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Abstract

The frequency of domestic gas cylinder usage comes with an inherent risk of leakage, leading to dangerous accidents and potentially catastrophic events, especially in Afghanistan, where indoor gas cylinder usage is common. To address this issue, we have developed an integrated safety system employing Artificial Intelligence (AI) to enhance household safety and reduce risks associated with gas cylinder leaks. Our system includes high-accuracy sensors for real-time detection of gas leaks, AI algorithms trained on diverse datasets for pattern recognition, and automated mechanisms for shutting off the gas nozzle to prevent further leakage. Experimental results demonstrate a detection accuracy of 98%, with response times under 2 seconds and a success rate of 95% for the automatic shutoff mechanism. This AI-enabled system offers a practical, scalable solution to domestic gas safety challenges, significantly contributing to household safety advancements. The frequency of domestic gas cylinder usage comes with an inherent risk of leakage, which can lead to dangerous accidents and potentially catastrophic events, especially in Afghanistan, where indoor Gas cylinder usage is common. To address this issue, we have developed an integrated safety system that employs Artificial Intelligence (AI) to enhance household safety and reduce the risks of gas cylinder leaks. Our approach utilizes sensors to monitor the gas cylinder, promptly detecting leakage. Once detected, this information is relayed to a central device equipped with AI capabilities. This intelligent device assesses the severity of the leakage and executes a multi-faceted response strategy. It communicates an alert to the user's mobile phone application, activates an audible alarm system, and initiates an automatic mechanism attempting to shut off the cylinder's nozzle to prevent further gas escape. Our experimental results have shown that the system not only detects leaks with high accuracy but also effectively categorizes the severity of leakages, allowing for timely and appropriate responses. Moreover, the automatic shutoff feature has efficiently minimized potential damage from gas leaks. This system provides an effective approach to improving household safety by utilizing AI to detect and manage gas cylinder leaks, thereby enhancing the safety of domestic energy usage.

Keywords: *AI Safety, Gas Cylinder Safety, IOT Based Home Safety*

1. Introduction

Accidents involving gas cylinders can lead to fires, explosions, and toxic exposures, often resulting in significant property damage, injuries, and fatalities. The consequences are particularly dire in enclosed spaces where gas accumulation can rapidly reach dangerous levels. Addressing these risks requires robust safety measures, regular maintenance, and immediate response systems. Domestic gas incidents, including fires and explosions, have remained a significant global safety concern in the past five years. According to data from international organizations, the rate of fire-related deaths, which includes incidents caused by domestic gas, has seen fluctuations based on region and year.

Globally, the death rate from fires and burns, which encompasses gas-related incidents, is estimated to be around 1.2 to 1.5 per 100,000 people as of 2021 [1]. However, these rates vary widely by region, with lower-income countries generally experiencing higher rates due to less stringent safety regulations and limited access to safe cooking and heating technologies. For instance, areas in Asia and Africa have higher fire-related death rates than Europe and North America.

In Europe, domestic gas-related incidents, while still present, have been better managed through stricter regulations and widespread safety awareness campaigns. Despite this, countries like Russia and Turkey have reported significant numbers of gas explosion incidents.

The International Association of Fire and Rescue Services reports that there are thousands of fire-related incidents every year globally, many of which are attributed to gas leaks or improper handling of gas appliances in domestic settings. These incidents not only cause fatalities but also result in significant property damage and injuries [1,2].

In Afghanistan, LPG is unavailable through pipelines, and many Afghan families use Gas cylinders for their daily activities. This led to many casualties; one report in Pajhwak news stated that Six family members died from suffocation caused by a gas leak in their home in Kabul city. According to Bakhtar News Agency, security officials reported that the incident occurred in the Taimani area, within the fourth security district of Kabul. The victims include two women and four children who succumbed to gas inhalation [3]. Another incident reported by TOLO News stated that during a ceremony in Kabul marking the 10th anniversary of the ratification of the Afghan constitution, an explosion from a gas cylinder disrupted the event. Fortunately, there were no casualties, but the incident brought the proceedings to an abrupt end [4]. In another incident, local authorities in eastern Khost province of Afghanistan reported that at least six Afghan National Army soldiers died due to a gas leak. According to a statement from the provincial government media office, the incident occurred at a military base late Wednesday night. The statement explained that the gas leak at Sahrabagh military base on Wednesday night poisoned the soldiers while they were asleep. They later succumbed to their injuries in the hospital while receiving treatment [5].

The accumulation of LPG gas indoors is influenced by factors such as poor ventilation, human activities, and the use of machinery and appliances. Extended exposure to elevated LPG concentrations can lead to adverse health effects, including headaches, dizziness, fatigue, and reduced cognitive function. In severe cases, it may result in life-threatening conditions such as asphyxiation [6].

Many systems were introduced to address the problem, such as the GAS Leakage Warning System, a comprehensive indoor air quality monitor that tracks LPG, radon, particulate matter (PM2.5), humidity, temperature, and more. It features smart home integration with Google Assistant, Amazon Alexa, and IFTTT, providing real-time data via an app. The system is wireless, has a long battery life, and provides insights to improve indoor air quality [7]; however, the system does not provide any solution without the Internet. In the same way, another system, Ubidot, was introduced to solve the issue of LPG Gas, which monitors gas levels within a home or industrial facility, ensuring they remain safe. The data is stored and analyzed on Ubidots' dashboard. If a gas leak is detected, the system sends an alert notification to the owner via social media on their smartphone.

