Experimental Study on the Performance of an Enhanced Smoke Detector

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ABSTRACT

Fire accidents continue to pose significant risks to households, schools, and communities, making early detection essential for minimizing damage and saving lives. This study introduces an enhanced prototype smoke detector designed to integrate multiple sensing capabilities—smoke, gas, and fire detection—into a single unit. The system is equipped with LED indicators and sound alarms, providing both visual and auditory alerts to ensure timely awareness. By combining these features, the prototype offers a more affordable and comprehensive safety solution compared to conventional single-sensor devices.

The research evaluates the prototype's performance across several critical parameters, including detection distance, detection speed, sensitivity to varying smoke concentrations, and effective coverage area within a controlled room environment. Results demonstrate that the system responds reliably within short distances and maintains extended detection capabilities at longer ranges, highlighting its potential for broader applications. Sensitivity tests further reveal that the detector can adapt to different smoke densities, ensuring responsiveness under diverse fire scenarios.

Despite these promising outcomes, the study acknowledges certain limitations. Material availability restricted the refinement of components, and the absence of commercial-grade certification prevents immediate large-scale deployment. Nonetheless, these constraints do not diminish the value of the prototype as a proof of concept.

Lastly, the findings underscore the importance of developing accessible, multi-sensor detection devices that can strengthen fire safety awareness and preparedness. Such innovations hold particular relevance for households, educational institutions, and community-based programs, where affordable and reliable safety systems can significantly reduce risks and enhance resilience.

Keywords: Smoke detector, fire safety, multi-sensor system, detection threshold, response time, sensitivity, prototype design, community preparedness

INTRODUCTION

Fire accidents can occur unexpectedly and spread rapidly, often leading to severe damage and loss of life. Because of this, early detection is critical in ensuring safety. Smoke detectors have long been recognized as essential devices in households and buildings since they provide reliable alerts when smoke is present. However, commercial smoke detectors, while tested and proven effective, can be costly for families, schools, and small establishments with limited budgets.

With the growing accessibility of electronic components such as sensors, buzzers, LEDs, and microcontrollers, opportunities have emerged to design enhanced smoke detector that go beyond the capabilities of traditional detectors. Unlike conventional devices that focus solely on smoke, our prototype integrates gas detection, fire sensing, LED indicators, and sound alarms to provide a more comprehensive safety mechanism. This innovation aims to address both affordability and functionality, making fire safety more accessible to communities and educational institutions.

Since smoke detectors are safety devices, their performance must be reliable. A detector that reacts too slowly or fails to sense smoke or fire in certain areas may put people at risk. As researchers, we recognize that this reliability is critical, especially in environments where lives and property depend on early warning systems. Because of this, our study seeks to evaluate the performance of the enhanced smoke detector through controlled experiments. By measuring detection speed, distance, and sensitivity, the research will determine how well the enhanced device performs and what limitations it may have.

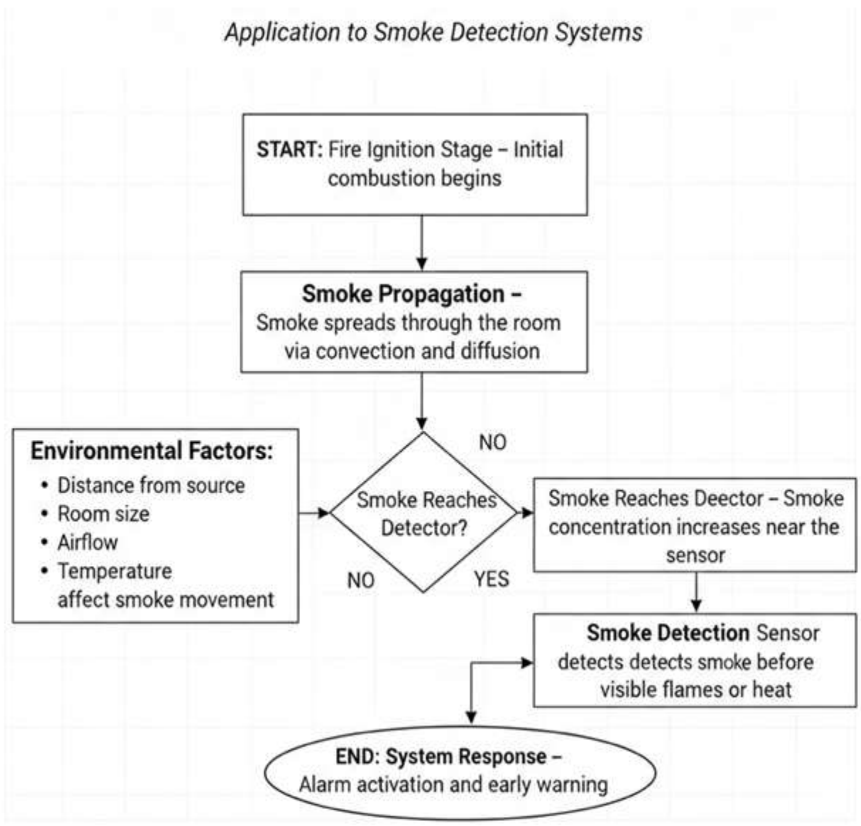
The results of this study may help future students, researchers, and users understand whether an enhanced smoke detector can serve as a reliable and affordable option for personal use, school projects, or community applications, ultimately contributing to improved fire safety awareness and preparedness.

