Design and Implementation of an Arduino Nano–Based Automated Fire and Smoke Detection System with Integrated Water Sprinkler Control

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ABSTRACT

Fire hazards continue to pose serious risks to human life and property, particularly in residential settings where immediate detection and response are crucial. This study presents the design and development of an Arduino Nano–based automated fire and gas detection system integrated with a water sprinkler mechanism. The system utilizes an MQ-2 gas and smoke sensor together with a KY-026 flame sensor to continuously monitor environmental conditions and identify potential fire-related threats.

When elevated gas or smoke levels are detected, the system generates early warning signals through slow visual and audible alerts using a red LED and a passive buzzer. In the presence of an active flame, the system prioritizes fire conditions by activating faster and more intense alarms and automatically operating a water pump to discharge water through a sprinkler for fire suppression. The system employs threshold-based decision logic and priority control within a closed-loop embedded framework to ensure accurate and timely responses.

Experimental testing showed that the prototype reliably detected gas, smoke, and flame conditions and responded appropriately in real time. Due to its low cost, simple design, and expandability, the proposed system is suitable for educational purposes, prototype fire safety demonstrations, and small-scale residential applications.

Keywords: Fire Detection System, Gas and smoke sensor, Flame Sensor, Water Sprinkler, Arduino Nano, Embedded Control System

INTRODUCTION

Background of the Project

Fire incidents remain one of the major causes of property damage, environmental destruction, and loss of human life, particularly in residential buildings. The increasing use of electrical appliances, gas systems, and flammable household materials has raised the risk of accidental fires. Traditional fire safety systems in homes are commonly limited to smoke detectors and manual fire extinguishers. Although these devices provide warning, they rely heavily on human intervention, which may not always be immediate or effective, especially when occupants are absent or unable to respond promptly.

Several studies have emphasized the importance of integrating automation and embedded systems into fire safety applications. Randive *et al.* (2022) developed an Arduino-based fire detection and water sprinkler system designed to provide a low-cost and automated fire suppression solution. Their study demonstrated that combining fire detection with automatic sprinkler activation significantly improves response time and minimizes fire damage.

Similarly, Jagtap *et al.* (2023) proposed a fire and smoke detection alarm system using an Arduino microcontroller and MQ-2 gas and smoke sensor. Their research highlighted the importance of early smoke detection as a critical warning stage before the occurrence of visible flames. The study confirmed that embedded sensor-based systems are capable of accurately detecting smoke conditions and generating timely alerts.

Paul *et al.* (2025) presented a real-time fire monitoring system using Arduino technology, emphasizing continuous environmental monitoring and immediate alarm generation. Their findings showed that low-cost microcontroller platforms can provide reliable and responsive fire detection suitable for small-scale safety applications. In addition, Tun *et al.* (2020) demonstrated that multi-sensor fire detection systems improve detection accuracy and system reliability.

Despite these advancements, many residential fire safety solutions remain limited to passive alert mechanisms and lack integrated fire suppression features. Commercial sprinkler systems, while effective, are often expensive and impractical for small residential structures and academic prototypes. This gap highlights the need for a cost-effective, automated, and integrated fire detection and suppression system.

This project is grounded in the principles of feedback and control systems, where sensor feedback is continuously processed to determine appropriate control actions. By integrating flame and gas and smoke sensors with an Arduino Nano microcontroller and a water pump–based sprinkler mechanism, the system provides automated detection, alerting, and suppression of fire hazards in a closed-loop embedded control system.

Importance and Relevance of the Study

This study is important as it demonstrates the application of embedded systems and feedback control principles in the development of an automated fire safety system. Automated fire detection and suppression systems have been shown to reduce response time and minimize fire-related damage. Randive *et al.* (2022) emphasized that integrating fire detection with automatic sprinkler mechanisms enhances fire suppression efficiency and reduces dependence on manual intervention.

From an engineering perspective, the study highlights the use of sensor feedback in controlling system behavior. Bolton (2015) and Ogata (2010) explained that closed-loop control systems rely on continuous feedback to ensure accurate and responsive operation. The integration of flame and gas and smoke sensors with a microcontroller and water pump in this project illustrates these control concepts in a practical embedded system.

The relevance of this study extends to residential fire safety and engineering education. Jagtap *et al.* (2023) showed that early smoke detection provides critical warning before fire escalation, while Monk (2022) noted the effectiveness of Arduino-based platforms for teaching sensor interfacing and control logic. This project provides a low-cost and scalable prototype suitable for educational use and small-scale safety applications.

REVIEW OF RELATED LITERATURE

Fire Detection and Smoke Monitoring Systems

Fire detection systems are designed to minimize the risks associated with fire incidents by providing early warnings and enabling timely response. Conventional fire safety solutions, such as smoke alarms and manual fire extinguishers, mainly function as alert mechanisms and rely heavily on human action to control fire hazards. Research has shown that detecting smoke and fire at an early stage plays a crucial role in reducing fire-related injuries, property loss, and environmental damage. Tun *et al.* (2020) developed an Arduino-based fire detection and alarm system using gas and smoke sensors and identified smoke detection as a reliable early indicator of potential fire incidents. Their findings demonstrated that sensor-based systems are effective in providing prompt alerts before fires escalate.

