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Fire Alarm System Alert Via Short Message Service (SMS)

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Abstract

This paper presents a low-cost fire alarm alert system that integrates a smoke sensor, a flame sensor, and a GSM module to provide both local audible warning and remote notification via Short Message Service (SMS). The prototype was implemented using an Arduino Uno and was designed to reduce false alarms by requiring dual-sensor validation before triggering an alert. Experimental testing was conducted to evaluate sensor response versus distance and installation orientation. For smoke detection, the system was configured to trigger when the smoke sensor output exceeded 300 bits, where vertical sensor placement produced higher readings than horizontal placement and achieved the threshold at approximately 45 cm. For flame detection, the alarm condition was defined as a flame sensor output below 1000 bits, and the prototype reliably detected flame up to approximately 45 cm, with minor differences between horizontal and vertical orientations. GSM performance tests showed that the SMS alert was delivered within 5–6 seconds, where Celcom achieved the fastest and most consistent delivery time (5 s) compared to Digi and Maxis (6 s). Overall, the results confirm that the proposed system can provide timely fire alerts and stable sensor triggering behavior under short-range indoor test conditions, supporting its suitability as an affordable early-warning prototype for residential applications.

1. Introduction

Fire remains a critical threat to life, property, and economic stability in both residential and commercial environments. In Malaysia, the Fire and Rescue Department reported a consistent increase in house fire incidents—2,761 cases in 2011, 2,919 in 2012, and 3,235 in 2013—highlighting the urgency of improving household fire safety technologies [1]. The causes of such fires are well-documented and include electrical faults, unattended cooking, carelessness with combustible materials, and negligence in disposing of cigarette butts [2], [3].

While traditional fire alarm systems remain prevalent, these systems largely rely on local notifications such as sirens or buzzers. Their effectiveness is diminished when the premises are unoccupied, as they are incapable of sending remote alerts [4]. To overcome these limitations, modern solutions increasingly integrate microcontroller-based systems with mobile communication technologies, particularly the Global System for

Mobile Communication (GSM). Arduino-based fire detection systems paired with GSM modules are gaining popularity due to their low cost, simplicity, and ability to send real-time Short Message Service (SMS) alerts to users regardless of their location [5]–[7].

These systems typically employ smoke, flame, or gas sensors, which detect environmental changes and send input signals to an Arduino controller. When a threshold is surpassed, the Arduino activates a GSM module to dispatch an SMS alert to the user, while also triggering local indicators such as buzzers or LEDs [6], [8], [9]. Such configurations have proven especially valuable in low-resource settings where internet connectivity is either unstable or unavailable, as they operate independently of Wi-Fi networks [5], [10]. To maintain system stability, voltage regulators are often employed to step down power from 12V to 5V, ensuring compatibility with sensitive Arduino components [11], [12].

For example, Boganotan et al. and Makandar each developed Arduino-GSM based systems that enabled remote SMS notification upon flame or smoke detection. These systems demonstrated low-cost adaptability, although their simplicity sometimes limited sensor diversity [4], [5]. Similarly, Surana et al. and Raghunath et al. validated the reliability of such systems, emphasizing their usefulness in residential environments where immediate response is critical [7], [8].

Furthermore, the performance of mobile networks in delivering SMS-based alerts has been analyzed. Chinchmalatpure et al. found that average SMS delivery times in Malaysia range between 5 to 6 seconds, with Celcom consistently providing the fastest response [13]. Studies also show that timely alerts, when acted upon, significantly reduce damage and improve evacuation success rates [14], [15].

This study aims to develop a portable, dual-sensor fire detection and alert system that utilizes Arduino and GSM technology to send immediate alerts. The proposed system is designed for offline operation, enabling functionality in areas without internet access and offering an effective, affordable alternative to internet-dependent fire safety solutions. Unlike many existing Arduino-GSM fire alarm systems that rely on a single sensor or internet-dependent platforms, the proposed system integrates dual-sensor validation (smoke and flame) with offline SMS notification, experimentally validating sensor orientation, distance sensitivity, and GSM transmission performance for practical residential deployment.

2. Related Work

Recent studies (2023–2025) increasingly explore IoT- and machine learning-based fire detection systems; however, these approaches often require stable internet connectivity and higher system complexity, which may limit their suitability for low-resource residential environments. A variety of fire detection systems have been developed over the past decade to improve safety through remote monitoring and intelligent alert mechanisms. These systems commonly integrate microcontrollers with communication modules such as GSM or Zigbee to provide rapid response notifications. This section reviews ten relevant studies that have informed the development of the current project.

Numerous studies over the past decade have explored the integration of GSM modules with microcontrollers such as Arduino to create intelligent fire detection systems. Each system varies in complexity, cost, connectivity, and intended use case. Daadoo et al. proposed a GSM-based smart security system for homes, offering multipoint detection and Android integration, although it was costlier due to extended functionality [16]. Rajee's design focused on gas and smoke detection using Arduino and GSM modules, highlighting a simple and budget-friendly implementation [17]. Similarly, Mudunuru et al. utilized ZigBee modules for wireless fire detection, though range limitations made it unsuitable for large premises [18].

Debnath introduced an IoT-based smart home system for fire alerts, using cloud platforms and Wi-Fi modules. While technologically advanced, the system's reliability in rural or low-connectivity areas was limited [19]. Agazi et al. also implemented a GSM-based system suitable for residential contexts, although their system lacked integration with visual feedback [20]. Vishwakarma et al. designed a GSM-based fire detection system using smoke and gas sensors, finding that multi-sensor integration reduced false positives and enhanced response accuracy [21]. Ali and Islam extended this concept by integrating federated learning into forest fire detection using the Green IoT, though the application scope was more ecological than residential [22]. Maity et al. proposed a machine-learning smart fire detection device for agriculture, demonstrating precision and accuracy in large-scale fields, while Morchid et al. developed an IoT-based early fire detection model suited for smart agriculture applications [23], [24].

Nabusha et al. presented a multi-sensor fire detection system that used GSM communication and sensor fusion, optimizing alert reliability and power efficiency for small businesses and schools [25]. Meanwhile, Koggalage and Welihinda emphasized the importance of high-temperature detection using GSM-based systems, enhancing sensitivity to flame-based fires [11]. System performance evaluations by Rana et al. showed that GSM-based systems can maintain voltage regulation efficiently, ensuring safe operation of Arduino components under varied loads [12]. Chinchmalatpure et al. confirmed that SMS transmission times via Malaysian mobile providers are within acceptable latency for emergency response [13]. Harun Al Rasyid et al. proposed a wireless sensor network (WSN) model to complement fire detection, offering scalability and multi-node monitoring, although the dependence on Wi-Fi makes it less viable for offline applications [14].

Barbosa et al. introduced NotiFire, a prototype system for residential detection, integrating sensor fusion and real-time alerts. Their study supports the practicality of low-cost modular systems [15]. Krutskikh et al. also contributed to the field by exploring industrial applications of fire control through IIoT algorithms, underscoring the need for smart fire control in broader infrastructures [8].