REVIEW OF RELEVANT THEORY, STUDIES, AND LITERATURE

This section presents the theoretical foundations and related studies that support the development and evaluation of the enhanced smoke detector. It discusses fundamental concepts in smoke detection, multi-sensor fire detection systems, and prior experimental and technological research relevant to the study.

Related Theories

Figure 1. Theory of Fire Development and Smoke Propagation



Fire development generally follows four stages: ignition, growth, fully developed fire, and decay. During the early stages of ignition and growth, smoke is produced before flames become fully visible. Smoke consists of fine particles and gases that spread rapidly within enclosed spaces due to convection and diffusion. According to fire dynamics theory, smoke often reaches detectors earlier than heat or flames, making smoke detection a critical component of early warning systems. The behavior of smoke—such as dispersion rate, density, and concentration—is influenced by factors including distance from the source, room size, airflow, and temperature.

This theory underpins the study's focus on detection distance, response time, and coverage area, as these parameters directly affect how quickly and effectively smoke particles reach the sensor.

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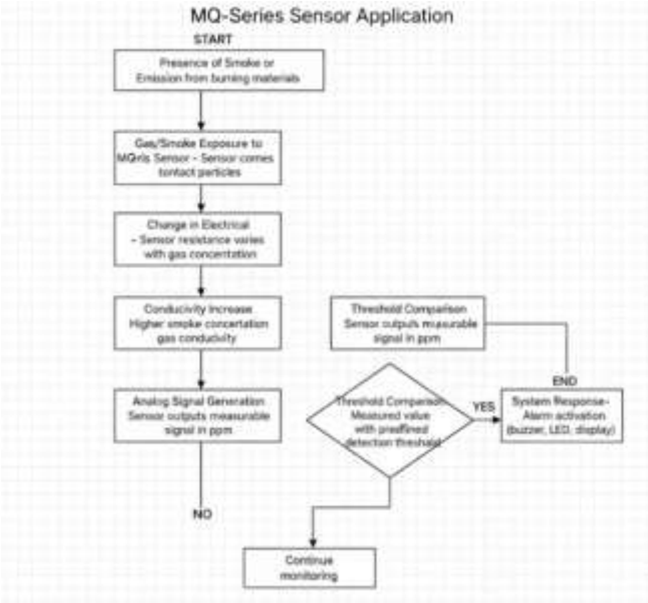
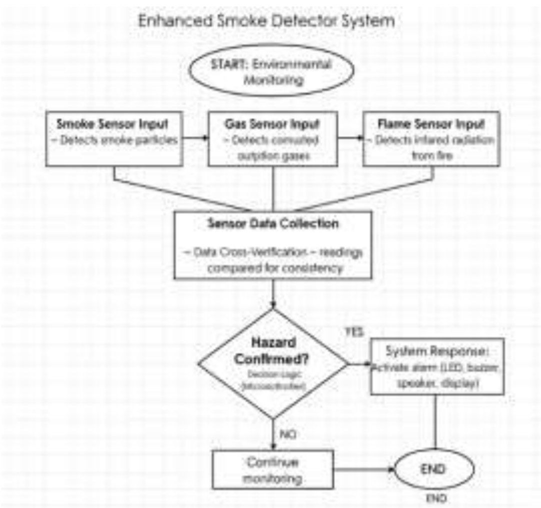
Figure 2. Gas and Particle Detection Theory



Gas sensors, such as the MQ-series sensor used in this study, operate based on changes in electrical resistance when exposed to combustible gases and smoke particles. As smoke concentration increases, the sensor's conductivity changes, allowing the system to quantify gas levels in parts per million (ppm). Detection threshold theory explains that a predefined threshold must be exceeded before the system triggers an alarm, balancing sensitivity and false alarm prevention.