In a related study, Jagtap *et al.* (2023) designed a fire and smoke detection system utilizing an Arduino microcontroller and an MQ-2 gas and smoke sensor. Their work emphasized that gas and smoke sensors often identify hazardous conditions earlier than flame sensors in many fire scenarios. While the system successfully generated warning alarms, it lacked an automated fire suppression feature. This limitation highlights the need for fire safety systems that not only detect hazards but also actively respond to suppress fire conditions.

Automated Fire Suppression Using Water Sprinkler Systems

Automated fire suppression systems have been widely recognized for their effectiveness in controlling fires during the early stages. Randive *et al.* (2022) developed an Arduino-based fire detection system integrated with a water sprinkler mechanism. Their study demonstrated that the automatic activation of sprinklers significantly improves response time and reduces dependence on manual firefighting efforts. The authors concluded that microcontroller-controlled water pumps offer a practical and low-cost approach to fire suppression, particularly for residential and small-scale applications.

Further supporting this approach, Paul *et al.* (2025) presented a real-time fire monitoring system using Arduino technology. Their research highlighted the importance of continuous environmental monitoring and automated system response without human intervention. The integration of actuators such as water pumps, along with appropriate power sources and control mechanisms, enables the practical implementation of automated fire suppression systems. These studies confirm that combining fire detection with sprinkler-based suppression enhances system reliability and overall fire safety performance.

Arduino-Based Embedded and Control Systems

Arduino microcontrollers are widely used in embedded system applications due to their affordability, simplicity, and capability for real-time data processing. Monk (2022) emphasized that Arduino platforms are well suited for sensor-based automation projects, especially in educational settings and prototype development. Arduino-based systems allow continuous acquisition of sensor data and immediate control of output devices, making them suitable for safety-critical applications such as fire detection and suppression.

From the perspective of control systems engineering, feedback is a fundamental component in regulating system behavior and achieving desired outputs. Ogata (2010) explained that feedback control systems operate by continuously adjusting system actions based on sensor measurements. In automated safety systems, this feedback mechanism enables rapid response to changing environmental conditions. Bolton (2015) further explained that embedded control systems commonly operate as closed-loop systems, where sensor feedback is continuously fed into the controller to regulate actuator behavior.

Most existing studies focus on fire detection or alarm systems as independent solutions. In contrast, the present study integrates fire detection, smoke monitoring, and automated water sprinkler control—including pump actuation and power management—into a single closed-loop embedded system using Arduino Nano. This integrated approach demonstrates the combined application of sensing, processing, and actuation within one platform and addresses the limitations identified in previous research.

Table 1. Comparison Matrix of Related Studies and Current Research

Study	Sensors Used	Controller	Main Outputs	Scope	Key Features	Gap Addressed by This Study
Tun *et al.* (2020)	Gas and smoke sensor	Arduino	Alarm	Fire detection system	Early smoke-based fire warning	No automatic fire suppression

Jagtap *et al.* (2023)	MQ-2 Gas and smoke sensor	Arduino	Alarm	Fire and smoke monitoring	Early hazard detection using smoke	Lacks sprinkler or suppression mechanism
Randive *et al.* (2022)	Flame Sensor	Arduino	Water Sprinkler	Automated fire suppression	Automatic sprinkler activation	Limited to single-sensor detection
Paul *et al.* (2025)	Flame & Gas and smoke sensors	Arduino	Alarm	Embedded fire monitoring	Real-time environmental monitoring	No integrated suppression control
Current Study (Design and Implementation of an Arduino Nano–Based Automated Fire and Smoke Detection System with Integrated Water Sprinkler Control)	Flame Sensor (KY-026), Gas and smoke sensor (MQ-2)	Arduino Nano	Alarm and Water Sprinkler	Small-scale fire safety prototype	Closed-loop feedback control, detection and suppression	Integrates detection, alerting, and suppression in one system

PROBLEM STATEMENT AND OBJECTIVES

Problem Statement

Fire safety systems in most residential environments are primarily limited to smoke alarms and manually operated fire extinguishers. While these devices are capable of providing basic warnings, they depend heavily on human intervention to respond to fire incidents. Delayed response due to absence of occupants, panic, or lack of immediate access to firefighting equipment can result in rapid fire escalation, leading to severe property damage, environmental impact, and potential loss of life. Moreover, automated fire suppression systems such as sprinklers are rarely installed in residential areas because of high cost and complex installation requirements.

In addition, many existing low-cost fire detection systems focus mainly on alarm generation and lack automated suppression capabilities. These systems do not dynamically respond to fire conditions through active control mechanisms. The absence of sensor-based feedback and automatic actuation significantly limits their effectiveness in controlling fire hazards during the early stages of ignition (Ogata, 2010).

There is therefore a need to develop an automated fire safety system that integrates real-time environmental sensing, data processing, and active response mechanisms. Such a system should utilize smoke and flame sensors to detect hazardous conditions, process sensor data using a microcontroller, and generate immediate visual and audible alerts. Furthermore, the system should automatically activate a water pump and sprinkler mechanism to suppress fire without relying solely on human intervention. Integrating sensing, control, and actuation within a closed-loop embedded control system can significantly enhance fire safety in residential and small-scale applications.

General Objective

To design and implement an automated fire and smoke detection system with integrated water sprinkler control using sensor-based feedback and embedded control principles.

