IoT-based systems

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often involve higher costs and increased complexity, which may limit their adoption in low-resource environments.

Another important aspect highlighted in the literature is the issue of **false alarms**, which can occur due to environmental factors such as dust, humidity, or minor smoke. Researchers have addressed this challenge by implementing sensor calibration techniques and threshold optimization methods to improve system reliability.

Furthermore, studies emphasize the importance of **power stability and system robustness**, as fluctuations in power supply can affect sensor performance and microcontroller operation. The use of regulated power supplies and proper circuit design has been recommended to ensure consistent system performance.

Despite significant advancements, there remains a need for a **cost-effective, reliable, and easy-to-implement fire detection system** that can be deployed widely without requiring complex infrastructure. The system proposed in this work addresses these challenges by combining sensor-based detection with an Arduino platform, offering a practical solution for early fire detection with scope for future enhancements.

From the literature review, it is evident that:

- Many systems are either **costly or complex (IoT-based)**
- Conventional systems suffer from **delayed response and false alarms**
- There is a need for **simple, low-cost, and reliable embedded solutions**

This research aims to bridge this gap by developing a **sensor-based, Arduino-controlled fire detection system** that ensures early detection, affordability, and ease of implementation.

The main objectives of this research work are as follows:

**1. To develop an Arduino-based fire and smoke detection system**

The primary objective of this project is to design and implement an embedded system using the Arduino microcontroller for detecting fire hazards. The system integrates hardware components such as sensors, microcontroller, and output devices to create a complete functional prototype. The use of Arduino ensures ease of programming, flexibility, and cost-effectiveness, making the system suitable for practical applications.

**2. To detect smoke and temperature changes in real time using sensors**

The system aims to continuously monitor environmental conditions using an MQ-2 smoke sensor and a temperature sensor (LM35/DHT11). These sensors detect the presence of smoke,

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combustible gases, and abnormal temperature rise, which are key indicators of fire. Real-time data acquisition ensures early detection, enabling timely preventive actions.

**3. To provide immediate alerts through buzzer and LED indicators**

Another important objective is to design an effective alert mechanism that responds instantly when hazardous conditions are detected. The system activates a buzzer for audible warning and an LED for visual indication, ensuring that occupants are alerted promptly and can take necessary safety measures.

**4. To design a low-cost, reliable, and user-friendly safety system**

The project focuses on developing an economical solution that can be easily deployed in residential, commercial, and small-scale industrial environments. The system is designed to be simple to install and operate, while maintaining high reliability and consistent performance under different conditions.

**5. To enable future enhancement with IoT-based remote monitoring**

The system is developed with a modular architecture that allows future integration with Internet of Things (IoT) technologies. This enhancement would enable remote monitoring, mobile notifications, and automated emergency response, thereby improving overall system efficiency and usability.

## 2. System Overview

The proposed Fire and Smoke Detection System is designed as an embedded safety solution that continuously monitors environmental conditions and provides immediate alerts in case of hazardous situations. The system is structured into three major functional units: **Input Unit, Processing Unit, and Output Unit**. These units work in coordination to ensure accurate detection and rapid response to fire-related parameters such as smoke and temperature.

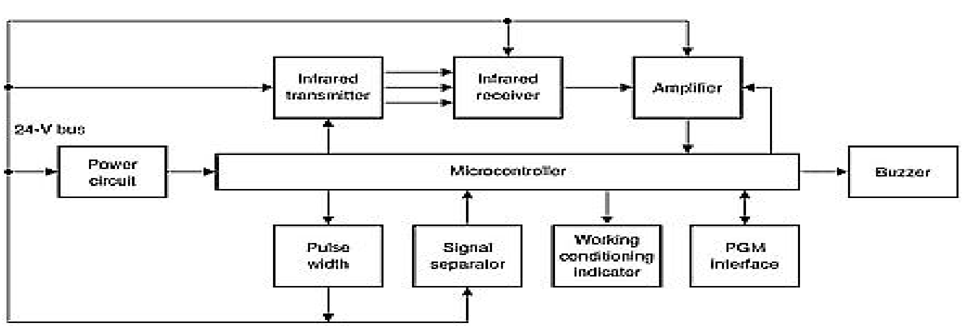


**Figure 1:Block Diagram**

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### 2.1 Input Unit

The input unit is responsible for sensing environmental parameters and converting them into electrical signals that can be processed by the microcontroller. It consists of the following sensors:

**• MQ-2 Smoke Sensor**

The MQ-2 sensor is a gas and smoke detection sensor widely used for detecting combustible gases such as LPG, methane, hydrogen, and smoke particles. It operates on the principle of change in resistance when exposed to gas molecules. As the concentration of smoke or gas increases, the sensor's resistance decreases, resulting in a change in output voltage. This analog signal is sent to the microcontroller for further processing. The MQ-2 sensor is preferred due to its high sensitivity, fast response time, and cost-effectiveness.

**• Temperature Sensor (LM35/DHT11)**

The temperature sensor is used to detect any abnormal rise in temperature, which is a critical indicator of fire hazards. The LM35 provides an analog output proportional to temperature in degrees Celsius, whereas the DHT11 provides digital output along with humidity data. These sensors continuously monitor ambient temperature and help in identifying overheating conditions. The integration of temperature sensing improves system reliability by complementing smoke detection.

Together, these sensors ensure comprehensive monitoring of fire-related parameters, reducing the chances of false detection and improving accuracy.

### 2.2 Processing Unit

The processing unit acts as the brain of the system and is implemented using an **Arduino microcontroller (Arduino Uno)**. It is responsible for receiving, analyzing, and processing the data obtained from the sensors.

The microcontroller performs the following functions:

- Reads analog/digital signals from the smoke and temperature sensors
- Converts analog signals into digital values using an internal ADC (Analog-to-Digital Converter)
- Compares sensor readings with predefined threshold values
- Makes logical decisions based on programmed conditions

If the sensed values exceed the safe threshold limits (e.g., high smoke concentration or elevated temperature), the microcontroller triggers the output unit. The Arduino platform is chosen due to

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its simplicity, flexibility, low cost, and ease of programming, making it highly suitable for embedded applications.

### 2.3 Output Unit

The output unit is responsible for alerting users when a potential fire hazard is detected. It includes the following components:

**• Buzzer (Audio Alert System)**

The buzzer provides an audible warning signal when the system detects abnormal conditions. It ensures that occupants are immediately notified, even if they are not visually monitoring the system.

**• LED Indicator (Visual Alert System)**

The LED acts as a visual indicator of system status. Under normal conditions, the LED remains off or indicates standby mode. When a fire hazard is detected, the LED turns ON, providing a clear visual warning.

The combination of audio and visual alerts enhances the effectiveness of the system by ensuring that warnings are noticeable under different conditions.

### 2.4 Overall System Operation

The system operates on a continuous monitoring principle. Once powered, the sensors begin detecting environmental parameters in real time. The collected data is transmitted to the Arduino microcontroller, which processes and evaluates the data against predefined safety thresholds.

- Under **normal conditions**, the system remains in monitoring mode.
- Under **abnormal conditions** (presence of smoke or high temperature), the system immediately activates the buzzer and LED.

This rapid detection and alert mechanism ensure early warning, allowing users to take timely action to prevent fire accidents.

## 3. Methodology

The methodology of the proposed Fire and Smoke Detection System is based on a **three-stage operational process**, namely: **Sensing Stage, Processing Stage, and Output Stage**. These stages work sequentially to ensure continuous monitoring, accurate detection, and immediate response to fire hazards.

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### 3.1 Sensing Stage

The sensing stage is the first and most critical step in the system, where environmental parameters are continuously monitored using sensors. The system utilizes an **MQ-2 smoke sensor** and a **temperature sensor (LM35/DHT11)** to detect fire-related conditions.