This theory supports the evaluation of detection thresholds and sensitivity to different smoke sources, as varying materials produce smoke with different particle sizes and chemical compositions.

Figure 3. Multi-Sensor Integration Theory



Multi-sensor integration theory states that combining multiple sensing modalities improves detection accuracy and system reliability. Single-sensor systems may fail or produce false alarms due to environmental interference, while multi-sensor systems provide redundancy and cross-verification. By integrating smoke, gas, and flame sensors, a system can compensate for the limitations of individual sensors and improve decision-making.

This theory justifies the design of the enhanced smoke detector as a multi-sensor system, improving early detection and reducing the likelihood of missed hazards.

Related Studies

Several studies support the effectiveness of enhanced and multi-sensor smoke detection systems. Ali et al. (2025)

developed an integrated fire control system combining gas, smoke, and flame detection, demonstrating improved reliability compared to single-sensor designs. Their findings support the current study's approach of integrating multiple sensors into one prototype.

Costea and Schiopu (2018) proposed an improved smoke detector design that enhanced response time and detection reliability. Their experimental results emphasized the importance of sensor placement and calibration, which aligns with this study's evaluation of detection distance and coverage area.

Fang and Yuan (2007) investigated smoke detection in thermally stratified environments and found that smoke concentration and detector sensitivity significantly affect response time. This supports the present study's findings that response time increases as distance from the smoke source increases.

Recent studies using advanced detection methods, such as deep learning and infrared-based smoke recognition (Amjad et al., 2025; He et al., 2025), highlight the growing trend toward intelligent fire detection systems. While these approaches offer high accuracy, they are often costly and complex. In contrast, the current study emphasizes affordability and accessibility, making it more suitable for households, schools, and community use.

Idoniboyeobu et al. (2017) demonstrated that improved smoke detection systems built using microcontrollers can perform effectively when properly calibrated. Their work supports the feasibility of using Arduino-based platforms for fire safety applications, as implemented in this research.

Synthesis Of Literature

The reviewed theories and studies collectively emphasize that early smoke detection is crucial for fire safety, and system performance is strongly influenced by sensor sensitivity, distance, environmental conditions, and system integration. Prior research confirms that multi-sensor systems outperform single-sensor detectors in reliability and responsiveness. However, many existing solutions focus on advanced or commercial-grade technologies, leaving a gap in affordable, educational, and community-level fire safety devices.

This study addresses that gap by experimentally evaluating a low-cost, enhanced smoke detector prototype using accessible components, contributing practical insights into detection performance, limitations, and real-world applicability.

THEORETICAL FRAMEWORK

The theoretical framework of this study is anchored on Fire Development Theory, Gas and Smoke Detection Theory, and Multi-Sensor Integration Theory. These theories collectively explain how smoke is generated, how it propagates through an environment, and how sensor-based systems detect and respond to hazardous conditions.

In the framework, fire or smoke sources act as the independent variables that produce smoke particles and combustible gases. These are detected by the MQ-2 gas/smoke sensor and IR flame sensor, which convert physical and chemical changes into electrical signals. The Arduino Uno microcontroller processes these signals using predefined thresholds and logical conditions. Once hazardous levels are detected, the system activates output devices—LED indicators, buzzer, speaker, and LCD display—to alert users.

The dependent variables of the study include detection speed, detection distance, sensitivity, and coverage area, which are used to measure the system's performance. Environmental factors such as room size, temperature, and smoke source type act as moderating variables that may influence detection behavior.

This framework guides the experimental design and analysis by illustrating how sensor inputs, system processing, and alert outputs interact to achieve early fire detection. It provides a logical basis for evaluating whether the enhanced smoke detector can function as a reliable and affordable fire safety solution.

