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G.A.R.D. (GAS ALERT AND REAL-TIME DETECTION): DEVELOPMENT OF AN IOT-ENABLED GAS (LPG) LEAKAGE DETECTION WITH MOBILE APP INTEGRATION

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ABSTRACT

This study developed an IoT-enabled LPG gas leakage detection system with real-time alerts to reduce fire and explosion risks. Using an MQ-6 gas sensor and DHT22 temperature sensor, data is processed by an ESP32 microcontroller, triggering a five-LED indicator and buzzer for local alerts. Simultaneously, a LoRa module sends data to a secondary ESP32 and the G.A.R.D. mobile app for remote monitoring. Tests showed reliable detection and notifications within 10–30 m (mean times 10.69–13.28 s, SD < 1). G.A.R.D. maintains reliable performance between 40m and 60m; however, signal failure occurs beyond 70m due to environmental and signal interference. The system provides a portable, IoT-integrated solution that combines local and remote alerts.

Keywords: *IoT-enabled, LPG leak, detection system, real-time alert, bluetooth*

INTRODUCTION

Background of the Study

The presence of gas leaks poses severe risks to both human health and property, requiring immediate and accurate detection. When detected early, individuals can take timely action to prevent harm. However, many accidents still occur because leaks are discovered too late, and conventional detectors often underperform due to delayed response, leaving homes at risk of fire and explosions.

The introduction of G.A.R.D. aims to significantly enhance home safety by detecting gas leaks and delivering real-time alerts through a custom built mobile application. Furthermore, the device offers portability through Star network enabling offline functionality. This integration guarantees reliable performance even in low-connectivity environments, offering continuous protection without requiring an internet connection.

In the Philippines, gas leaks and related incidents remain a persistent public safety concern. Residential and commercial establishments rely heavily on liquefied petroleum gas (LPG) for cooking and heating; however, leaks caused by faulty appliances, damaged tanks, or improper handling have repeatedly led to accidents. For instance, on July 5, 2023, two individuals were injured after an LPG tank exploded in a pizza and pasta restaurant in Quezon Province (Estacio, 2023).

Similarly, on February 1, 2024, three persons sustained second-degree burns following a gas tank explosion in Makati City (Bautista, 2024). More recently, in February 2025, six restaurant workers in Davao City were hospitalized after an LPG tank leak ignited near an electric fryer, causing a severe explosion (Esteban, 2025). These recurring incidents underscore the vulnerability of Filipino households and communities to undetected gas leaks and highlight the urgent need for reliable, technology-based safety systems that can reduce risks and safeguard lives.

A gas detector serves as a safety mechanism that prevents accidents by providing early warning signals when hazardous substances are detected. Devices that monitor gases such as LPG, methane, and carbon monoxide allow users to detect leaks before they escalate. The presence of detectors enables prompt evacuation, emergency response, and corrective action, reducing the likelihood of fire and explosions. Beyond saving lives, gas detectors also protect property and promote a culture of safety within homes and workplaces.

Existing gas detection systems minimize the risk of combustible and toxic gas exposure to prevent incidents. These devices are typically stand-alone detectors equipped with sensors such as metal-oxide-semiconductor (MOS), catalytic-bead (pellistor), or electrochemical sensors that trigger alarms when gas concentrations exceed safe limits. These detectors are commonly wall-mounted near gas appliances or leak-prone areas and rely on alarms or indicator lights to alert owners. While these systems have proven useful, their main limitation is delayed response.

Recent technological advancements have given rise to smart and IoT-based gas detection systems, which integrate sensors with microcontrollers and communication modules (Luca, 2025). Unlike conventional detectors, these systems provide real-time monitoring and are capable of sending alerts through various channels, such as text messages, mobile applications, or internet-based notifications.