The MQ-2 sensor detects the presence of smoke and combustible gases such as LPG, methane, and carbon monoxide. It operates on the principle of variation in resistance when exposed to gas particles. As the concentration of smoke increases, the sensor produces a corresponding change in output voltage. This analog signal represents the level of smoke present in the environment.

Simultaneously, the temperature sensor measures the ambient temperature. The LM35 sensor provides an analog output proportional to temperature in degrees Celsius, while the DHT11 provides digital temperature (and humidity) readings. A sudden increase in temperature beyond normal limits is considered an indication of potential fire.

Both sensors continuously sense environmental conditions in real time and generate electrical signals proportional to the detected parameters. These signals are then transmitted to the microcontroller for further processing.

### 3.2 Processing Stage

The processing stage is carried out by the **Arduino microcontroller**, which acts as the central control unit of the system. It receives input signals from the sensors and performs necessary computations and decision-making operations.

The Arduino reads the analog signals from the sensors through its input pins. For analog sensors such as MQ-2 and LM35, the built-in Analog-to-Digital Converter (ADC) converts the analog voltage into digital values for processing. The microcontroller then compares these sensor readings with predefined threshold values programmed into the system.

The threshold values are carefully selected based on safe environmental limits. If the sensor readings remain below the threshold, the system continues in monitoring mode. However, if the values exceed the threshold (indicating high smoke concentration or elevated temperature), the microcontroller identifies it as a hazardous condition.

This stage ensures intelligent decision-making and minimizes false alarms through proper calibration and logical conditions.

### 3.3 Output Stage

The output stage is responsible for generating alerts when a fire hazard is detected. Once the microcontroller identifies abnormal conditions, it activates the output devices connected to the system.

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- **Buzzer Activation:**

The buzzer produces a loud audible alarm to immediately alert occupants about the potential danger. This ensures that even individuals who are not directly observing the system are notified.

- **LED Indicator:**

The LED provides a visual indication of the detected hazard. When the system detects abnormal conditions, the LED turns ON, signaling the presence of fire-related risk.

These alert mechanisms operate simultaneously to ensure maximum effectiveness. The system continues to monitor environmental conditions even after activation and can reset automatically when conditions return to normal.

**3.4 Overall Working Mechanism**

The entire system operates in a continuous loop:

1. Sensors detect environmental parameters (smoke and temperature)
2. Signals are sent to the Arduino microcontroller
3. The microcontroller processes and compares values with thresholds
4. If abnormal condition detected → buzzer and LED are activated
5. If conditions are normal → system continues monitoring

This methodology ensures **real-time monitoring, fast response, and reliable fire detection**, making the system effective for practical safety applications.

**4. Design and Implementation**

The design and implementation of the proposed Fire and Smoke Detection System involve the integration of both **hardware components** and **software programming** to achieve real-time monitoring and alert generation. The system is carefully designed to ensure reliability, accuracy, and ease of implementation.

**4.1 Hardware Design**

The hardware design focuses on the proper selection and interconnection of components such as sensors, microcontroller, and output devices. All components are interfaced with the Arduino microcontroller to form a complete embedded system.

**• MQ-2 Smoke Sensor Connection**
The MQ-2 smoke sensor is connected to the **analog pin A0** of the Arduino. It detects smoke and

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combustible gases by producing an analog voltage output proportional to gas concentration. This analog signal is continuously read by the microcontroller for analysis.

**• Temperature Sensor Connection (LM35/DHT11)**

The temperature sensor is connected to the **analog pin A1** (in case of LM35) or a digital pin (in case of DHT11). It measures ambient temperature and outputs a signal corresponding to temperature variations. This helps in detecting abnormal heat conditions associated with fire.

**• Buzzer Connection**

The buzzer is connected to **digital pin 8** of the Arduino. It acts as an audible alert device. When triggered by the microcontroller, it produces a sound to notify users about potential danger.