Importance And Relevance

According to the National Fire Protection Association (NFPA), nearly two-thirds of home fire deaths occur in residences without smoke detectors. This alarming statistic highlights the critical role of early warning systems in preventing loss of life and property. As researchers, we conducted this study with the primary goal of protecting lives, preventing injuries, and minimizing property damage caused by fire.

To address this pressing need, we the researchers developed an enhanced smoke detector prototype. Our prototype integrates smoke, gas, and fire detection, along with LED indicators and sound alarms, to provide a comprehensive safety mechanism. By combining multiple sensing features, the device aims to deliver early and enhance detection, especially in environments where standards detectors may be limited.

This research holds significant value across multiple areas of society. For households and communities, it offers a reliable alternative to standard detectors, making fire safety more accessible to families with limited resources. In educational institutions, it serves as both a practical teaching resource and a functional safety device for schools and laboratories. For researchers and innovators, it contributes to the growing body of knowledge on multi-sensor systems, encouraging further exploration into high-performance safety technologies.

Finally, for disaster preparedness programs, it demonstrates how enhanced prototypes can support community-based initiatives aimed at reducing fire-related risks, thereby strengthening collective resilience against emergencies.

Statement Of the Problem

The increasing incidence of fire-related hazards underscores the need for more reliable and responsive detection systems. This research therefore seeks to address the problem of how effective an enhanced smoke detector system can be in detecting early signs of smoke. Specifically, it examines the system's capability to reliably detect smoke particles at varying distances from the source, as well as its response time once smoke is present. Furthermore, the study investigates the sensitivity of the sensor when exposed to different type of flammable materials, ensuring that it can distinguish between minimal and critical levels of smoke.

Finally, the research explores the effective coverage area of the enhanced smoke sensor within a room, determining whether the system can provide comprehensive monitoring across diverse spatial conditions. By addressing these concerns, the study aims to establish the potential of enhanced smoke sensor systems as a more efficient and accessible solution for fire safety.

General And Specific Objectives

The primary objective of this study is to evaluate the performance of an enhanced prototype smoke detector in terms of its reliability, responsiveness, and coverage for fire safety applications. In pursuit of this general aim, the research specifically seeks to determine the effectiveness of the enhanced smoke detector with respect to detection distance and detection speed, thereby establishing its capability to identify early signs of smoke in a timely manner. It also aims to assess the detection sensitivity of the sensor when exposed to varying smoke concentrations, ensuring that the system can distinguish between minimal and critical levels of smoke. Finally, the study intends to measure the effective coverage area of the enhanced smoke detector within a room, providing insights into its capacity to deliver comprehensive monitoring across different spatial conditions.

The primary scope of this study is to evaluate the operational effectiveness of the researchers' enhanced smoke detection system as a viable and affordable safety device. The study will specifically focus on three measurable performance criteria when detecting smoke and fire: Detection Distance, Detection Speed, and Detection Area.

Scope And Limitations

The enhanced smoke detector developed in this study was designed and constructed from scratch using readily accessible electronic components. The scope of the research is limited to evaluating the operational performance of the prototype in a controlled environment, focusing on key parameters such as detection distance, response time, sensitivity, and coverage area. The system integrates additional features including gas detection, fire sensing, LED indicators, and sound alarms to provide a more comprehensive safety mechanism.

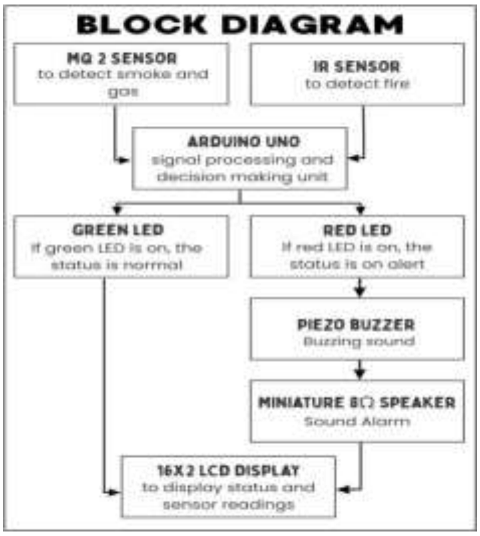
However, despite these enhancements, the prototype's overall performance may not be comparable to that of fully commercialized smoke detectors. Commercial devices undergo extensive testing, certification, and quality assurance procedures to ensure long-term reliability, accuracy, and compliance with safety standards. In contrast, the prototype is constrained by the availability of materials, manual assembly processes, and limited testing conditions. Furthermore, the system has not been subjected to standardized certification or long-term durability testing, which may affect its consistency and real-world applicability.