An Arduino Uno microcontroller with an MQ-series gas sensor and a GSM module (SIM900A) can detect gas leaks and automatically send warning notifications to the owner via SMS, sound an alarm, or even activate a DC fan to disperse gas (Arduino Documentation, 2025). To ensure that users are informed even in the absence of an internet connection, another prototype combines the NodeMCU ESP8266 microcontroller with the MQ-6 sensor to transmit alerts via SMS and the Blynk mobile app.

This connectivity ensures that users are informed of gas leaks even when they are away from their homes, allowing for faster emergency responses. Studies have shown that IoT-enabled detectors significantly improve safety by extending awareness beyond physical alarms (Luca, 2025). However, these systems remain relatively costly and less accessible for widespread adoption in average Filipino households, signaling the need for more affordable and practical implementations.

Existing gas detectors commonly utilize conventional alert systems such as buzzers and indicator lights to signal the presence of gas leaks. While effective for immediate, localized alerts, these systems offer limited functionality in terms of remote accessibility and user engagement. This research addresses the opportunity to enhance gas detection systems by integrating traditional alert mechanisms with wireless communication technologies to enable remote notifications.

By combining these features, G.A.R.D. strives to elevate safety, convenience, and responsiveness while also optimizing efficiency and user accessibility in gas leak monitoring.

Objectives of the study

This study aims to design and implement an IoT-enabled gas (LPG) leakage detection system with real-time alert monitoring features through app integration to minimize fire-related risks: (1) to develop an IoT-enabled gas leakage detection and real-time notification system; (2) to integrate an application that serves as the user's platform for real-time alert notifications; and (3) to evaluate the performance of the system in terms of (a) detection accuracy and (b) app notification responsiveness.

Review of Related Literature

Gas leak-related fire cases

Gas leaks remain one of the most significant and dangerous hazards in industrial and confined environments due to their potential to cause fires and explosions. Liaw et al. (2023) revealed that corrosion-induced pipeline failure, combined with lapses in Process Safety Management (PSM), led to the incident, causing billions in damages. They highlighted systemic weaknesses in hazard analysis, mechanical integrity, and emergency preparedness.

In another case study conducted by Ddakani et al. (2021), a gas pressure was examined using ALOHA software to simulate gas leakage and fire situations. Their findings revealed that seasonal conditions significantly influence the extent of threat zones, with larger impact areas recorded during hot weather for gas leaks and during cold weather for fire incidents.

Similarly, the study examined gas leak scenarios and fire risks, stressing the critical importance of early detection systems, infrastructure design, and emergency response measures. This highlights the importance of context-specific modeling in risk management. Collectively, these studies emphasize the urgent need for proactive safety measures, especially in urban areas where industrial gas systems are located near residential communities.

Meanwhile, Çalık (2025) found that as little as 10 kg of leaked methane could create a lethal overpressure zone within 15 minutes, leading to a probability of over 90% fatality for individuals within a 1-meter radius. The case underscored the importance of timely gas detection, adequate ventilation systems, and emergency protocols tailored for confined industrial environments, emphasizing the significance of precautionary measures in high-risk settings.

In another related study, Cai et al. (2022) conducted both laboratory and simulation-based analyses of the impact of gas concentration levels and ventilation efficiency on explosion risks and fire behavior in indoor environments. The study showed that gas concentration levels and ventilation efficiency significantly affect the severity of explosions, flame spread, and internal damage. These findings are crucial for improving building design, evacuation plans, and firefighting response procedures during gas-related emergencies, offering valuable insights into structural safety and emergency response strategies in industrial and residential areas prone to gas leaks.

All of these studies highlight critical factors in gas leak-related fire incidents and the importance of effective risk management. Liaw et al. (2023) and Ddakani et al. (2021) stress the role of systemic failures in safety management and infrastructure, emphasizing that seasonal conditions and confined spaces influence the severity of leak-related fire incidents. Çalık (2025) emphasizes the need for early detection systems and adequate ventilation to mitigate risks, especially in high-risk environments such as urban areas and confined industrial spaces. Lastly, Cai et al. (2022) further highlight how gas concentration and ventilation efficiency are key factors in controlling explosions and fire behavior.