Collectively, these works highlight the potential of combining GSM technology with sensor-based fire detection for affordable and scalable solutions. However, most prior systems either lack dual-sensor input, require internet connectivity, or are designed for industrial rather than residential settings. This project builds upon these foundations by developing a cost-effective, dual-sensor Arduino-GSM fire detection system that functions entirely offline, ensuring reliable alerts and enhanced safety in household environments.

Existing GSM-based fire alert systems commonly demonstrate basic detection and SMS notification; however, many studies do not provide systematic evaluation of detection sensitivity as a function of distance and installation orientation. Furthermore, SMS delivery performance is rarely validated across different network providers under controlled conditions. Therefore, a key motivation of this work is to provide a low-cost offline fire alert system accompanied by quantitative placement and communication performance evidence.

3. Methodology

The methodology adopted in this project consists of three main components: the development of system logic through software programming, the construction of the physical device using hardware components, and the simulation of the system using Proteus to evaluate circuit behavior and sensor integration. The objective of this section is to explain the step-by-step process used to design, develop, and validate a low-cost fire alarm security system that can alert users via Short Message Service (SMS) when a fire is detected. The system combines flame and smoke sensors with an Arduino microcontroller and a GSM modem to achieve this objective.

3.1 Software Development

The software development for this project was carried out using the Arduino Integrated Development Environment (IDE). This open-source platform provides a user-friendly environment for writing, compiling, and uploading code to the Arduino board. The program was written in C/C++ language and structured to monitor analog and digital input from the flame and smoke sensors continuously. The main tasks of the software are to process the signals from both sensors, evaluate their threshold levels, activate output devices such as the buzzer and LED, and send a command to the GSM modem to trigger the SMS notification.

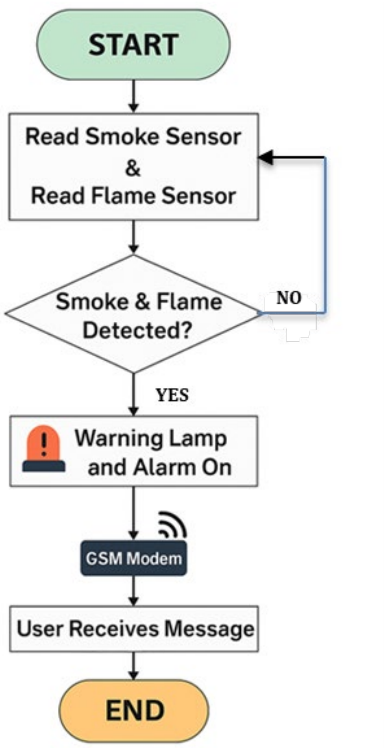

Fig. 1 *Flow chart of fire alarm security system*

A threshold-based logic was implemented, where both sensors must surpass predefined danger values to initiate the alert process. This dual-condition approach helps reduce false positives caused by minor disturbances such as cooking smoke or lighting interference. Once both sensors are triggered, the Arduino processes the inputs using digital and analog signal readings. If the conditions meet the programmed thresholds, the software initiates a digital HIGH signal to activate the alarm and turns ON the LED indicator. Concurrently, the Arduino transmits AT commands to the GSM modem using serial communication (UART) to compose and send an SMS to the predefined mobile number stored in the program. The overall logic of the system is illustrated in Figure 1, which presents the operational flowchart. This diagram shows how the system responds to sensor inputs and processes the alert functions.

3.2 Device Construction

The hardware construction of the system includes the integration of flame and smoke sensors, an Arduino Uno microcontroller, a GSM modem (SIM900A), a buzzer, an LED indicator, and a voltage regulation circuit. The final design of the prototype is shown in Figure 2. The goal was to develop a compact and user-friendly device that can be easily installed in residential buildings without specialized technical knowledge.

The flame sensor used is an infrared-based module capable of detecting flame presence within a specified wavelength. The smoke sensor is typically an MQ-2 sensor, which responds to smoke, methane, and other combustible gases. Both sensors provide analog output to the Arduino. The GSM modem communicates using AT commands and requires a Subscriber Identity Module (SIM) card for SMS capability.

The entire system is powered through a 12V DC source. To protect the microcontroller and sensors from excess voltage, a 7805-voltage regulator is used to step down the voltage to a safe 5V level. The buzzer and LED are directly controlled by Arduino digital pins to provide local alerts. The system was assembled on a breadboard for prototyping and later transferred to a printed circuit board (PCB) for stability and portability.

To support real-time alerts, the GSM modem is connected to the Arduino via serial communication. The modem is configured to operate on commonly used mobile networks such as Celcom, Maxis, and Digi. It is capable of sending SMS within 5 to 6 seconds once triggered. The compact design allows the system to be installed in kitchens, living rooms, or hallways, where fire hazards are most likely to originate.

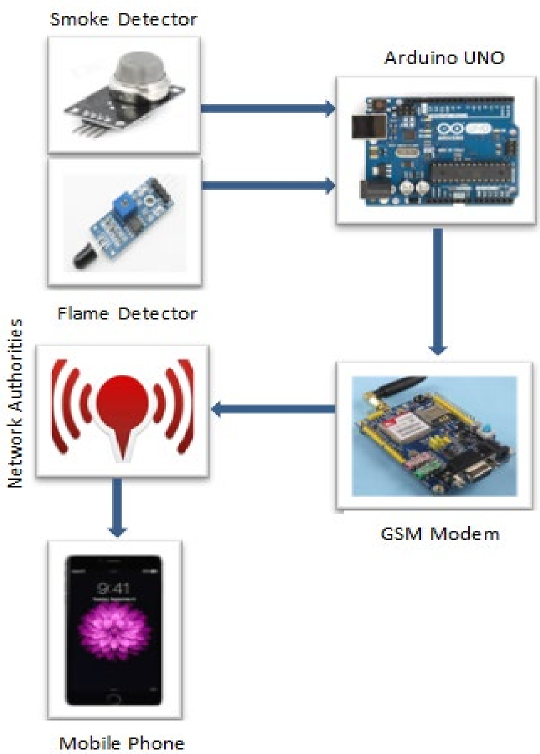

Fig. 2 *Developed fire alarm security system*

Meanwhile, Figure 3 highlights the hardware–software interface points used in the embedded program. The smoke and flame sensors provide analog input signals for the Arduino Uno, while the buzzer is controlled through a digital output pin for local alarm activation. The GSM modem is interfaced via UART serial communication, enabling the Arduino to transmit AT commands for SMS notification. This interface layout clarifies how the software layer interacts with sensing, decision-making, and alert transmission modules during system operation.