These limitations indicate that the prototype is intended primarily as a proof of concept rather than a direct replacement for commercially certified smoke detectors.

METHODOLOGY

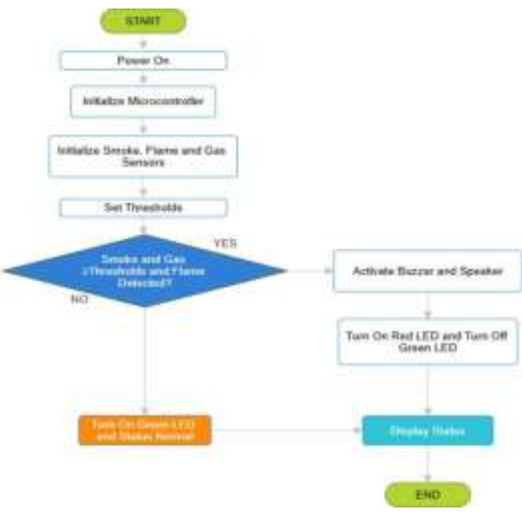
The methodology of this study was designed to systematically evaluate the performance of the enhanced smoke detector prototype under controlled experimental conditions. Guided by the research objectives, the approach focused on measuring detection distance, response time, sensitivity to varying smoke concentrations, and effective coverage area. To achieve this, the system was constructed using accessible electronic components—including the MQ-2 gas sensor, IR flame sensor, and Arduino Uno microcontroller—integrated with visual and auditory alert mechanisms. A structured sequence of development, calibration, and testing ensured that each component functioned reliably and that the prototype's performance could be assessed against predefined thresholds. By employing repeated trials, controlled environments, and standardized input sources, the methodology provided a rigorous framework for validating the detector's responsiveness and identifying its limitations. This section outlines the experimental design, system operation, tools and software used, and the procedures followed to ensure accuracy, consistency, and replicability of results.

Figure 4. Block Diagram



Represents the system overview of the enhanced smoke detector system. The system consists of MQ-2 sensor, for gas and smoke detection, and an IR flame sensor module for fire detection. Sensor outputs are processed by an Arduino Uno microcontroller, which serves as the main control unit. When smoke and/or gas is detected beyond predefined thresholds, the Arduino Uno activates the visual and audible alarms, this includes the red LED, piezo buzzer and an 8-ohm miniature speaker. A green LED indicates the status is normal. A 16 x 2 LCD module displays the real-time system status and gas/smoke sensor reading.

Figure 5. Flowchart/System Operation



The flowchart shows how the smoke, flame, and gas detection system operates using a microcontroller. After the system is powered on, the microcontroller and all sensors are initialized, and threshold values are set. The system continuously checks if the smoke or gas level exceeds the threshold or if a flame is detected. If a hazard is detected, the buzzer, speaker, and LED are activated to warn users. Once the hazard is no longer detected, the alarm is turned off and the system returns to monitoring mode.

Components List and Functions

The functional requirements of the Enhanced Smoke Detector focus on its real-time monitoring and alert capabilities. The system continuously monitors the environment for infrared radiation (via the Flame Sensor) and gas concentrations (via the MQ Series sensor) to ensure early detection of hazards. Alert activation is triggered only when the sensors detect values above a safe threshold. To enhance usability, green and red LEDs provide immediate visual feedback, with the green LED signaling a safe status and the red LED indicating an active fire or smoke alert. All decision-making and control logic are implemented via the Arduino Uno, ensuring a structured and sequential response involving the LCD display, Piezo buzzer, and MP3 voice notifications.