Specific Objectives

- To detect the presence of smoke using a gas and smoke sensor
- To detect the presence of flame using a flame sensor
- To provide visual warning indications using LED indicators during hazardous conditions
- To generate audible alarms using a buzzer with distinct alert patterns
- To automatically activate a water pump and sprinkler mechanism when flame is detected
- To demonstrate the integration of sensing, control, and actuation within a single closed-loop embedded system

SYSTEM DESIGN AND METHODOLOGY

Research Design

This study employed a developmental and experimental research design aimed at designing, constructing, and evaluating an automated fire and smoke detection system with water sprinkler control. The system was implemented as a miniature house prototype to allow controlled testing and clear visualization of sensor-based feedback and automated response mechanisms. This approach enabled the evaluation of the embedded system's functionality while maintaining a realistic representation suitable for an academic laboratory setting.

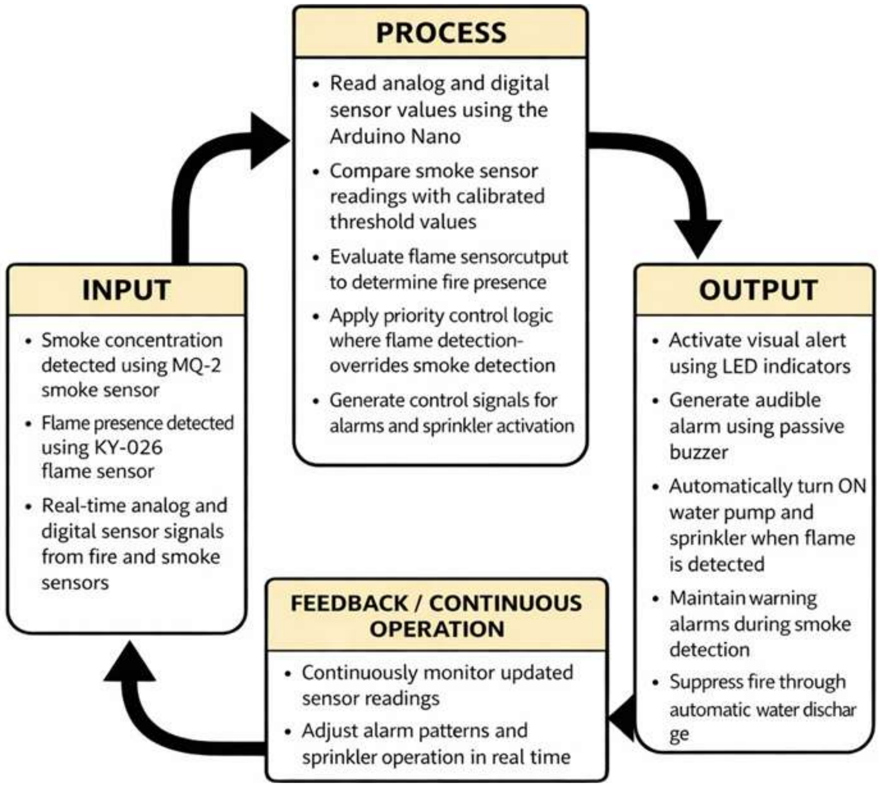
Input–Process–Output (IPO) Model

The Automated Fire and Smoke Detection with Water Sprinkler System operates based on the Input–Process–Output (IPO) model. At the input stage, a gas and smoke sensor and a flame sensor are utilized to continuously monitor environmental conditions and detect potential fire hazards. The gas and smoke sensor measures the concentration of smoke present in the air, while the flame sensor detects infrared radiation emitted by fire sources. These sensor outputs provide real-time analog and digital signals to the Arduino Nano microcontroller.

During the processing stage, the microcontroller continuously reads and interprets the sensor data using its internal processing and analog-to-digital conversion capabilities. The acquired data is evaluated using predefined threshold-based decision logic to determine whether smoke or flame is present. Priority control logic is applied to ensure that flame detection overrides smoke detection due to its higher level of risk. Based on the evaluated sensor feedback, the system determines the appropriate operational state.

At the output stage, the system executes corresponding actions based on the processing results. Visual warning indicators are activated using LED outputs, while audible alerts are generated through a buzzer with distinct alarm patterns for smoke and flame detection. When flame presence is confirmed, the Arduino Nano automatically activates a water pump powered by an external supply, allowing water to flow through a connected tube and sprinkler mechanism to suppress the fire. The continuous interaction between sensing, processing, and actuation forms a closed-loop embedded control system that enables real-time and adaptive response to fire hazards.

Figure 1. Input–Process–Output (IPO) Model of the Automated Fire, Smoke Detection, and Water Sprinkler System



System Architecture

The proposed system is designed as a closed-loop embedded control system composed of three main subsystems: sensing, processing, and actuation. The overall architecture follows fundamental principles of mechatronics and control engineering, where continuous sensor feedback is used to regulate system behavior and enable timely responses to hazardous environmental conditions (Bolton, 2015).

The sensing subsystem utilizes an MQ-2 gas and smoke sensor and a KY-026 flame sensor as the primary input devices. The MQ-2 sensor is capable of detecting combustible gases and smoke, producing an analog signal that varies according to the concentration of detected substances in the surrounding air. This allows early identification of abnormal gas or smoke levels that may indicate a potential fire hazard. The KY-026 flame sensor detects infrared radiation emitted by open flames and provides a digital output that indicates the presence or absence of active fire. Together, these sensors provide continuous real-time feedback representing different levels of fire-related risk in the monitored environment.