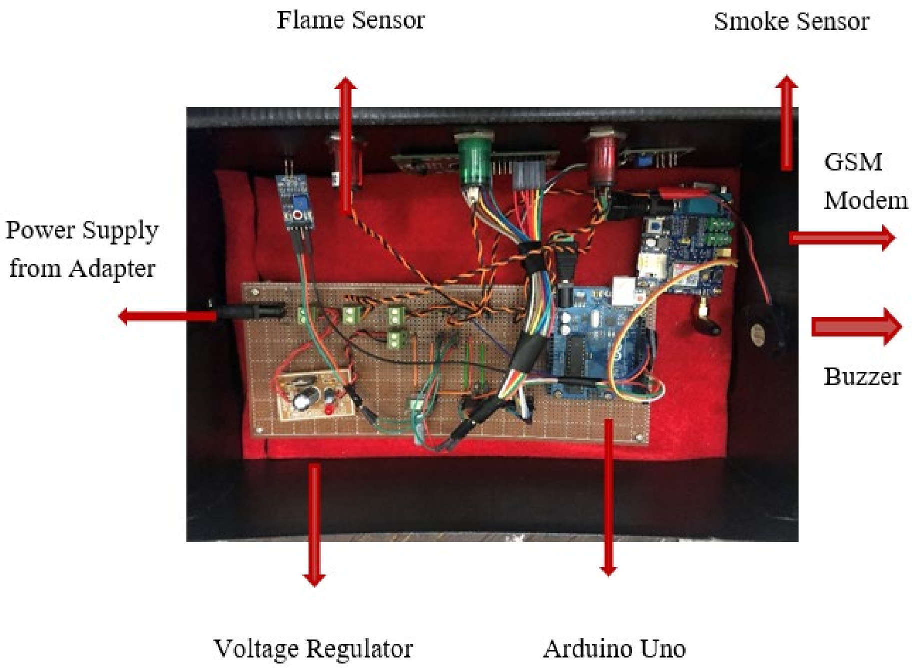

Fig. 3 *Hardware–software interface of the developed prototype, showing the main sensor inputs (smoke and flame), communication module (GSM modem via UART), and output actuator (buzzer), powered through a regulated 5V supply*

3.3 Schematic Diagram and Simulation

Simulation of the entire circuit was performed using Proteus Design Suite, a powerful tool for verifying electronic designs before hardware implementation. Figure 4 presents the complete schematic used in the simulation phase. This circuit includes the microcontroller unit (Arduino Uno), sensors, buzzer, LED, GSM modem, and voltage regulator.

The simulation allowed for testing of various operational conditions such as sensor triggering, power supply behavior, and serial communication between Arduino and the GSM modem. By simulating different values for smoke and flame sensors, the circuit was validated to respond appropriately under fire-detection scenarios.

The use of a 7805 regulator was verified in the simulation to ensure consistent voltage delivery to all components. This prevented voltage spikes that could damage the GSM modem or Arduino. The Proteus simulation supported verification of circuit integration and component connectivity prior to hardware testing.

Through the combined use of software programming, hardware integration, and circuit simulation, the project achieved its goal of developing a robust and portable fire alarm system. The methodology ensures that the system performs reliably under typical fire conditions and offers a cost-effective alternative to expensive commercial fire alert systems. Figure 5 illustrates the evaluation concept used to analyze sensor response as a function of distance. The smoke and flame sources were positioned at 15, 30, 45, 60, and 75 cm from the sensor modules, and the corresponding ADC readings and voltage outputs were recorded.

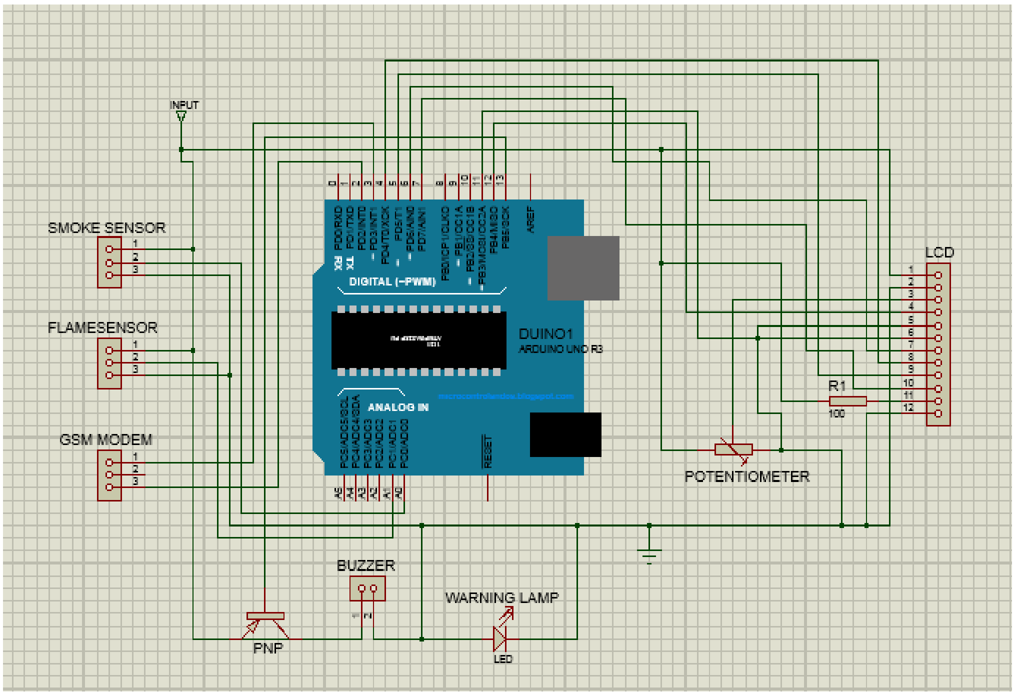

Fig. 4 *Schematic of Arduino-based circuit connection (Proteus simulation)*

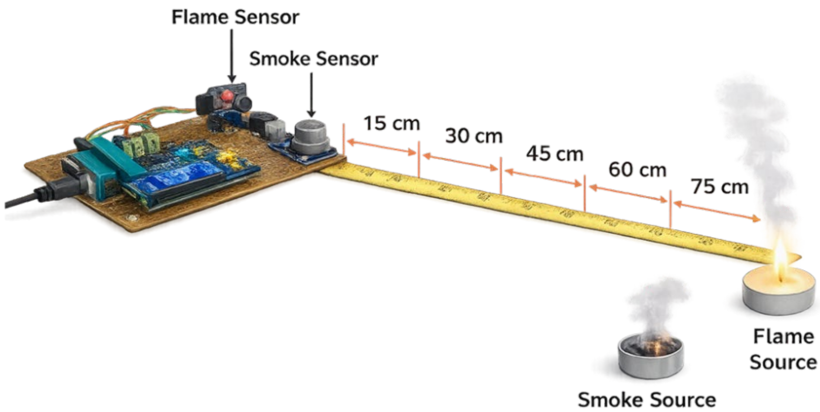

Fig. 5 *Conceptual arrangement for evaluating sensor response versus distance*

4. Results and Discussion

This section presents and analyzes the data collected from the functional testing of the fire alarm system prototype, including the smoke and flame sensor behavior, corresponding voltage readings, and SMS transmission time using different mobile networks. Each subsection addresses the relationship between distance and detection effectiveness, with vertical versus horizontal detection angles evaluated for both sensor types. The insights provided here are essential for validating the system's practicality in a real-world fire scenario.

4.1 Smoke Sensor Analysis

Table 1 presents the analog detection values recorded by the smoke sensor when positioned at various distances ranging from 15 cm to 75 cm, measured in both horizontal and vertical orientations. The results show a clear and consistent pattern: the vertical orientation yields significantly higher bit values than the horizontal placement at every distance interval.