Table 1. Variables and Conditions of the Enhanced Smoke Detector

Variable / Component	Type (Input / Output)	Parameter Measured / Controlled	Condition or Range	System Response / Action
Arduino Uno	Controller	Processes logic and controls outputs	Operates at 5V logic; continuous loop evaluation	Reads sensors, processes conditions, and drives all output modules.
IR Flame Sensor	Input	Detects infrared light from fire	Logic HIGH (No fire) / LOW (Fire detected)	Triggers “Fire Alert” state when flame is detected.
Gas Sensor (MQ Series)	Input	Detects smoke and gas levels	Analog / Digital threshold	Triggers “Smoke Detected” state when concentration is high.
16x2 LCD Module	Output	Visual notification display	Text display	Displays “System Initialized,” “Fire Alert,” or “Smoke Detected.”
MP3 Player & Speaker	Output	Audible voice notification	Triggered by Arduino	Plays pre-recorded voice warnings when sensors are triggered.
Piezo Buzzer	Output	High-frequency audible alarm	HIGH / LOW digital	Emits a loud, continuous beep during emergency alerts.
Green LED	Output	Indicates safe environment status	ON when no threat is detected	Remains lit to signal the system is monitoring and safe.
Red LED	Output	Indicates fire / smoke alert	ON when fire / smoke is detected	Flashes or stays lit to signal an active hazard.
Resistor (100-ohm)	Protection	Controls current to LEDS	Constant resistance	Prevents damage to LEDs by limiting current flow.
9V Battery	Power Source	Supplies electrical energy to the system	9V DC supply	Provides portable power and ensures current stability for the Arduino and sensors.

Table 2. Variables and Conditions of the Enhanced Smoke Detector

Test #	Input Condition	Observed Output	Expected Output	Pass / Fail	Remarks / Behavior Explanation
1	No Flame / No Smoke	Green LED ON; LCD shows “Normal,” Red LED OFF	System idle, monitoring	Pass	System waits for sensor input; no accidental activation.
2	Flame / Smoke detected	Red LED ON, Buzzer active, Speaker active, LCD alerts	Immediate emergency notification	Pass	Alert triggers only when hazard is present; clears when safe.

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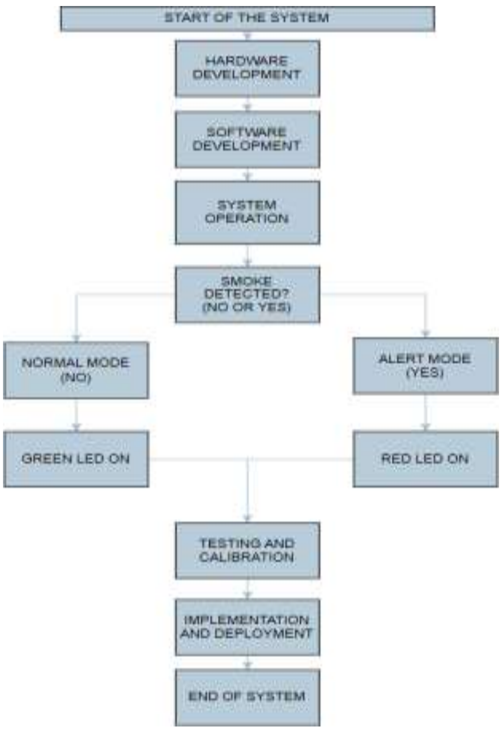
3	System power reset (Battery reconnected)	Green / Red LED OFF, LCD initializes	Default to safe idle mode	Pass	System avoids accidental alarm startup after reset.

Development And Implementation Steps

The enhanced smoke detector system is composed of input sensors, a processing unit, and output devices. The MQ2 smoke sensor and IR sensor serve as input components, while the Arduino Uno acts as the central processing unit. Output devices include LED indicators, a piezo buzzer, a miniature 8-ohm speaker, and a 16×2 LCD display for status indication.

Figure 6. Development and Implementation Steps



Illustrates the methodological flow of the enhanced smoke detector system from development to deployment. The process begins with hardware development, wherein the MQ2 smoke sensor, IR sensor, LEDs, buzzer, speaker, and LCD are integrated with the Arduino Uno. This is followed by software development, where the system program is implemented using the Arduino IDE, sensor thresholds are established, and logical conditions for system operation are defined.

During system operation, the Arduino continuously monitors sensor inputs and determines whether the detected smoke level exceeds the predefined threshold. Under normal conditions, the system activates the green LED and displays a normal status message. When smoke is detected, the system transitions to alert mode, activating the red LED, audible alarms, and a warning message on the LCD. The process concludes with system testing, calibration, and final implementation to ensure reliable and continuous operation.