The processing subsystem is implemented using an Arduino Nano microcontroller (ATmega328P), which continuously acquires both analog data from the MQ-2 gas sensor and digital signals from the flame sensor. The microcontroller converts analog inputs using its built-in analog-to-digital converter and evaluates all sensor readings using predefined threshold-based decision logic. A priority control strategy is implemented in software, wherein flame detection is given higher priority than gas or smoke detection due to the increased severity of active fire conditions. Based on the evaluated sensor feedback, the controller determines the appropriate operating mode and generates corresponding control signals for warning and suppression mechanisms.

The actuation subsystem consists of output devices responsible for alerting occupants and suppressing fire hazards. A red LED serves as a visual indicator, while a passive buzzer provides audible alerts with distinct patterns to differentiate between gas/smoke detection and flame detection. In addition, a water pump connected to a sprinkler

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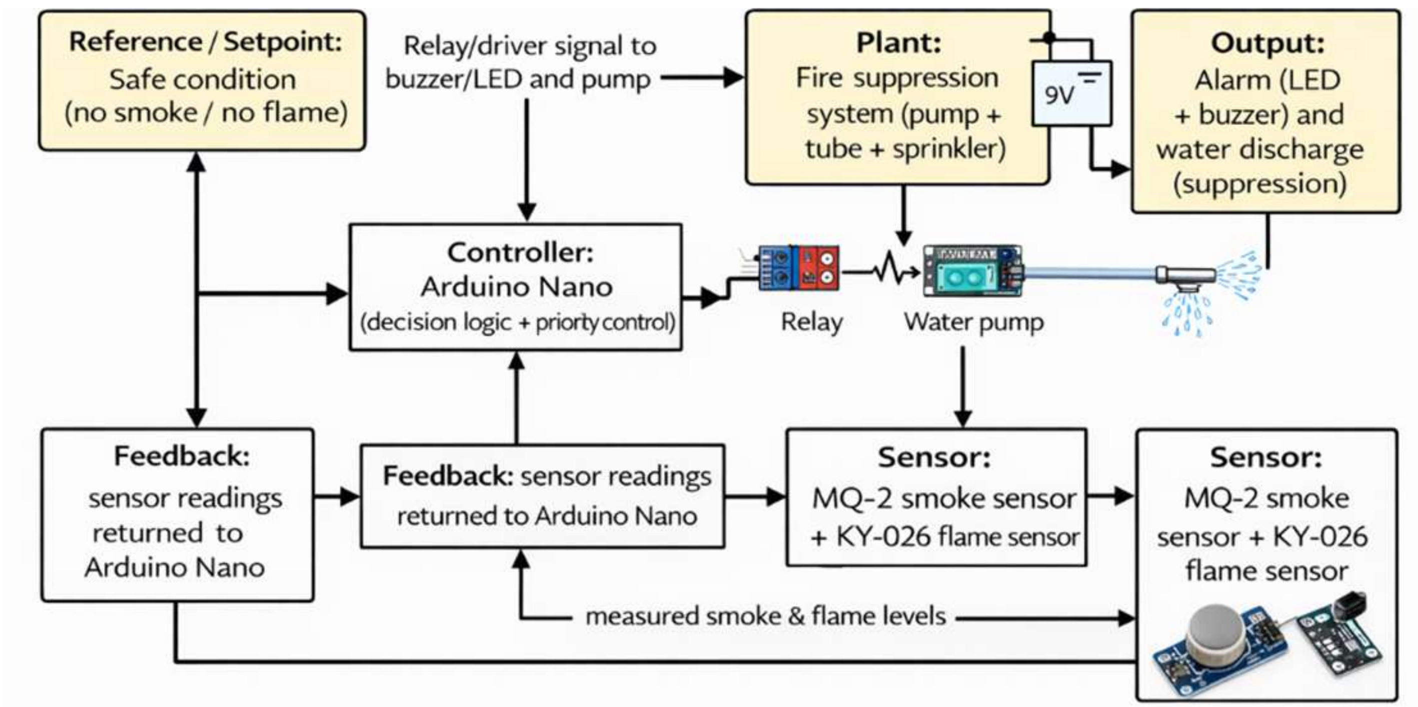
mechanism acts as the fire suppression actuator. When flame presence is confirmed, the microcontroller automatically activates the water pump to discharge water and help control fire escalation. These output actions are continuously updated based on real-time sensor feedback, forming a complete closed-loop control system that integrates detection, decision-making, and automated response within a single embedded platform (Ogata, 2010).

Block Diagram

Figure 2. Closed-Loop Feedback Control Block Diagram of the Automated Fire and Smoke Detection with Water Sprinkler System.



The proposed system is considered to be a closed-loop feedback control system for automated fire detection and suppression. A gas and smoke sensor (MQ-2) and a flame sensor (KY-026) provide real-time environmental data to an Arduino Nano microcontroller, which continuously compares the sensed smoke concentration and flame presence with predefined safety threshold levels. Based on this comparison, the controller determines the operating condition of the system and generates appropriate control signals for alarm activation and fire suppression.

When smoke is detected, the controller activates visual and audible warning indicators, while flame detection triggers a higher-priority response. In this condition, the Arduino Nano sends a control signal to a relay or driver circuit that activates a water pump connected to a sprinkler mechanism, allowing water to be discharged for fire suppression. The sensors continuously monitor the environment after actuation and return updated feedback to the controller, enabling stable, adaptive, and reliable system operation under varying fire hazard conditions.