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Table 1 *Relationship between distance of smoke and the sensor reading (bit)*

Distance (cm)	Horizontal (bit)	Vertical (bit)
15	368	432
30	281	360
45	264	300
60	228	256
75	205	223

This variation in sensitivity can be attributed to the physics of smoke propagation. Smoke particles naturally rise due to thermal buoyancy and convection, leading to a higher concentration of smoke in the vertical axis above the source. When the sensor is aligned vertically above the emission point, it benefits from direct exposure to the upward-moving smoke, thereby detecting it more efficiently and producing stronger analog readings. In contrast, a horizontally positioned sensor relies on lateral dispersion of smoke, which is both slower and less dense.

From a system design perspective, this finding has critical implications. The Arduino-based control algorithm is configured to trigger the fire alarm when the smoke sensor output exceeds a threshold of 300 bits. At 45 cm, the vertically oriented sensor meets this threshold exactly (300 bits), indicating a reliable detection point. However, the same distance in horizontal orientation results in only 264 bits, well below the activation threshold. This discrepancy highlights the importance of vertical sensor positioning in practical installations, as it allows earlier detection of smoke at greater distances, thereby enhancing the system's response time and effectiveness in emergency scenarios.

Figure 6 graphically illustrates the trend in vertical sensor data, revealing a clear inverse relationship between distance and detection intensity. As the distance increases, the sensor's bit output decreases, indicating lower smoke particle concentration reaching the sensor. The smooth, declining curve suggests that smoke dispersion weakens significantly beyond 45 cm, reaffirming the sensor's optimal placement range in real-world applications.

Overall, this analysis confirms that vertical placement of the smoke sensor not only improves detection speed but also extends the sensor's effective range, making it particularly suitable for ceiling-mounted installations in enclosed environments such as residential rooms or office spaces. It also supports the Arduino system's threshold logic, ensuring that alerts are triggered with minimal false negatives. These insights validate both the hardware and software design choices implemented in this fire alarm prototype.

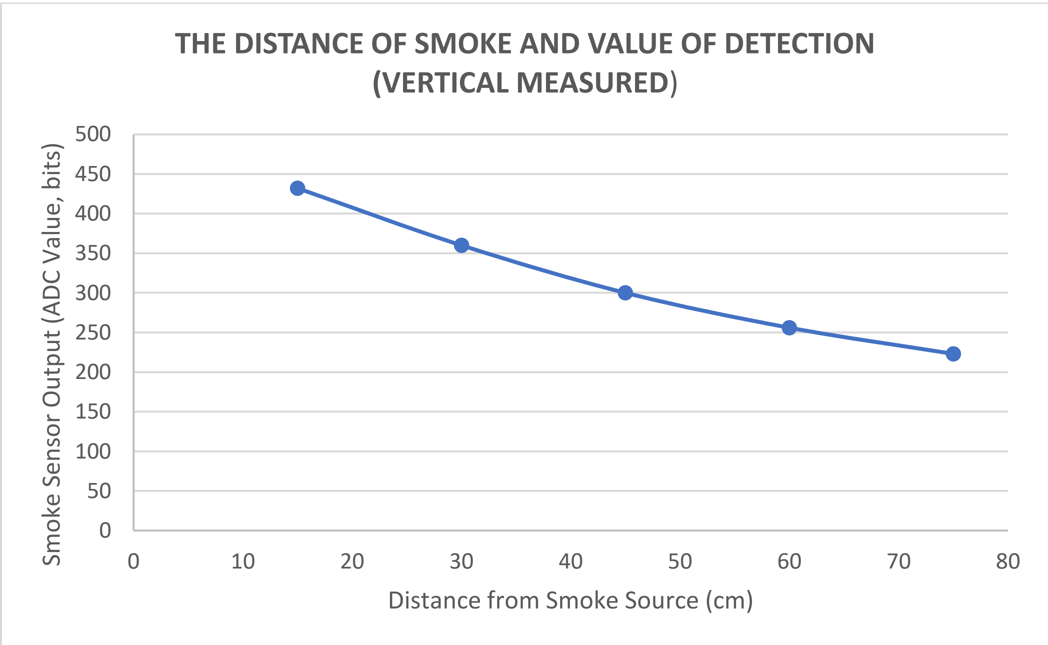


Fig. 6 *Relationship between distance and smoke detection (vertical orientation)*

4.2 Flame Sensor Analysis

Table 2 presents the analog bit values measured by the flame sensor at various distances ranging from 15 cm to 75 cm, evaluated in both horizontal and vertical orientations. The flame sensor detects infrared (IR) radiation emitted by fire, which propagates linearly through space. Unlike smoke, which is affected by convection and airflow, IR radiation is generally isotropic and less influenced by the orientation of the sensor. However, the data reveals subtle differences in detection efficiency between horizontal and vertical positions, especially at shorter distances. The flame sensor is configured such that an alert is triggered when the analog output falls below the threshold of 1000 bits, as defined in the Arduino programming logic. At 45 cm, the horizontal orientation yields an exact threshold value of 1000 bits, whereas the vertical orientation provides a slightly lower value of 993 bits. This suggests that vertical placement allows slightly earlier detection as the flame approaches the sensor. At very close distances (e.g., 15 cm), the vertical reading (681 bits) is also slightly lower than its horizontal counterpart (737 bits), indicating stronger IR signal absorption. These differences, though marginal, can influence system performance in practical deployment where rapid detection is critical.

Table 2 *Relationship between distance of flame and the sensor reading (bit)*

Distance (cm)	Horizontal (bit)	Vertical (bit)
15	737	681
30	989	957
45	1000	993
60	1014	1004
75	1019	1013

The variation in reading also reflects the optical characteristics of the flame sensor. IR sensors typically have a conical detection field, and slight changes in orientation may affect the alignment between the flame's IR emission and the sensor's optimal focal point. In vertical placement, this alignment may more consistently intersect the sensor's field of view, especially if the flame is positioned slightly below or above the sensor.