**• LED Indicator Connection**

The LED is connected to **digital pin 9**. It serves as a visual alert system. When the system detects hazardous conditions, the LED turns ON to indicate the presence of fire risk.

**• Power Supply**

All components are powered using a regulated **5V DC supply** from the Arduino. Proper grounding is ensured to maintain circuit stability and prevent noise or malfunction.

**• Circuit Considerations**

- Proper wiring and secure connections are maintained
- Resistors are used with LEDs for current limiting
- Sensors are calibrated for accurate readings
- Noise and voltage fluctuations are minimized

The hardware is assembled on a breadboard or PCB to ensure easy testing and reliability.

**4.2 Software Design**

The software design is implemented using the **Arduino Integrated Development Environment (IDE)**. The program (sketch) is responsible for controlling the entire system by reading sensor data, processing it, and triggering output devices.

The algorithm follows a simple yet effective logic:

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**Algorithm Steps**

1. **Initialization Stage**
   - Define input and output pins
   - Initialize sensors and serial communication
   - Set buzzer and LED pins as output
2. **Reading Sensor Values**
   - Read analog value from MQ-2 smoke sensor (A0)
   - Read temperature value from temperature sensor (A1)
   - Convert analog readings into meaningful units (e.g., °C for temperature)
3. **Data Processing and Comparison**
   - Compare sensor values with predefined threshold limits
   - Example:
     - Smoke threshold (e.g., > 400)
     - Temperature threshold (e.g., > 50°C)
4. **Decision Making**
   - If either smoke or temperature exceeds threshold → Fire condition detected
   - Otherwise → Normal condition
5. **Triggering Output Devices**
   - If fire detected:
     - Turn ON buzzer
     - Turn ON LED
   - Else:
     - Keep buzzer OFF
     - Keep LED OFF
6. **Loop Execution**

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- Repeat the process continuously for real-time monitoring

### 4.3 System Integration

The hardware and software are integrated to form a complete working system. The sensors provide input to the microcontroller, which processes the data and controls the output devices accordingly.

The system operates in a continuous loop, ensuring that environmental conditions are monitored at all times. The integration ensures:

- Real-time response
- Accurate detection
- Reliable performance

### 4.4 Summary

The design and implementation of the system demonstrate the effective use of embedded technology in safety applications. The combination of simple hardware and efficient software results in a reliable, low-cost fire detection system capable of providing early warnings and preventing potential hazards.

## 5. Results and Testing

The performance of the proposed Fire and Smoke Detection System was evaluated through a series of experimental tests conducted under controlled conditions. The objective of testing was to verify the system's ability to accurately detect fire-related parameters such as smoke and temperature, and to assess its response time, reliability, and overall effectiveness.

### 5.1 Testing Procedure

The system was tested using two primary methods: **smoke testing** and **heat testing**. These tests were performed multiple times to ensure consistency and reliability of results.

### 5.2 Smoke Testing

Smoke testing was conducted to evaluate the sensitivity and responsiveness of the MQ-2 smoke sensor.

- Smoke was artificially generated using an incense stick or similar source and introduced near the sensor.
- As smoke particles entered the sensing chamber, the sensor detected an increase in gas concentration.

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- This resulted in a change in output voltage, which was transmitted to the Arduino microcontroller.
- When the sensor reading exceeded the predefined threshold value, the system successfully triggered the alert mechanisms.

**Observation:**

- The buzzer was activated immediately, producing an audible warning.
- The LED indicator turned ON simultaneously, providing visual confirmation.
- The system responded quickly without noticeable delay.

This test confirmed that the MQ-2 sensor is highly effective in detecting smoke and initiating timely alerts.

### 5.3 Heat Testing

Heat testing was performed to verify the functionality of the temperature sensor.

- The temperature sensor was exposed to a controlled heat source such as a lighter or heated object placed at a safe distance.
- As the temperature increased, the sensor output varied proportionally.
- The Arduino continuously monitored these values and compared them with the preset threshold temperature.