Figure 7. Actual Photo of the Enhanced Smoke Detector

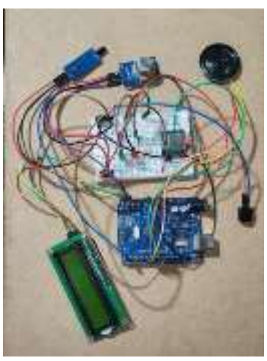


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Figure 8. Source Code of the Enhanced Smoke Detector

Shows the Arduino program used to operate the enhanced smoke detector prototype. The code integrates smoke, gas, and flame sensors with output devices such as LEDs, buzzer, LCD display, and the DFPlayer Mini module. It continuously monitors sensor values, compares them against predefined thresholds, and triggers visual and auditory alerts when hazards are detected. The program also manages the real-time display of system status, blinking intervals for the buzzer, and playback of sound alarm, ensuring reliable monitoring and timely response during fire or gas emergencies.

Tools And Software Used

Table 3. Tools used for the Enhanced Smoke Detector

Tool	Function
Soldering Iron	Used to permanently join electronic components and wires by melting solder, ensuring reliable electrical connections.
Soldering Lead (Solder Wire)	Used to create conductive joints between electronic components and circuit connections.
Acrylic Board	Used as the base or enclosure for mounting and protecting the electronic components.

Table 3. lists the tools used in the development of the enhanced smoke detector. A soldering iron and soldering lead were used to securely join electronic components and wiring, ensuring stable and reliable electrical connections. An acrylic board served as the base and enclosure for mounting the components, providing structural support and protection for the circuit during testing and operation.

Table 4. Software used for the Enhanced Smoke Detector

Software	Function
Arduino IDE	Used to write, compile, and upload the program to the microcontroller for sensor reading and alarm control.
SolidWork	Used to design and model the physical layout and enclosure of the project before fabrication.

Table 4. presents the software utilized in the development of the enhanced smoke detector. The Arduino IDE

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was used to write, compile, and upload the control program to the microcontroller, enabling sensor data processing and alarm activation. SolidWorks was used to design and model the physical layout and enclosure of the system prior to fabrication, ensuring proper component placement and structural accuracy.

RESULTS AND DISCUSSIONS

Table 5. Smoke Detector Response Time at Varying Distances

Distance (cm)	Trials	Source Type	Room Temperature	Detection Threshold	Response Time		
					1	2	3
10	3	Paper	30 °C	150	21 sec	12 sec	5 sec
20	3	Paper	30 °C	150	35 sec	18 sec	10 sec
30	3	Paper	30 °C	150	58 sec	36 sec	24 sec
40	3	Paper	30 °C	150	1 min 48 sec	58 sec	46 sec
50	3	Paper	30 °C	150	2 min 12 sec	1 min 5 sec	58 sec
60	3	Paper	30 °C	150	2 min 48 sec	1 min 30 sec	1 min
70	3	Paper	30 °C	150	3 min 4 sec	2 min 48 sec	1 min 56 sec
80	3	Paper	30 °C	150	3 min 53 sec	2 min 43 sec	2 min
90	3	Paper	30 °C	150	4 min 36 sec	3 mins 20 sec	2 min 52 sec
100	3	Paper	30 °C	150	5 min 12 sec	4 min 5 sec	3 min 28 sec

Table 5. shows that the response time of the smoke detection system increases as the distance from the smoke source increases. At shorter distances (10–40 cm), the detector activated quickly, generally within one minute, due to the higher concentration of smoke reaching the sensor. As the distance increased to 60–100 cm, response times rose to approximately two to five minutes, which can be attributed to smoke dispersion and reduced particle concentration in the air.

The results also indicate that the second and third trials consistently produced faster response times than the first trial. This trend suggests possible residual smoke presence or a temporary conditioning effect of the sensor, leading to earlier detection in subsequent trials. Overall, the findings confirm that while the detector is effective across varying distances, optimal placement closer to potential smoke sources is critical for faster detection.

Table 6. Detection Thresholds Across Source Types

Trial	Source Type	Room Temperature	Detection Threshold	Time	Maximum Threshold	
					1	2
2	Paper	32 °C	150	30 sec	122	128
2	Tissue	32 °C	150	30 sec	156	164
2	Cloth	32 °C	150	30 sec	170	177
2	Match (Posporo)	32 °C	150	30 sec	94	103
2	Wood	32 °C	150	30 sec	168	170

Table 6. summarizes the maximum threshold responses of the smoke detection system to different source types under controlled conditions at a constant temperature of 32 °C, a detection threshold of 150 ppm, and a 30-second exposure period. The results show clear variations in sensor response depending on the smoke source.