Schematic Diagram

Figure 3. Schematic Diagram of the Automated Fire and Smoke Detection with Water Sprinkler System presents the complete hardware configuration of the proposed system. The MQ-2 gas and smoke sensor and KY-026 flame sensor are interfaced with the Arduino Nano to continuously monitor environmental conditions. The gas and smoke sensor provides analog data representing smoke concentration, while the flame sensor supplies a digital signal indicating the presence of fire.

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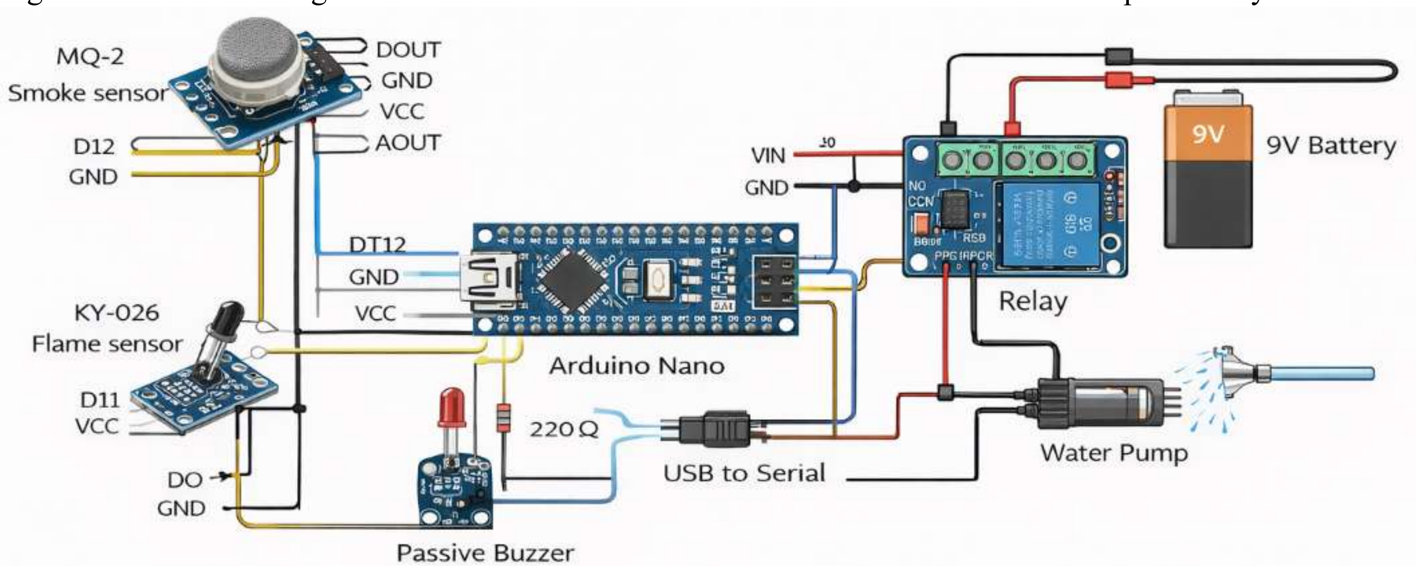
The Arduino Nano processes the sensor inputs using threshold-based decision logic and generates control signals for the output devices. Visual and audible alerts are produced through a red LED and a passive buzzer with different alert patterns for smoke and flame detection. When flame presence is confirmed, the microcontroller activates a relay module that controls a water pump powered by an external 9V battery. The pump delivers water through a tube and sprinkler mechanism to suppress the fire.

This schematic illustrates the integration of sensing, processing, and actuation components in a closed-loop embedded control system that enables automatic fire detection, warning, and suppression.

Figure 3. Schematic Diagram of the Automated Fire and Smoke Detection with Water Sprinkler System



Components and Their Functions

The system is composed of input sensors, a central controller, output devices, and supporting components. Each component performs a specific function in implementing the sensor-based feedback control mechanism of the automated fire and smoke detection with water sprinkler system.

Table 2. System Components and Corresponding Functions

Category	Component	Function
Input Components	MQ-2 Gas and smoke sensor	Detects the presence and concentration of smoke and combustible gases and provides an analog signal to the microcontroller
Input Components	KY-026 Flame Sensor	Detects infrared radiation emitted by fire sources and provides a digital signal indicating flame presence
Controller	Arduino Nano (ATmega328P)	Processes sensor data, executes threshold-based decision logic, applies priority control, and generates control signals for alarms and sprinkler activation
Output Components	Red LED	Provides visual warning indication during smoke and fire detection
Output Components	Passive Buzzer (KY-006)	Generates audible alarms with distinct patterns for smoke detection and flame detection