In summary, all of these studies underscore the importance of proactive safety measures, risk assessments, and advanced detection technologies to reduce the impact of gas leaks and help prevent fire incidents.

Integration of IoT in gas leak detection

Jena et al. (2022) pointed out that accidents involving LPG have become a significant social concern because of its widespread domestic and industrial use. Leaked LPG can ignite easily with even the smallest spark. Although odorants are added to assist in detecting leaks, many users fail to observe safety measures, which leads to incidents. To mitigate these risks, the development and use of the Internet of Things (IoT) enable gas sensors to provide continuous monitoring and send instant alerts through smartphones, making detection more efficient and reliable compared to traditional methods.

According to Aakash et al. (2025), an IoT-enabled gas leak detection system can be applied to both homes and industries. It is equipped with gas sensors that continuously monitor air quality and transmit data to a microcontroller, which communicates through wireless protocols. Upon detecting a leak, the system can immediately send real-time notifications and take preventive actions that can be modified remotely, using simple tools to help minimize risks. The system improves accuracy through multi-sensor fusion and artificial intelligence (AI), outlining a feasible and scalable path toward more intelligent and safer spaces.

Jena et al. (2022) emphasize that LPG leaks continue to pose risks, as traditional detection methods and user negligence often lead to accidents, making IoT-based monitoring essential. Similarly, Aakash et al. (2025) present a more advanced model that allows real-time tracking through mobile apps and web dashboards. These studies demonstrate that IoT strengthens safety by offering smarter, more efficient, and reliable gas leak detection.

Application of LoRa in wireless alert systems

According to Gonzalez et al. (2020), LoRa is a technology designed for long-range wireless communication. It is affordable, reliable, and energy-efficient, making it suitable for safety monitoring systems. By enabling long-range wireless data transmission, LoRa provides timely warning alerts to help prevent accidents, particularly in areas with limited or weak Wi-Fi connectivity.

LoRa is useful as a wireless alert system, as it can send data over long distances of up to 20 km while using minimal power, as stated by Kolobe et al. (2020). Devices equipped with LoRa can last up to 10 years, making them reliable for long-term monitoring. Studies show that LoRa is suitable for wireless sensor networks in both rural and urban settings, although it still requires further testing in some areas. It is resistant to noise, which helps ensure that messages are transmitted accurately, making it appropriate for gas leak detection and other real-time alerts.

Taken together, these studies underscore LoRa's effectiveness as a wireless alert system. Gonzalez et al. (2020) emphasized its affordability and efficiency in safety monitoring, while Kolobe et al. (2020) focused on its long-range, low-power, and durable performance. Overall, both studies demonstrate that LoRa is a practical and reliable communication technology for real-time alerts, including gas detection and disaster monitoring.

Temperature and humidity in gas sensors

Abdullah et al. (2020) analyzed how temperature and humidity influence the performance of gas leak sensors at different concentrations. They found that most sensors show decreased performance as temperature and humidity rise, resulting in inaccurate and unreliable detections. They emphasized the importance of environmental conditions in the effectiveness of gas leak detectors and the need for calibration and compensation to maintain accurate detection in real-world environments.

Similarly, Furuta et al. (2022) illustrated how gas sensors are affected by environmental factors such as temperature and humidity, sometimes even more than by the gas they are intended to detect. The study showed that excessive humidity makes it difficult for gas to be detected on the sensor surface, while temperature changes can affect conductivity and baseline resistance, causing inaccurate results. These conditions may lead to false alarms; however, the use of compensation and calibration models can help maintain sensor accuracy.

Abdullah et al. (2020) and Furuta et al. (2022) both highlighted that temperature and humidity affect gas leak sensors, showing reduced response as these environmental factors increase. Rising humidity can block gas absorption, and temperature changes can affect the sensor's conductivity and stability, leading to inaccurate detection.