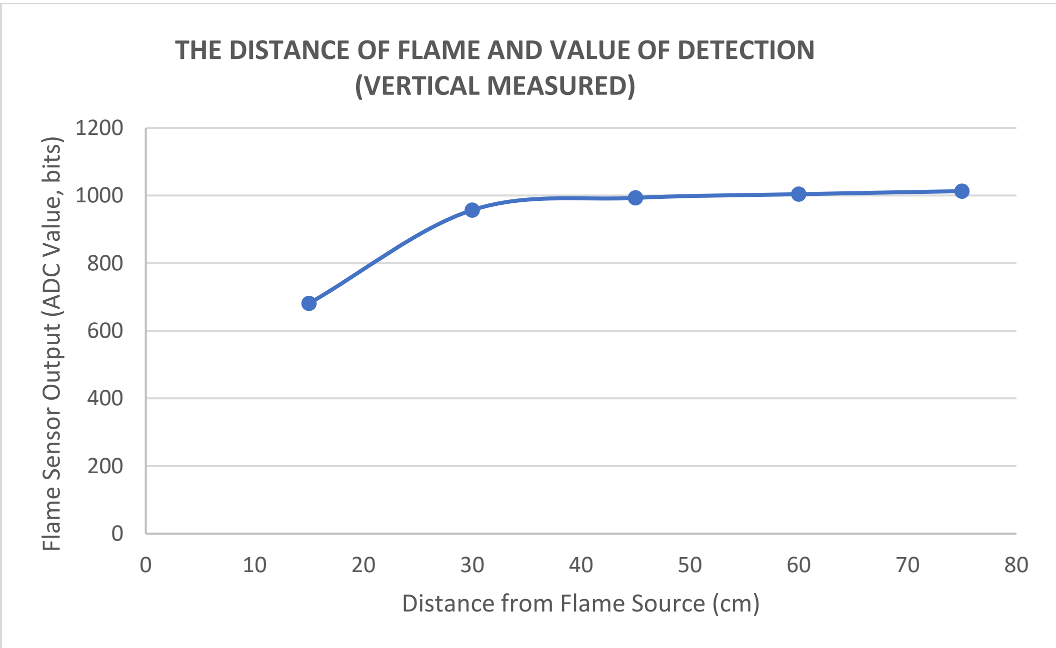


Fig. 7 *Relationship between distance of flame and the sensor reading (bit)*

Figure 7 illustrates the relationship between detection values and distance for vertical sensor orientation. As the distance increases from 15 cm to 75 cm, the analog bit output rises from 681 to 1013 bits. This upward trend indicates that the intensity of the detected infrared signal diminishes with distance, as expected due to attenuation and the inverse-square law governing radiant energy dispersion. Notably, the curve flattens at greater distances, suggesting saturation or reduced sensitivity of the sensor beyond 60 cm. This pattern implies that the flame sensor is most responsive and discriminative within the 15 to 45 cm range, while beyond that, it approaches a plateau with minimal variation.

From an engineering perspective, these findings underscore the importance of considering flame sensor placement and orientation relative to typical fire sources. Although the flame sensor performs reliably in both orientations, slight gains in response time and accuracy can be achieved by positioning the sensor vertically and closer to areas where open flames are more likely to occur, such as near stoves, gas appliances, or candles.

In conclusion, the flame sensor effectively detects fire-related infrared emissions across varying distances and orientations. While the signal differences between horizontal and vertical configurations are not as pronounced as in smoke detection, the vertical alignment still offers marginal benefits in detection sensitivity, particularly at critical thresholds. The system's configuration to respond when the analog value drops below 1000 bits is well-justified by the experimental data, supporting both its functionality and safety performance for real-time flame detection.

4.3 Smoke Sensor Voltage Readings

Table 3 displays the voltage output readings from the smoke sensor at increasing distances from the smoke source, ranging from 15 cm to 75 cm. This data provides a complementary perspective to the analog bit readings previously discussed, serving as an important validation layer for the signal integrity and reliability of the Arduino-based analog-to-digital conversion process.

Table 3 *Relationship between distance and smoke sensor voltage output*

Distance (cm)	Voltage (V)
15	2.3
30	1.9
45	1.5
60	1.3
75	1.1

The results indicate a clear inverse correlation between distance and voltage output. At a close range of 15 cm, the voltage reaches 2.3V, reflecting high smoke particle density near the sensor. As the distance increases, the voltage output drops consistently, reaching a minimum of 1.1V at 75 cm. This behavior is expected because as smoke disperses over a wider area with increasing distance, the concentration of particulates reaching the sensor diminishes, thereby reducing the sensor’s conductivity and its analog voltage output.

This voltage reduction mirrors the trend observed in the bit-level readings discussed in Section 4.1. Since Arduino microcontrollers convert analog sensor voltages (0–5V) into 10-bit digital values (0–1023), the consistency between voltage and bit output demonstrates accurate and stable conversion logic within the system. It confirms that higher voltage levels directly translate into higher bit values, reinforcing confidence in the alarm activation threshold mechanism based on analog data.

Figure 8 graphically illustrates this voltage trend, showing a smooth and predictable decline in output as the smoke source is moved farther from the sensor. This behavior validates the sensor’s ability to operate as a distance-sensitive device and supports the assumption that its detection sensitivity is highly influenced by placement and environmental factors. Notably, the slope of the curve steepens between 15 cm and 45 cm, after which it flattens slightly. This suggests that the sensor is most responsive to changes in smoke density at closer ranges, while beyond 60 cm the detection becomes less sensitive and may fall below practical alert thresholds.

From a deployment standpoint, this reinforces the engineering decision to place smoke sensors closer to potential ignition sources such as kitchens, power outlets, or fuse boxes, ideally mounted vertically near ceiling levels. Proper positioning maximizes the likelihood of detecting dense smoke before it disperses or becomes diluted by airflow.

In summary, the smoke sensor’s voltage output provides a reliable secondary metric that confirms the validity of bit-level detection values used for fire alert activation. The decreasing trend in voltage with increasing distance highlights the system’s sensitivity to environmental conditions and supports strategic sensor placement to ensure early and effective fire detection.

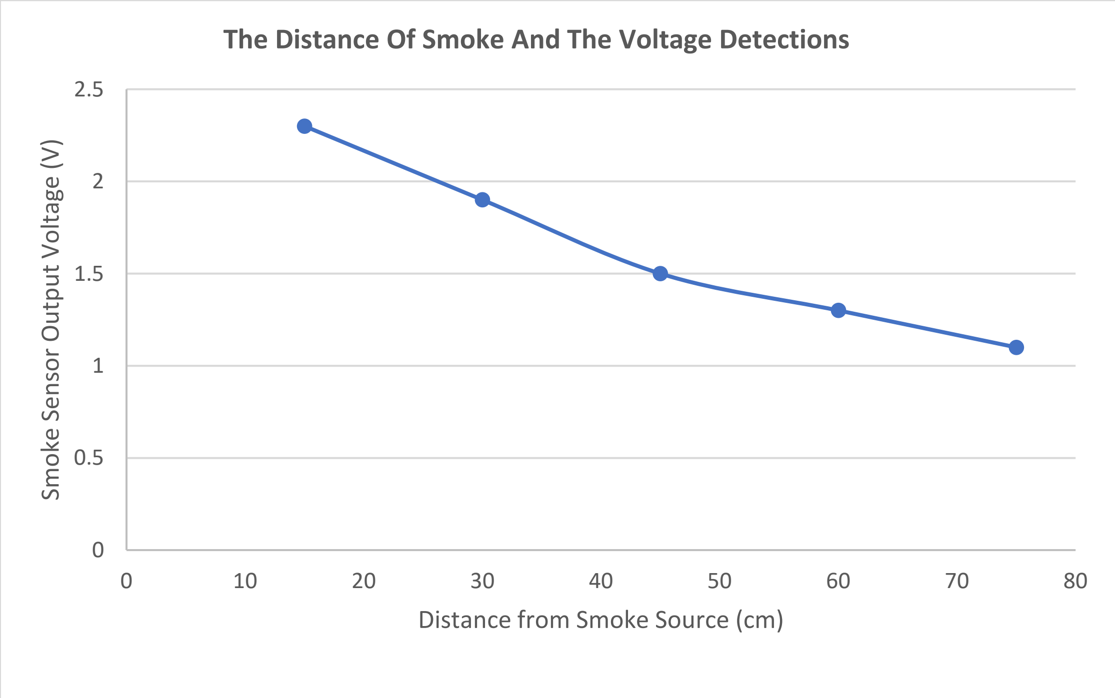


Fig. 8 *Relationship between distance and smoke sensor voltage output*

4.4 Flame Sensor Voltage Readings

Table 4 provides the voltage output readings of the flame sensor at incremental distances from the flame source, ranging from 15 cm to 75 cm. The sensor's voltage readings are crucial in validating its analog response to flame intensity and infrared radiation levels over distance.