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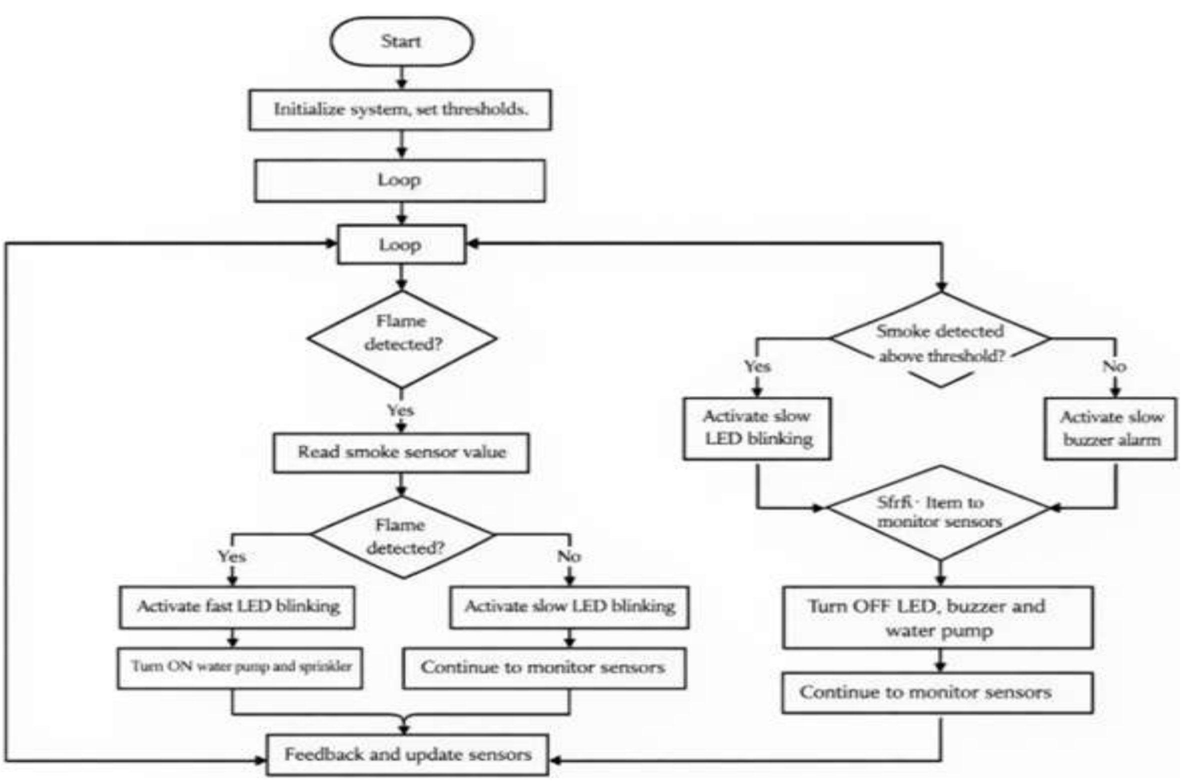
Output Components	Water Pump	Pumps water during fire detection to suppress flames through the sprinkler mechanism
Output Components	Sprinkler and Water Tube	Directs and disperses water from the pump to the fire source
Output Components	Relay Module	Acts as an electrical switch allowing the low-power Arduino signal to control the higher-current water pump
Supporting Components	9V Battery and Battery Holder	Supplies independent power to the water pump subsystem
Supporting Components	Switch / Push Button	Allows manual control of system power or pump activation during testing and emergency conditions
Supporting Components	Resistors (220Ω, 10kΩ)	Used for current limiting, signal conditioning, and circuit stability
Supporting Components	Breadboard and Jumper Wires	Provide temporary connections and support circuit prototyping

Operation Flow of the System

To illustrate the sequence of operations and decision-making process of the proposed system, a flowchart is provided. The flowchart describes how sensor inputs from the smoke and flame sensors are continuously acquired, processed by the Arduino Nano microcontroller, and translated into appropriate control actions such as alarm activation and water sprinkler operation. This representation highlights the closed-loop nature of the system, wherein real-time sensor feedback continuously influences system behavior to ensure timely warning and automatic fire suppression.

Figure 4. Flowchart of the Automated Fire and Smoke Detection with Water Sprinkler System



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HARDWARE AND SOFTWARE REQUIREMENTS

List of Hardware Components

- Arduino Nano (ATmega328P) – serves as the main controller of the system
- MQ-2 Gas and smoke sensor – detects smoke and combustible gas concentration
- KY-026 Flame Sensor – detects infrared radiation emitted by fire sources
- Red LED – provides visual warning indication
- Passive Buzzer (KY-006) – generates audible alerts with different alarm patterns
- Water Pump – pumps water during fire detection
- Sprinkler and Water Tube – distributes water to suppress fire
- Relay Module – allows the Arduino to control the water pump safely
- 9V Battery and Battery Holder – supplies independent power to the water pump
- Switch / Push Button – used for system power control or testing
- Resistors (220Ω, 10kΩ) – used for current limiting and signal conditioning
- Breadboard and Jumper Wires – used for circuit connections and prototyping

Software Tools and Platforms Applied

1. **Arduino Integrated Development Environment (IDE)**
    - Used for writing, compiling, and uploading the control program to the Arduino Nano
    - Serves as the main development platform for the embedded system
2. **Arduino Core Libraries**
    - Provide built-in functions for digital and analog input/output operations
    - Support timing control for LED blinking and buzzer alarm patterns
3. **No Simulation Software Used**
    - The system was tested and validated directly on actual hardware
    - No circuit simulation tools such as Proteus or Multisim were used

Hardware and Software Integration or Communication.

The proposed system achieves effective integration between hardware components and embedded software through continuous coordination of sensor inputs, control logic, and actuator outputs. As part of this integration process, proper sensor calibration and signal conditioning were performed to ensure accurate communication between the sensing devices and the microcontroller.