Application Through Offline Connection

Offline mobile applications rely on app integration that allows different modules to communicate and function without an internet connection (Sheharyar, 2025). This can be achieved by using local storage and device-level services. It allows notifications, data input forms, and analytics to work together without the internet. This integration prevents interruptions in critical situations, supports users with unstable internet connections, and ensures access to important notifications.

According to the article by Think-It (2025), offline app integration allows applications to function without relying on the internet through local storage, background processes, and queued data synchronization. This enables users to continue performing important tasks even in areas with weak connections. The app saves information on the device, allowing it to load faster and reducing the risk of data loss. Offline integration also supports real-time actions, such as alerts or notifications. This makes offline applications reliable, user-friendly, and efficient, especially for critical functions like monitoring, reporting, or emergency notifications.

Both Sheharyar (2025) and Think-It (2025) explain that offline application integration allows apps to function without the internet by using local storage and background processes. They highlight that this integration keeps notifications, data entry, and real-time actions working even in weak connections. Both sources emphasize that offline apps make applications more accessible, reliable, and safe for users.

Theoretical Framework

This study adopts the Internet of Things (IoT) framework and Gas Diffusion Theory, complemented by principles of gas behavior and environmental conditions. The IoT framework enables real-time monitoring of gas leakage through sensors, communication protocols, and data transmission, sending timely alerts to users' smartphones and ensuring safety and efficiency without constant human supervision (Ray, 2018).

Fick's Law of Diffusion states that molecules naturally move from regions of high concentration to regions of low concentration, with the flux proportional to the concentration gradient (Jin et al., 2023). In the case of LPG leaks, this principle explains how gas can spread and accumulate in enclosed areas, highlighting why early detection and strategic placement of sensors are essential for safety.

Dalton's Law of Partial Pressures clarifies that each gas in a mixture contributes to the total pressure according to its partial pressure (Smith et al., 2018). This principle helps explain how LPG behavior, along with the presence of other gases such as water vapor, can affect sensor readings and accuracy.

The Clausius–Clapeyron relation further illustrates how temperature and humidity influence sensor performance (Çengel & Boles, 2019). Warm air holds more water vapor, and high humidity levels can compete with LPG molecules on the sensor surface, potentially causing false readings.

Gas detection also involves surface interactions that may include endothermic processes, where the sensor absorbs energy when gas molecules interact with its surface (Korotcenkov, 2020). This energy absorption affects how sensitive the sensor is, how quickly it responds, and how accurate the readings are, offering a thermodynamic explanation of how environmental conditions can affect its performance.

Overall, these theories provide a clear scientific and technological basis for understanding the different factors that influence gas behavior and sensor performance. This strengthens the study's development of a reliable gas leak detection and real-time notification system designed to enhance safety in households and communities.

Conceptual framework

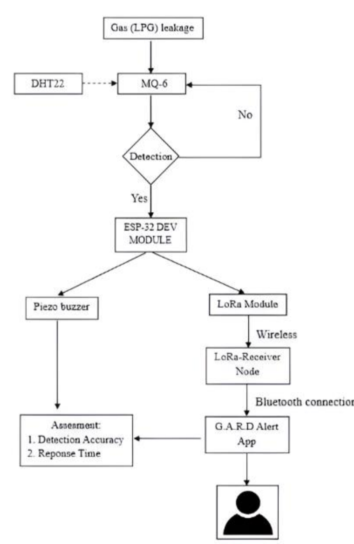

Figure 1. Conceptual framework

The figure illustrates the workflow of the device, which is centered on the ESP32 microcontroller. The ESP32 functions as the central processing unit, receiving input from the MQ-6 gas sensor, while the DHT22 sensor provides environmental parameters such as temperature and humidity to ensure more reliable readings. The sensors are installed in proximity to the LPG cylinder to enable the detection of potential gas leakage. Upon detection, the microcontroller activates an audible alarm through a piezoelectric buzzer and powers a five-LED indicator to convey the system status. Simultaneously, it transmits a wireless alert signal via a LoRa module. The LoRa main circuit then sends the signal to another LoRa module, which communicates with the ESP32 Dev Module before transmitting the alert notification to the mobile application.