Table 4 *Flame sensor voltage output at different distances*

Distance (cm)	Voltage (V)
15	4.7
30	4.3
45	3.9
60	3.6
75	3.2

The data reveals a relatively linear and consistent decline in voltage as the flame source moves farther from the sensor. At 15 cm, the sensor records its highest voltage (4.7V), indicating close proximity and direct infrared exposure. As the distance increases, the voltage gradually drops, reaching 3.2V at 75 cm. Compared to the smoke sensor, this decline is more stable and less steep, which suggests that the flame sensor is inherently more resilient to distance-induced attenuation in signal strength.

This stability is largely due to the nature of infrared radiation emitted by flames, which travels directly in straight lines and is less affected by convection or dispersion. Consequently, while smoke particles disperse and thin out over distance, making smoke detection more variable, infrared-based flame sensors maintain clearer signal integrity if there is an unobstructed line of sight between the sensor and flame.

Figure 9 visually depicts the voltage response trend, highlighting a predictable, nearly linear decrease as distance increases. The consistent gradient supports the flame sensor's reliability in monitoring environments where open flames may appear, such as near gas stoves, furnaces, or candle-lit areas. At closer ranges, the sensor exhibits peak sensitivity, enabling rapid detection of flame presence.

The observed voltage response also affirms the accuracy of the Arduino's analog-to-digital conversion, as each voltage level correlates with a specific bit output threshold for triggering alerts. The system logic activates flame detection when the bit value drops below 1000, which corresponds approximately to voltage levels below 4.0V. This ensures timely notification without excessive sensitivity that may lead to false alarms from distant or small light sources.

From a practical engineering standpoint, sensor placement plays a critical role in achieving reliable flame detection. The flame sensor should be positioned to maintain an unobstructed view of high-risk flame areas. It should be mounted at an angle and location that optimizes exposure to potential ignition points while avoiding reflective surfaces or barriers that may block infrared signals. Additionally, the flame sensor's detection field should be periodically checked for cleanliness, as dust or grime on the lens may reduce its optical sensitivity.

In conclusion, the flame sensor exhibits robust voltage output and consistent responsiveness across varying distances, making it an effective component in early fire detection systems. Its performance is optimal when deployed in direct line-of-sight environments, and the observed voltage patterns reinforce its reliability within an Arduino-based alert architecture.

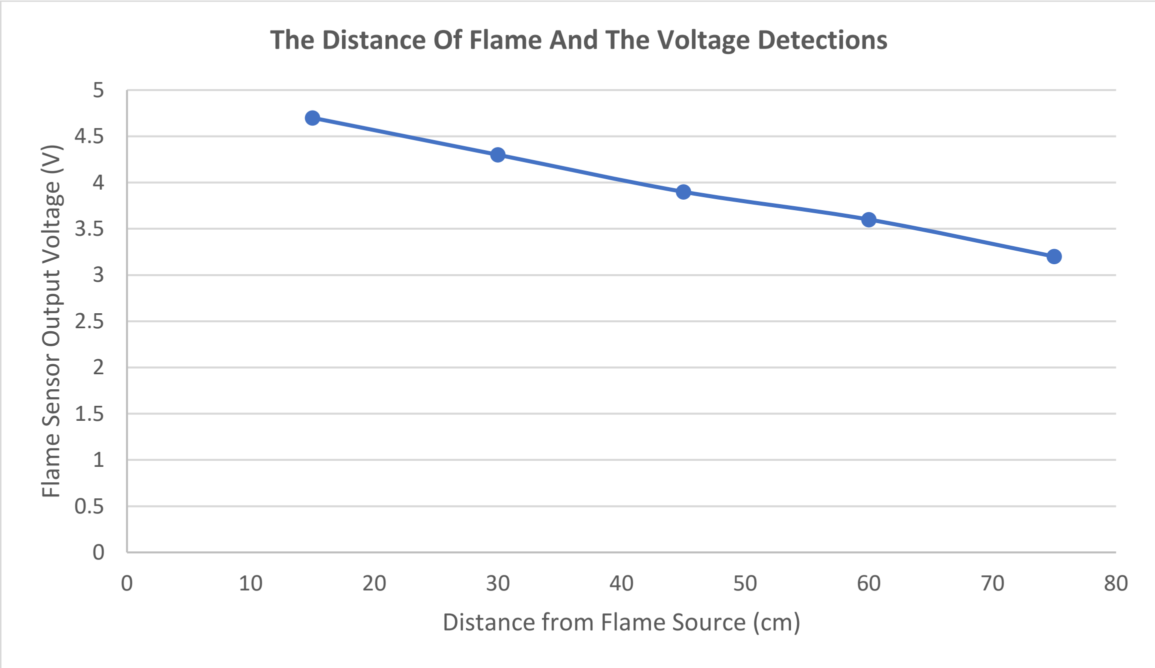
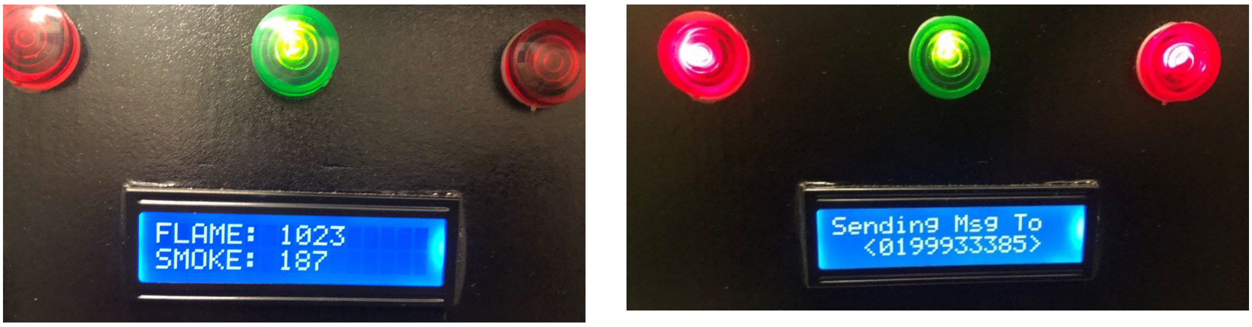


Fig. 9 *Relationship between distance and flame sensor voltage output*

4.5 GSM Transmission Performance

The performance of the Global System for Mobile Communications (GSM) module in delivering SMS notifications was evaluated through controlled tests using different Malaysian mobile network providers. Figure 10(a) shows the system in monitoring mode, where real-time smoke and flame sensor readings are displayed on the LCD. Once the alarm condition is satisfied, the embedded program activates the GSM modem and initiates SMS delivery, as indicated by the LCD status shown in Figure 10(b), which displays the transmission process to a predefined mobile number.