**Observation:**

- When the temperature exceeded the threshold limit, the system activated the buzzer and LED.
- The response was consistent across multiple trials.

This test validated the system's ability to detect abnormal temperature rise, which is a key indicator of fire hazards.

### 5.4 Performance Parameters

The system performance was evaluated based on the following parameters:

**• Response Time**
The system demonstrated a fast response time, with alerts being triggered almost instantly after detection of abnormal conditions.

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**• Detection Accuracy**
The combination of smoke and temperature sensors improved detection accuracy, reducing the chances of missed detection.

**• Reliability**
Repeated testing under different conditions showed consistent performance, indicating high system reliability.

**• Stability**
The system operated smoothly without fluctuations or errors, even during continuous monitoring.

**5.5 Result Analysis**

The experimental results indicate that the proposed system is capable of:

- Detecting fire hazards at an early stage
- Providing immediate and effective alerts
- Maintaining consistent performance under varying conditions

The system showed **minimal delay in response** and **high sensitivity to both smoke and temperature changes**, making it suitable for real-world applications.

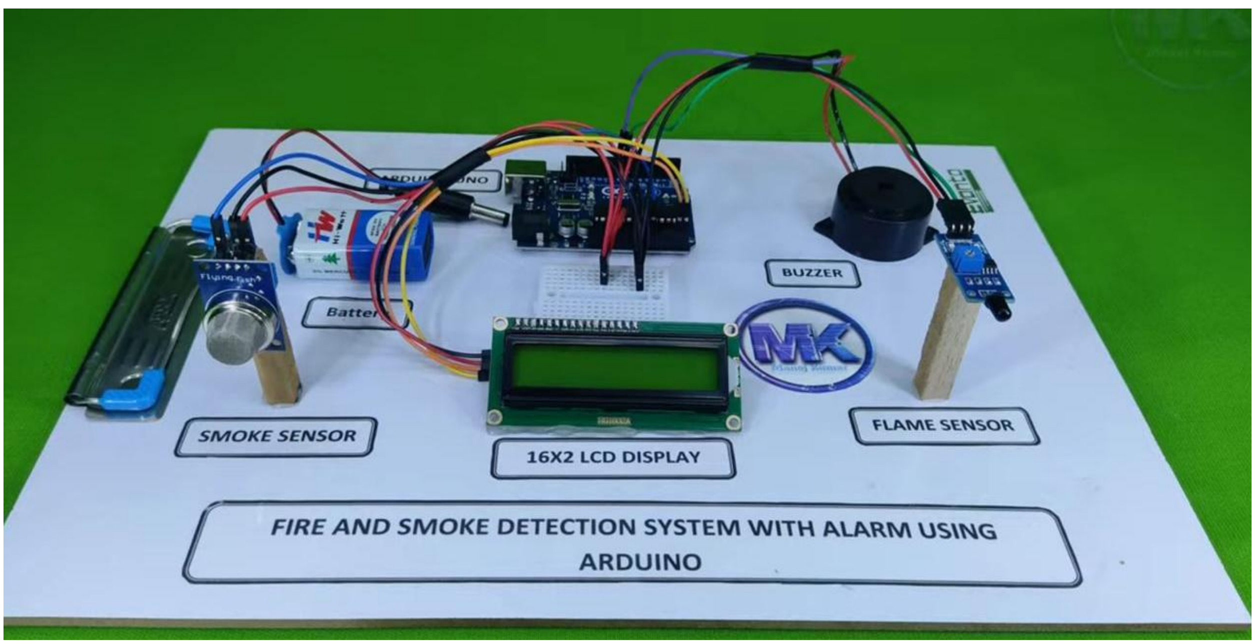


**Figure 2: Hardware Pictorial View**

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### 5.6 Summary

Overall, the Fire and Smoke Detection System performed efficiently during testing. The integration of sensors with the Arduino microcontroller ensured accurate detection, rapid response, and reliable operation. The results validate that the system is an effective and practical solution for early fire detection and safety enhancement.