The MQ-2 gas and smoke sensor generates real-time analog signals that vary according to the concentration of combustible gases and smoke in the environment, while the KY-026 flame sensor provides a digital signal indicating the presence of infrared radiation from active fire sources. These signals are directly read by the Arduino Nano through its analog and digital input pins. During system initialization, calibration is conducted under normal, hazard-free conditions to establish baseline reference values. Threshold limits and short processing delays are applied within the software to minimize false alarms and improve signal stability, accounting for environmental factors such as airflow, humidity, and temperature variations.

The embedded control program processes the calibrated sensor data using threshold-based decision logic and priority control, where flame detection is given higher priority than gas or smoke detection. Based on the evaluated sensor inputs, the Arduino Nano generates appropriate control signals to activate the red LED and passive buzzer for early warning purposes. When flame presence is confirmed, the microcontroller triggers the relay module to safely activate the water pump, allowing water to flow through the tube and sprinkler mechanism for fire suppression.

Continuous feedback from the sensors enables real-time monitoring and adaptive system response, forming a closed-loop embedded control system. This integrated interaction between hardware components and software logic ensures reliable operation, accurate hazard detection, and timely activation of warning and suppression mechanisms under varying environmental conditions.

Power Management and System Safety

To ensure safe operation and protect the microcontroller from high-current loads, the water pump was powered using an external 9V battery and controlled through a relay module. This design prevented electrical interference and potential damage to the Arduino Nano. The relay provided electrical isolation between the low-power control circuitry and the higher-power pump, ensuring stable and safe system operation during fire suppression.

TESTING AND RESULTS

Testing Procedures and Scenarios

The testing of the proposed system was conducted to ensure that the operational flow described in the system flowchart functions correctly and consistently. The testing process focused on validating sensor calibration, hazard detection accuracy, alarm behavior, and automated fire suppression response. A total of ten (10) trial tests were performed using an improved miniature house prototype to simulate realistic fire and smoke conditions in a controlled environment.

At the beginning of each trial, the system was powered on and allowed to initialize under normal, hazard-free conditions to establish baseline sensor readings. This calibration phase ensured that the smoke and flame sensors operated within their reference thresholds and minimized false triggering. After calibration, different testing scenarios were introduced by varying environmental conditions such as the presence of smoke and flame.

Smoke detection tests were conducted by introducing smoke near the MQ-2 sensor to simulate early fire conditions. These trials evaluated the system’s ability to activate visual and audible warning indicators without triggering the water sprinkler. Flame detection tests were performed by exposing the KY-026 flame sensor to a controlled flame source. These scenarios tested the system’s capability to identify active fire conditions and automatically activate the water pump and sprinkler mechanism.

Additional trials involved combined smoke and flame conditions to verify the priority-based control logic of the system. Each trial assessed whether the system correctly distinguished between smoke-only warnings and flame-triggered suppression, as well as its ability to reset once hazardous conditions were removed. The results of the ten trials confirmed that the system reliably detected fire hazards, activated appropriate responses, and maintained continuous feedback operation as designed.

System testing included scenarios involving gas or smoke detection, flame detection, and combined hazard conditions. The results showed that the system consistently activated early warning alerts during gas detection while reserving water sprinkler activation for confirmed flame presence. The priority-based control logic effectively prevented unnecessary water discharge, demonstrating reliable closed-loop system behavior.

Results of System Testing (10 Trials)

Table 3. System Testing and Validation Results

Trial No.	Input Condition	Observed Output	Expected Output	Pass / Fail	Remarks / Behavior Explanation
1	No smoke, no flame	LED OFF, buzzer OFF, pump OFF	Normal system state	Pass	System remains idle under safe conditions
2	Light smoke only	Slow blinking LED, slow buzzer	Early warning activated	Pass	Smoke detection functioning correctly
3	Moderate smoke only	Slow LED, slow buzzer continues	Warning without sprinkler	Pass	Correct suppression avoidance
4	Flame detected only	Fast LED, fast buzzer, pump ON	Alarm and sprinkler activated	Pass	Fire detected and suppressed
5	Smoke then flame	Fast LED, fast buzzer, pump ON	Flame priority override	Pass	Flame detection correctly prioritized
6	Smoke present, flame removed	Slow LED, slow buzzer, pump OFF	Warning mode maintained	Pass	Proper mode switching
7	Flame present briefly	Pump activates, water released	Immediate suppression	Pass	Fast response verified
8	Continuous flame	Pump remains ON, alarms active	Sustained suppression	Pass	Stable fire control
9	Smoke and flame cleared	LED OFF, buzzer OFF, pump OFF	System reset	Pass	Feedback loop working
10	Repeated smoke–flame cycle	Correct response every cycle	Reliable operation	Pass	System consistency verified

Observations and System Performance Analysis

Based on the experimental trials conducted, the proposed system demonstrated stable and reliable performance under various testing conditions. The smoke and flame sensors were able to accurately detect changes in the environment and respond according to the programmed control logic. During smoke-only conditions, the system consistently generated early warning signals through slow LED blinking and low-speed buzzer alarms, indicating potential fire hazards without activating the water sprinkler.

When flame presence was introduced, the system immediately shifted to a high-priority response mode. The red LED blinked rapidly, the buzzer produced a faster and higher-pitched alarm, and the water pump was automatically activated to release water through the sprinkler mechanism. This response confirmed that the priority control logic, where flame detection overrides smoke detection, functioned correctly in all test scenarios.