(a) Real-time smoke and flame sensor readings displayed on the LCD

(b) LCD display indicating SMS transmission to the predefined mobile number

Fig. 10 *System LCD display during fire detection and SMS notification*

To quantify the SMS delivery performance, Table 5 summarizes the average SMS transmission time measured for three major Malaysian network providers, namely Celcom, Digi, and Maxis. The results indicate that the proposed system successfully transmitted SMS alerts within a short time window of 5–6 seconds across all tested networks, demonstrating reliable real-time notification capability. Among the tested providers, Celcom recorded the fastest delivery time (5 seconds), while Digi and Maxis recorded slightly longer times (6 seconds).

In addition, repeatability testing was conducted to assess the consistency of SMS delivery. Table 6 presents five repeated trials using the Celcom network under similar operating conditions. The results show stable performance, with consistent transmission times recorded across all repetitions. Overall, the GSM transmission evaluation confirms that the proposed system is capable of issuing timely SMS alerts with minimal delay, supporting its suitability for offline fire notification in residential environments.

Table 5 *Network performance*

Network	SMS Transmission Time (s)
Celcom	5
Digi	6
Maxis	6

Table 6 *Celcom network test repetition*

Test Number	Time (s)
1	5
2	5
3	5
4	5
5	5

The findings indicate that the Celcom network consistently delivers SMS alerts within five seconds, which is faster than both Digi and Maxis networks that averaged six seconds. While the one-second difference may seem marginal, it becomes highly relevant in emergency situations where timely alerts can prevent extensive damage and potential loss of life. The consistent performance across all five Celcom test repetitions further validates the reliability of this network for use in critical alert systems.

In the system configuration, SMS notifications are sent only when both the smoke sensor and the flame sensor are activated simultaneously. This dual-trigger condition is essential for reducing false alarms and ensuring that alerts are sent only in genuine fire scenarios. Such a condition increases the credibility of the system while preserving its operational efficiency and the user's trust.

Additionally, the consistent results confirm that the GSM module performs effectively under standard urban network conditions. The module, which communicates with the Arduino microcontroller, is able to transmit SMS alerts swiftly once the sensor conditions are met. This confirms the reliability of the SIM900A-based modem and supports its application in real-time safety systems.

However, potential variations in performance should be considered for deployment in rural or low-signal areas, where network stability may not be as strong. In such cases, slight delays in message delivery may occur. To mitigate this risk, future versions of the system may include signal quality checks using standard GSM commands, which would enable the system to verify adequate network strength before attempting transmission. Furthermore, implementing dual-SIM options or extending the communication capability through additional wireless technologies such as Wi-Fi or Long-Range Wide Area Network (LoRaWAN) can provide redundancy and improve performance in edge cases.

Overall, the experimental results validate the GSM module's role in supporting timely fire alert systems. The system successfully demonstrates its potential as a low-cost and efficient safety solution, particularly when supported by a stable network provider. With further enhancements, the system can be adapted for broader deployment scenarios including those with more challenging connectivity environments.

4.6 Engineering Implications and System Optimization

The results obtained from the experiments provide several important insights that have direct implications for engineering design and system optimization. One of the most significant findings is the superior performance of the sensors when oriented vertically. Both the smoke and flame sensors demonstrated enhanced detection capabilities in the vertical position, which aligns with physical expectations, particularly for smoke particles that naturally rise due to thermal convection. This finding emphasizes the importance of strategic sensor placement, particularly near ceilings or ventilation outlets where smoke is likely to accumulate first.

Moreover, the experiments confirm that sensor sensitivity is highly dependent on the distance from the fire source. This effect was especially pronounced in the case of the smoke sensor, where detection values declined sharply as the distance increased. Such behavior reinforces the need to install sensors in close proximity to high-risk zones such as kitchens, fuse boxes, or gas lines to ensure prompt hazard detection.

The voltage readings obtained from both smoke and flame sensors also showed a consistent and proportional decline with increasing distance, which correlated well with the bit output values read by the Arduino. This consistency supports the reliability of the analog-to-digital conversion process used in the microcontroller, thereby validating the system's ability to accurately interpret sensor data for triggering alarm conditions.

In terms of communication, the GSM module demonstrated fast and reliable performance under stable network conditions. Among the networks tested, Celcom consistently delivered SMS alerts within five seconds, outperforming others such as Digi and Maxis. This rapid alert delivery is crucial in fire safety applications, where every second counts in preventing damage or loss. The system's logic, which only sends an alert when both the smoke and flame sensors are triggered, effectively minimizes false positives and enhances user confidence in the system.

From a design and engineering standpoint, the integration of a 12V power supply regulated down to 5V using a voltage regulator is an essential feature that ensures the safe operation of sensitive components such as the Arduino and GSM modem. This voltage management helps prevent overheating and extends the operational lifespan of the system.

Overall, the prototype confirms the feasibility of developing a compact, affordable, and effective fire alarm system using off-the-shelf Arduino and GSM technology. The findings suggest that even low-cost components, when properly integrated and optimized, can deliver high-impact safety solutions suitable for residential or small commercial applications.

Future work could focus on enhancing the system by incorporating real-time data logging features and enabling cloud connectivity for data analytics. Integration with Wi-Fi modules could allow for compatibility with smart home platforms, while additional sensors such as temperature, gas, and humidity detectors could broaden the system's application scope. These enhancements would not only increase the accuracy and intelligence of the system but also position it as a scalable and adaptive solution in the context of modern smart infrastructure.

4.7 Relevance of SMS Technology in Modern Fire Detection Systems

Despite the rise of Wi-Fi-based IoT technologies, SMS continues to offer distinct advantages in safety-critical applications such as fire alarm notification systems. The primary reason lies in its independence from internet infrastructure. Unlike Wi-Fi or cloud platforms, SMS operates on the cellular network, making it more resilient in environments where internet access is unstable, unavailable, or compromised during emergencies such as power outages or router failures. Moreover, SMS provides direct, immediate communication to mobile phones without requiring users to install or configure additional applications. In urgent situations, simplicity and accessibility are crucial. SMS ensures that alerts are received by users even if they are using basic phones or are in locations with limited data coverage.

Additionally, GSM modules used for SMS transmission are cost-effective, energy-efficient, and require minimal bandwidth compared to IoT modules reliant on continuous internet connections. This makes SMS-based systems ideal for rural areas, industrial zones, and off-grid locations where network reliability is uncertain. Furthermore, SMS does not depend on third-party platforms or cloud services, thus avoiding potential data privacy concerns and service disruptions. For mission-critical alerts like fire detection, this independence enhances system robustness and user trust. In conclusion, while Wi-Fi and IoT offer advanced functionalities for integrated smart systems, SMS remains highly relevant as a standalone or backup alert mechanism due to its reliability, simplicity, and universal reach. For real-time emergency alerts where every second counts, SMS is still one of the most effective and dependable technologies.