Scope and Limitation

This study focuses on the development and implementation of a smart gas detection and notification system based on ESP32 technology. The device is specifically designed to be installed 1 foot above the ground and half a foot away from the LPG (Liquefied Petroleum Gas) tank to optimize accuracy, as gas is denser than air and tends to accumulate near the floor. The system monitors and detects LPG presence indoors, providing real-time alerts through visual, audio, and digital notifications.

The research scope is limited to evaluating functionality, sensitivity, and response time in detecting LPG. It excludes other hazardous gases and industrial-scale applications. To improve reliability, the device integrates a DHT22 sensor for temperature and humidity monitoring, calibrated to typical Philippine household conditions (25–30 °C, 30–90% RH). Testing excludes conditions such as direct sunlight, sudden cooking heat, or outdoor weather changes.

The system is designed for household use, providing portable, wireless alerts for gas leak detection. However, its performance may not be suitable for larger properties or industrial environments, where operating conditions and safety standards differ significantly. Additionally, the Bluetooth connection can be constrained by range limitations and environmental factors inherent to Bluetooth technology and is not configurable within the scope of this study. While the system could potentially operate over longer distances, its performance and reliability may still be affected by Bluetooth barriers, which must be considered when sending real-time alerts.

METHODOLOGY

Research Design

This study employs a non-iterative developmental design. According to Dwissink (2025), this design follows a linear process in which the product is developed in a single cycle without trial phases or feedback loops, making it suitable when the scope is clearly defined. Integrating this technology into a functional IoT-enabled gas leakage detection system rather than repeatedly redesign the product. Since the system is already finalized and functioning as intended, the results are presented as they are, allowing the researchers to evaluate the product's performance without relying on external feedback. Due to time constraints, an iterative process involving repeated testing and refinement could not be conducted, making non-iterative approach the most practical for the study.

Statistical Treatment

This study uses descriptive statistics to analyze the data collected from the trials of the gas detection alert system. Descriptive statistics summarize quantitative data by showing patterns, central tendency, and variability within a dataset, without making inferential conclusions (Illowsky & Dean, 2021). This approach allows the performance of the device under controlled conditions to be clearly examined.

The study employs the mean and standard deviation as its primary statistical measures. The mean represents the average accuracy across multiple trials, while the standard deviation reflects the consistency of the readings. These measures provide a basis for evaluating the device's effectiveness as a gas leak detector capable of sending real-time alert notifications.

Materials

The materials used in this study include prototyping components such as a breadboard and jumper wires. The main circuit consists of an ESP32 Dev Module, MQ-6 gas sensor, DHT22 temperature and humidity sensor, LED indicators (two green and one yellow), and a piezoelectric buzzer. For wireless communication, LoRa SX1278 modules were utilized. The receiver circuit includes an ESP32 Dev Module, LoRa SX1278 module, lithium-ion batteries, a battery holder, and a DC-to-DC buck converter. Additionally, printed circuit fabrication materials such as copper board, ferric chloride, and pin headers were used.

The equipment used in this study includes a handheld drill with 0.5 mm and 1 mm drill bits for circuit fabrication, a battery charger for powering the system components, and a soldering iron with appropriate soldering wire for assembling electronic connections.

Developmental Procedure for the Gas Detector with Alert System

The development of the gas leak detection system with alert functionality involved the integration of multiple hardware and software components. The system was built using an ESP32 microcontroller, an MQ-6 gas sensor for LPG detection, and a DHT22 sensor for monitoring temperature and humidity. Additional components included a piezoelectric buzzer for audible alerts, five LED indicators for visual status display, and LoRa modules to enable long-range wireless communication between the transmitter and receiver nodes.