Cloth and wood produced the highest maximum threshold values, reaching up to 177 ppm and 170 ppm, respectively, indicating denser and more persistent smoke. Tissue also generated relatively high readings, while paper and match (posporo) resulted in lower threshold values, suggesting lighter smoke and faster dispersion. These findings indicate that the detector's response is influenced by the smoke density and particulate characteristics of different materials, which affects how quickly and strongly the sensor registers smoke presence.

Table 7. Response Time in a Controlled Room

Area	Source Type	Room Temperature	Detection Threshold	Response Time
300cm x 156cm (room)	Paper	30 °C	150	18 mins 34 sec
	Paper	30 °C	150	15 mins 17 sec
	Paper	30 °C	150	14 mins 23 sec
	Paper	30 °C	150	12 mins 48 sec
	Paper	30 °C	150	11 mins 0 sec
	Paper	30 °C	150	9 mins 56 sec
	Paper	30 °C	150	7 min 33 sec
	Paper	30 °C	150	6 min 14 sec
	Paper	30 °C	150	4 min 8 sec
	Paper	30 °C	150	3 mins 10 sec

Table 7. presents the response time of the smoke detection system inside a controlled room with dimensions of 300 cm × 156 cm, using paper as the smoke source at a constant temperature of 30 °C and a fixed detection threshold of 150 ppm. The initial trial recorded the longest response time of 18 minutes and 34 seconds, indicating a delayed buildup of smoke concentration within the room.

Subsequent trials showed a consistent decrease in response time, reaching a minimum of 3 minutes and 10 seconds. This reduction suggests the influence of residual smoke accumulation or a conditioning effect on the sensor, resulting in increased sensitivity during repeated exposures. Overall, the results demonstrate that while initial detection in a larger enclosed space may be delayed, the system is capable of detecting smoke more rapidly after repeated operation under similar conditions.

Problems Encountered and Solutions

During the experiment, the researchers encountered several problems. The researchers first problem was the limited sample size. Since the experiment involved smoke and flame, the sample size was intentionally reduced for the safety of the researchers. To address this limitation, the researchers performed multiple trials, both indoors and outdoors, in order to obtain more accurate and reliable results. Another problem encountered was the effect of temperature. At an outdoor temperature of 32°C, the flame sensor detected the heat and triggered the alarm, which interfered with the smoke detection readings. To resolve this issue, the researchers temporarily removed the flame sensor, as the primary focus of the study was smoke detection and flame detection was not required.

CONCLUSION

The experimental study on the enhanced smoke detector prototype successfully demonstrates that integrating multiple sensors—specifically for smoke, gas, and fire—into a single device offers a comprehensive and affordable safety solution. By utilizing accessible electronic components such as the Arduino Uno, MQ-2 sensor, and IR flame sensor, the researchers developed a system capable of providing real-time visual and audible alerts through LED indicators, a piezo buzzer, and sound alarm. The prototype proved highly effective at close ranges, with detection speeds of approximately one minute at distances between 10 to 40 cm, though response times naturally increased at greater distances due to smoke dispersion. Furthermore, the system showed varying sensitivity based on the material source, with denser smoke profiles from wood and cloth triggering higher detection thresholds than paper or matches.

Despite its promising performance and reliability in controlled trials, the research acknowledges critical limitations regarding material constraints and the absence of commercial-grade certification. Environmental factors, such as high outdoor temperatures, were also found to interfere with the IR flame sensor's accuracy, suggesting a need for further calibration in diverse climates. Nevertheless, the study concludes that this enhanced smoke detector serves as a viable and cost-effective alternative for households, schools, and community-based programs. By bridging the gap between affordability and advanced multi-sensor functionality, this research contributes to improved fire safety awareness and provides a foundation for future development in high-performance, accessible safety technologies.

RECOMMENDATIONS

Future researchers are encouraged to test the system under varied environmental conditions, such as different temperatures, humidity levels, and airflow settings, to determine whether these factors influence its overall performance. In addition, enhancing signal processing through the implementation of advanced filtering techniques within the Arduino program is recommended to minimize false alarms caused by environmental noise or non-smoke signals. Finally, researchers should compare the performance of the enhanced smoke detector with commercially available smoke detectors to identify strengths, weaknesses, and areas requiring further improvement.

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