4.8 Cost and Performance Comparison

Compared with commercial and IoT-based solutions presented in Table 7, the proposed system offers lower cost, offline operation, and dual-sensor validation, making it more suitable for residential and low-resource environments. Meanwhile, Table 8 summarizes a comparison between the proposed system and representative previous works. It can be observed that many Arduino–GSM fire alert systems mainly focus on functional demonstration and do not provide structured quantitative validation of sensor response versus distance and installation orientation. In contrast, this work provides dual-sensor validation, distance-based evaluation (15–75 cm), orientation sensitivity analysis, and GSM SMS latency verification across multiple Malaysian networks.

Table 7 *Comparison with existing fire alarm systems*

System	Sensors	Connectivity	Internet Required	Alert Type	Approx. Cost (USD)
Commercial fire alarm	Smoke only	Wired	No	Siren	40–80
IoT-based system [19]	Smoke + Temp	Wi-Fi	Yes	App	60–100
GSM system [5]	Smoke	GSM	No	SMS	35–50
Proposed system	Smoke + Flame	GSM	No	SMS + Alarm	< 30

Table 8 compares the proposed Arduino–GSM fire alarm system with representative previous studies on low-cost fire detection and SMS-based alert systems. The comparison is intended to justify the novelty of the present work beyond a basic proof-of-concept. Several earlier GSM-enabled prototypes successfully demonstrated SMS alert functionality using Arduino platforms; however, many of these systems were designed around single-sensor triggering, most commonly smoke-only detection [5], [6]. While such approaches are cost-effective and simple to implement, the lack of multi-sensor confirmation may increase susceptibility to false alarms in real residential environments. Other systems focused on different application contexts, such as robot-based implementations, which limits their direct relevance to fixed indoor residential installation and placement guidelines [7].

In contrast, IoT- and WSN-based approaches provide advanced remote monitoring and cloud integration, often incorporating additional sensing modalities such as temperature [14], [19]. However, these solutions generally require stable Wi-Fi or internet connectivity, which may not be consistently available in low-resource settings or during emergency conditions. This dependency introduces a practical limitation for safety-critical applications, where fire incidents may coincide with power disruption, router failure, or unstable network access. Therefore, offline communication through GSM SMS remains an important design choice for ensuring universal and reliable alert delivery without requiring user-installed applications or cloud services.

The proposed system differentiates itself by combining dual-sensor validation (smoke and flame), structured distance-based testing, and installation-orientation evaluation, while maintaining offline SMS notification capability. Unlike many prior GSM-based systems that primarily demonstrate functional triggering, this work experimentally evaluates sensor response versus distance and compares horizontal versus vertical placement to provide practical deployment insight. In addition, the GSM notification performance is validated through SMS delivery latency testing across multiple Malaysian network providers, supporting the reliability of real-time alerts in emergency conditions. Although GSM latency studies exist [13], they are typically not integrated into full prototype evaluations. Overall, Table 8 confirms that the proposed work contributes both an affordable prototype and quantitative evidence supporting sensor placement and communication performance, strengthening its justification for residential fire safety applications.

Table 8 *Comparison of the proposed system with previous Arduino-based fire alert systems*

Ref.	Platform	Sensors Used	Alert Method	Internet Required	Dual-Sensor Validation	Distance-Based Evaluation	Orientation Evaluation	SMS Latency Validation	Remarks / Limitation
[5]	Arduino	Smoke	GSM (SMS)	No	No	Not explicitly reported	Not explicitly reported	Not explicitly reported	Low-cost GSM alert; limited quantitative testing
[6]	Arduino	Smoke	GSM (SMS)	No	No	Not explicitly reported	Not explicitly reported	Not explicitly reported	Functional demonstration; no placement guideline
[7]	Arduino + Robot	Flame	GSM (SMS)	No	No	Not explicitly reported	Not explicitly reported	Not explicitly reported	Different scope (robot-based); not residential placement
[9]	Microcontroller	Smoke/Flame	GSM (SMS)	No	Not clearly stated	Not explicitly reported	Not explicitly reported	Not explicitly reported	Early GSM approach; limited evaluation metrics

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Ref.	Platform	Sensors Used	Alert Method	Internet Required	Dual-Sensor Validation	Distance-Based Evaluation	Orientation Evaluation	SMS Latency Validation	Remarks / Limitation
[19]	IoT-based	Smoke + Temperature	Cloud/App	Yes	Partial	Not explicitly reported	Not explicitly reported	Not applicable	Requires internet connectivity; higher system complexity
[14]	WSN-based	Smoke/Temperature	Wi-Fi monitoring	Yes	Not focus	Not explicitly reported	Not explicitly reported	Not applicable	Not suitable for offline applications
[25]	Embedded system	Multi-sensor	GSM (SMS)	No	Yes	Not clearly stated	Not clearly stated	Not clearly stated	Multi-sensor design: evaluation details limited
[13]	GSM performance study	N/A	GSM (SMS)	No	N/A	N/A	N/A	Yes (typical 5–6 s)	Supports SMS latency range; not a prototype evaluation
Proposed	Arduino Uno	Smoke + Flame	GSM (SMS) + Buzzer	No	Yes	Yes (15–75 cm)	Yes (Horizontal vs Vertical)	Yes (5–6 s across networks)	Provides low-cost offline system with quantitative placement + communication validation

5. Conclusion and Recommendation

This paper presented the design, development, and experimental validation of a low-cost fire alarm security system that leverages Arduino-based microcontroller architecture and GSM communication for real-time SMS alerts. The system integrates both smoke and flame sensors, and its dual-sensor activation logic ensures reliable detection while minimizing false alarms. The experimental results demonstrated that sensor performance is significantly influenced by orientation and distance from the fire source. Vertical placement of sensors consistently yielded higher sensitivity, particularly for smoke detection, due to the upward movement of smoke particles.

Furthermore, voltage measurements correlated strongly with analog detection values, confirming the accuracy of signal processing through the Arduino platform. The GSM module performed efficiently across multiple network providers, with Celcom showing the fastest and most consistent SMS delivery. These findings validate the prototype's operational reliability and its potential as a practical solution for enhancing fire safety in residential and small commercial environments. From an engineering perspective, the system is both scalable and cost-effective, with minimal infrastructure requirements and ease of implementation. The integration of hardware and software components has been successfully optimized for real-time response, portability, and user accessibility.

For future enhancement, the system can be improved by integrating Wi-Fi or cloud-based IoT platforms to enable remote monitoring and data logging, allowing users to access real-time alerts through mobile applications. Additional environmental sensors such as temperature, gas, or humidity could be incorporated to expand hazard detection capabilities and improve system responsiveness. Furthermore, implementing machine learning algorithms for adaptive threshold detection may reduce false positives and enhance accuracy in variable conditions. Power optimization using rechargeable batteries or solar integration is also recommended to support uninterrupted operation, especially in off-grid or high-risk areas.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of results, and manuscript preparation:*** *Muhammad Zulhilmi Hussin, Jamaludin Jalani and Jumadi Abdul Sukor;* ***review and validation of the final manuscript:*** *Muhammad Irfan Rahimi, Ramlah Awang and Noorhamizah Mohamed Nasir. All authors reviewed the results and approved the final version of the manuscript.*

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