## 6. Applications

The proposed Fire and Smoke Detection System has wide applicability across various domains due to its simplicity, cost-effectiveness, and reliability. Some of the key application areas are as follows:

**• Residential Buildings**
The system can be installed in homes, apartments, and residential complexes to detect fire hazards at an early stage. It helps in safeguarding lives and property by providing timely alerts in case of smoke or excessive heat.

**• Offices and Commercial Spaces**
In offices, shopping complexes, and commercial establishments, the system can be used to monitor electrical equipment and prevent fire accidents caused by overheating or short circuits. It enhances workplace safety and ensures compliance with safety standards.

**• Industrial Environments**
Industries often involve the use of combustible materials, machinery, and high-temperature processes. The proposed system can be deployed in factories and warehouses to detect fire risks and prevent major industrial accidents, thereby reducing economic losses.

**• Hospitals and Public Places**
Public places such as hospitals, schools, malls, and transportation hubs require reliable fire detection systems to ensure the safety of large numbers of people. The system can provide early warnings, allowing for quick evacuation and emergency response.

## 7. Advantages

The developed system offers several advantages that make it suitable for practical implementation:

**• Low Cost**
The system is designed using inexpensive components such as Arduino, MQ-2 sensor, and basic electronic devices, making it affordable for widespread use.

**• Easy Implementation**
The hardware setup and programming are simple, allowing easy installation and operation even for users with basic technical knowledge.

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**• Real-Time Monitoring**
The system continuously monitors environmental conditions and provides instant alerts when abnormal conditions are detected.

**• High Reliability**
The use of multiple sensors improves detection accuracy and reduces the chances of failure or missed detection.

**• Scalable Design**
The modular architecture allows the system to be expanded with additional features such as IoT connectivity, remote monitoring, and automation.

## 8. Conclusion

The proposed Arduino-based Fire and Smoke Detection System successfully demonstrate an efficient and economical approach to early fire detection. By integrating smoke and temperature sensors with a microcontroller, the system ensures continuous monitoring of environmental conditions and rapid response to potential hazards.

The system effectively detects abnormal conditions such as increased smoke concentration and elevated temperature, and immediately activates alert mechanisms including a buzzer and LED. This quick response capability helps in minimizing damage and preventing accidents.

Furthermore, the system is simple in design, easy to implement, and highly reliable, making it suitable for deployment in residential, commercial, and industrial environments. It highlights the significant role of embedded systems in enhancing safety and provides a practical solution for fire hazard detection.

## 9.Future Scope

Although the proposed system performs effectively, it can be further enhanced by incorporating advanced technologies and additional features:

**• Integration with IoT for Remote Monitoring**
The system can be connected to IoT platforms to enable real-time monitoring through mobile applications or web interfaces, allowing users to access data from anywhere.

**• Mobile Alert System**
Incorporating GSM or Wi-Fi modules can enable the system to send SMS, email, or app notifications to users during emergencies.

**• Automatic Fire Suppression System**
The system can be extended to include automatic fire extinguishing mechanisms such as water sprinklers or gas suppression systems for immediate action.

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**• Cloud-Based Data Logging**

Sensor data can be stored on cloud platforms for analysis, monitoring trends, and improving system performance over time.

In conclusion, the developed Arduino-based Fire and Smoke Detection System provides a practical, reliable, and cost-effective solution for early fire hazard detection. By integrating smoke and temperature sensors with an embedded microcontroller, the system ensures continuous monitoring and immediate alert generation, thereby reducing the risk of severe damage and loss. The successful implementation and testing of the system demonstrate its effectiveness in real-time applications. Furthermore, its simple design and scalability make it suitable for widespread deployment and future enhancements, contributing significantly to improved safety and smart monitoring systems.

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