The MQ-6 sensor was interfaced with the ESP32 to detect the presence of gas, while the DHT22 sensor was connected via I²C protocol to monitor environmental conditions. Output devices, including the buzzer and LEDs, were connected to designated GPIO pins to provide real-time alerts and system status indications.

For wireless communication, a LoRa module was integrated with the ESP32 using the SPI interface. The transmitter node was configured to send alert signals to a receiver node, which was linked to a mobile application developed using Kodular. The application interface was designed through Kodular's Designer and Blocks environment, allowing real-time monitoring and notification through Bluetooth connectivity.

The system circuit was initially designed and implemented on a printed circuit board (PCB). Standard PCB fabrication techniques were followed, including layout transfer, etching using ferric chloride solution, drilling, and component soldering.

The ESP32 was programmed to process sensor data, compare readings against predefined threshold values, and trigger alerts when abnormal conditions were detected. Wireless notifications were also transmitted to the connected mobile application.

To evaluate system performance, the prototype was tested under controlled conditions with the assistance of the Bureau of Fire Protection. The device was assessed based on detection accuracy and response time to determine its reliability and efficiency in identifying gas leaks.

System Wiring Diagram

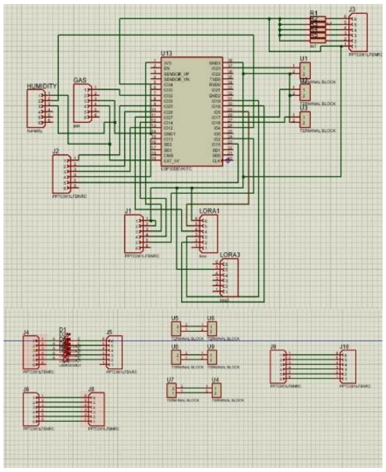

Figure 2. Physical connection of the gas leak detection with alert system.

Figure 2 shows the wiring of the gas leak detection prototype. The ESP32 microcontroller collects data from the MQ-6 gas sensor and the DHT22 temperature and humidity sensor. Visual alerts are provided by LEDs, while an audible alarm is generated by a piezo buzzer. The ESP32 also connects to a LoRa SX1278 module to wirelessly send alerts to a receiver node, which then forwards the warning to a smartphone via Bluetooth.

Printed Circuit Designing

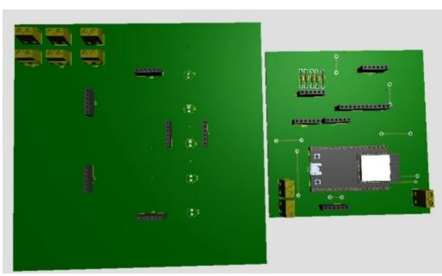

Figure 3. PCB design of sender and receiver circuit

The design shows the device's electronic connections on a PCB. MQ-6 and DHT22 sensors, connected to the microcontroller's GPIO pins, serve as inputs for continuous monitoring. Outputs include LEDs and a buzzer for visual and audible alerts. The microcontroller also interfaces with a LoRa module via GPIO pins to transmit alerts wirelessly.

App Invention

Figure 3. Sample Application interface

To utilize the IoT capabilities, the researchers developed a customized mobile application using Kodular Web. The app can establish Bluetooth connections between any Android smartphone and detected Bluetooth-enabled devices. It supports pairing with a single device at a time and displays notifications each time a gas leak is detected. The connection operates offline, requiring only a bluetooth connection between only android devices.