The system also exhibited effective closed-loop feedback behavior. After the activation of alarms and water discharge, the sensors continued monitoring the environment and allowed the system to maintain or deactivate outputs based on updated conditions. Minor fluctuations in sensor readings were observed due to environmental factors such as airflow and light reflections; however, these variations did not significantly affect the overall performance or reliability of the system. Overall, the system demonstrated accurate hazard detection, timely response, and effective integration of sensing, processing, and actuation components within a closed-loop embedded control framework.

Problems Encountered and Solutions Applied

Several challenges were encountered during the development and testing phases of the system, particularly related to sensor sensitivity, calibration, and actuator control. Initial testing revealed that the gas and smoke sensor was sensitive to sudden changes in environmental conditions, which occasionally resulted in unstable readings. This issue was addressed by implementing threshold-based decision logic and introducing controlled delays between consecutive sensor readings to improve measurement stability and reduce false triggering.

Another challenge involved ensuring accurate baseline calibration of the sensors. Proper system initialization required that no smoke or flame be present during startup to establish correct reference values. If calibration was performed under non-ideal conditions, inaccurate detection could occur. This issue was resolved by enforcing a controlled startup procedure, ensuring that the system was initialized only under safe and hazard-free conditions.

During early testing, fluctuations in output behavior were observed when the water pump was driven directly without proper electrical isolation. To address this, a relay module was incorporated to safely control the pump using low-power signals from the Arduino Nano. This modification provided stable pump operation and protected the microcontroller from high current loads. Through these corrective measures, the system achieved improved stability, accuracy, and reliability, ensuring consistent performance across all test trials.

DISCUSSION

The results of the experimental evaluation indicate that combining gas and smoke detection with flame sensing improves early hazard identification and overall system reliability. The MQ-2 gas and smoke sensor enabled early detection of combustible gases and smoke, allowing warning alerts to be generated before visible flames occurred. This early warning capability is critical in minimizing fire escalation and improving system responsiveness.

The implementation of priority-based control logic ensured that the water sprinkler mechanism was activated only when flame detection confirmed a critical fire condition. This prevented unnecessary water discharge during smoke-only scenarios and demonstrated proper application of feedback control principles in an embedded system. Continuous sensor monitoring and real-time processing allowed the system to adapt its response based on changing environmental conditions, reflecting closed-loop control behavior.

Although the MQ-2 sensor is sensitive to environmental variations such as airflow and humidity, the use of calibration and threshold-based decision logic helped maintain stable and reliable operation. As a prototype developed for educational and small-scale applications, the system successfully demonstrated the integration of sensing, processing, and actuation within a closed-loop embedded control framework.

CONCLUSION

This study successfully designed and implemented an automated fire and smoke detection system with an integrated water sprinkler mechanism using an Arduino Nano–based feedback control approach. By combining smoke and flame sensors with visual and audible alarms and automatic fire suppression, the system demonstrated reliable detection, warning, and response to fire hazards under various testing conditions.

The project also served as an effective learning platform for applying embedded systems and control engineering concepts such as sensor interfacing, real-time processing, and feedback control. Although developed as a small-scale prototype, the system met all stated objectives and showed potential for practical fire safety applications. Future enhancements may include advanced sensors and wireless or IoT-based monitoring to improve system scalability and functionality.

In addition, the inclusion of relay-based isolation and an external power supply for the water pump enhanced system safety by protecting the microcontroller from high-current loads during fire suppression.

FUTURE ENHANCEMENTS

Future improvements to the system may include the integration of additional sensors such as temperature sensors, infrared flame arrays, or specialized gas sensors to further improve detection accuracy and reduce environmental sensitivity. The system may also be enhanced by incorporating wireless communication technologies such as Wi-Fi or GSM modules, enabling remote monitoring, real-time alerts, and IoT-based data analysis. These enhancements would increase the system's scalability, reliability, and applicability to real-world residential fire safety systems.

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REFERENCES

1. Ogata, K. (2010). *Modern control engineering* (5th ed.). Prentice Hall.
2. Randive, A. S., Patil, S. S., & Deshmukh, P. R. (2022). Arduino-based fire detection and automatic water sprinkler system. *International Research Journal of Engineering and Technology (IRJET)*, 9(4), 987–991.
3. Monk, S. (2022). *Programming Arduino: Getting started with sketches* (2nd ed.). McGraw-Hill Education.
4. Jagtap, P. S., Patil, R. R., & Shinde, S. R. (2023). Fire and smoke detection system using Arduino and MQ-2 sensor. *International Journal of Advanced Research in Engineering and Technology*, 14(2), 45–52.
5. Bolton, W. (2015). *Mechatronics: Electronic control systems in mechanical and electrical engineering* (6th ed.). Pearson Education.
6. Tun, T. T., Aung, M. T., & Kyaw, Z. M. (2020). Arduino-based fire detection and alarm system using gas and smoke sensors. *International Journal of Scientific and Engineering Research*, 11(6), 123–128.
7. Patel, A., Shah, R., & Mehta, K. (2023). Design and implementation of sensor-based automated safety systems using microcontrollers. *International Journal of Modern Engineering Technology and Science*, 7(3), 101–108.
8. Paul, R., Das, S., & Mukherjee, A. (2025). Real-time fire monitoring system using Arduino technology. *Journal of Embedded Systems and Applications*, 12(1), 33–40.

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