RESULTS AND DISCUSSIONS

This chapter presents the results of G.A.R.D., showing that both the device and application functioned successfully under different conditions, including variations in distance and temperature. The system detected gas leaks within 2–4 seconds and the notification was sent within the same 2–4 second interval. In relation to the study by Riding et al. (2026), the alarm response occurred in less than 2 seconds and notification alerts were also sent within 2–3 seconds, while in terms of distance, the system detect gas leaks at 5–15 cm, with a success in detection rate within this range, but detection failed when it reached 20 cm. The present study showed a detection success with no missed trials, and consistent performance at 10-60 meters, it is less effective outside this range. The app responded promptly, confirming the warning and sending a notification to the owner. These outcomes demonstrate that the system is not only functional but also reliable under real-life conditions.

Table 1. G.A.R.D. System Trial of Device

Trial	Time (in seconds)	Temp	Alarm	Missed
1	4.11	31.8°C	Yes	No
2	2.98	31.8°C	Yes	No
3	3.88	31.6°C	Yes	No
4	3.61	31.5°C	Yes	No
5	3.40	31.5°C	Yes	No
$\bar{x}$	3.60			
σ	0.44			

Note: $\bar{x}$ (x-bar) represents the average (mean), while σ (sigma), the standard deviation measures how much the data values are spread out or vary from that mean.

Table 1 presents the performance of the G.A.R.D. device across all five trials, with a mean of 3.60 and a standard deviation of 0.44. This small standard deviation indicates that the device produced very similar results across trials, showing only minor differences and demonstrating consistency. The short detection time suggests that the system can efficiently recognize changes or triggers almost immediately after they occur. The results were most consistent during the 3rd to 5th trials, ranging from 3.40 to 3.88, while the first and second trials recorded 2.98 and 4.11, respectively. This demonstrates that the system remained highly responsive across repeated exposures to the same leak conditions.

Table 2. Mean and standard deviation

Distance (in meters)	M	SD
10	10.69	0.69
20	11.82	0.47
30	13.28	0.44
40	13.46	1.29
50	11.62	1.16
60	11.22	0.92
70		
80		

Table 2 presents the data across trials of application responsiveness. The system performed most consistently between 10 and 30 meters, with a mean ranging from 10.69 to 13.28, low detection times, and minimal variability (values less than one). Although time responsiveness increased and variability grew beyond 30 meters, the system remained

functional up to 60 meters, showing less consistent average performance of 11–13 and a standard deviation close to or greater than one. At 70–80 meters, the system failed to deliver valid notifications, indicating no data and concluding that it was ineffective.

CONCLUSIONS

This study aimed to design and implement an IoT-enabled LPG gas leakage detection system with real-time, app-integrated alert monitoring, intended to minimize fire-related risks. Analysis of the collected data showed that, with proper calibration and integration of the system's sensors and modules, all input and output components worked cohesively, allowing the device to perform as intended. The system effectively detected LPG leaks and transmitted notifications with minimal delay within its optimal operational range.

The gas sensor’s detection accuracy remained consistent across repeated trials, with detection times ranging from 2 to 4 seconds when gas was released half a foot away from the device, demonstrating the sensor's reliability under the tested conditions. The alert notification system performed reliably within its effective range of 10 to 30 meters, with optimal performance. Notifications were consistently received up to 60 meters from the main device, though delays were observed between 40 and 60 meters. Beyond 60 meters, occasional failures occurred, primarily due to environmental factors, obstacles, signal interference, and device positioning.

Recommendations

Based on the results and conclusions of the study, the researchers recommend enhancing both the device and its application to ensure that real-time notifications are fully supported on iOS devices in addition to existing platforms, and to add a push notification feature. It is also suggested to integrate a more precise, gas-specific sensor—preferably one designed to detect a single target gas—to improve accuracy and reduce detection delays. Furthermore, the researchers recommend upgrading the device’s mesh communication capability by using a more advanced antenna to extend and stabilize the effective range covered by the receiver node. Time limitations constrained the researchers' ability to optimize the device for maximum portability. Overall, an iterative design approach is suggested to further compact the system.

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