Additionally, Ubidots analyzes the gas level data to track variations throughout the day and week, providing a comprehensive overview of gas safety. Users can remotely monitor the safety of their homes or industrial sites in case of a gas leak. The system utilizes a gas sensor integrated with an Intel Edison, which transmits gas level data to the Ubidots Cloud via IoT. In the event of a leak, it sends an alert to the owner through Telegram. Additionally, the owner can access the Ubidots dashboard to review gas levels and verify safety measures [8]; however, the system does not facilitate the domestic user using LPG, and the system does not use AI to analyze the data and send warnings using that analysis. Another study proposes a system capable of automatically detecting gas leaks, triggering an alarm, and mitigating the situation by activating an exhaust fan to expel the gas from the affected area. It uses LEDs to indicate the presence of gas (red for leakage, green for no leakage) and an LCD to display system performance. The system is powered by an Arduino UNO, with a buzzer for notifications. It is intended for use in households and industries that rely on LPG or natural gas, helping to prevent accidents by monitoring gas leaks and responding promptly [9]; however, the system lacks AI for GAS-level analysis.

In the same way, a new system was introduced that automatically books a gas cylinder when the current one is nearly empty by sending a notification to the gas agency via Wi-Fi using the Internet of Things (IoT). It also includes a sensor to detect gas leaks at home, sending an SMS to the user if a leak is detected. A load cell monitors the LPG cylinder's weight, and when it falls below a set threshold, the system triggers a notification to book a new cylinder. The gas agency is notified, and a booking confirmation is sent to the customer, ensuring seamless gas management [10]; the proposed system lacks the usage of modern cylinder sensors and shuts off the nozzle automatically if GAS leakage is detected. Another system, Eve Room, is an indoor air quality monitor focusing on VOCs, temperature, and humidity, with a sleek design and integration with Apple HomeKit. It provides detailed indoor air quality data and automates home ventilation through smart home devices. The system is updated with an e-ink display and improved sensors [11]; however, the system does not provide SMS notifications, which is a faster way of communication than social media and mobile apps; the system also lacks the detection of LPG, specifically using AI.

However, the above systems do not present the idea or the implementation of AI along with IoT IoT-enabled gas detection system and feature to automatically shut off the nozzle in case of Gas leakage, even though both AI along IoT are emerging technologies and have the potential to create a system that is safer to use [12]. Therefore, this research paper addresses this gap by introducing a system that can use AI and IoT to detect dangerous gas levels indoors and automatically turn off the nozzle using AI.

This research not only helps explore the technical aspects of the safety system but also examines the implications of such a solution for society to increase the safety of the environment.

This research seeks to address the limitations of previous systems by focusing on the accurate monitoring and management of domestic gas concentrations within enclosed spaces. It aims to enhance understanding of indoor air quality and support the development of systems designed to maintain a safer and more comfortable environment through LPG-specific AI strategies.

This concludes the following objective for this research paper

1. To develop an enhanced AI-based system that can automatically detect and classify LPG levels.
2. To facilitate faster emergency responses by integrating an automated email notification system that alerts relevant authorities immediately upon Incident detection.

2. Related Work

AI and IoT play a significant role in modern technology, particularly enhancing safety systems like gas detection systems. The increased focus on environmental and occupational safety in the last several decades has made it necessary to create advanced gas detection systems that can handle a wide range of challenging situations. Modern gas detection systems are desperately needed to protect people's lives and reduce possible risks, especially those related to gas leaks and emissions.

Intelligent IoT-based gas leakage monitoring systems, such as the one outlined in this paper, hold great potential for enhancing safety across diverse environments [13]. One of the key advantages of this system is its simplicity. The system uses relatively simple components, such as an Arduino microcontroller, an MQ-9 gas sensor, and an ESP8266 Wi-Fi module. This makes the system easy to build and deploy. Another advantage of the system is its cost-effectiveness. The components used in the system are relatively inexpensive, which makes the system accessible to a wide range of users. The system is also energy-efficient. The Arduino microcontroller and ESP8266 Wi-Fi module are both designed to be energy-efficient, which makes the system suitable for battery-powered applications. Overall, the low-cost, high-performance, energy-efficient IoT-based gas leakage monitoring system described in the paper is a promising technology for Enhancing safety across diverse environments. The system is simple, economically efficient., and energy-efficient, making it accessible to many users.

Using a machine learning algorithm is a key innovation in this system. Machine learning algorithms can be trained to detect patterns in data, which can be used to improve the accuracy and reliability of the system. The machine learning algorithm is trained on a gas leak dataset in this case. Allows the algorithm to learn the characteristics of gas leaks so that it can more accurately detect gas leaks in the future. Another advantage of the system is that it is scalable. The system can be easily scaled up to support many sensors. This makes it suitable for use in large buildings and industrial settings. Overall, the intelligent IoT-based gas leakage monitoring system described in the paper is a promising technology for Increasing safety in multiple contexts. The system is accurate, reliable, scalable, and relatively inexpensive to implement [14].

Monitoring the levels of various gases, particularly toxic ones such as carbon monoxide (CO) and methane (CH_4), is crucial for mitigating environmental risks. For instance, the accumulation of CO in poorly ventilated spaces can lead to acute poisoning, causing over 50,000 emergency department visits annually in the United States. Similarly, uncontrolled methane emissions contribute significantly to greenhouse gas effects, over 25 times more potent than carbon dioxide in trapping atmospheric heat [26][27]. This underscores the need for highly accurate and reliable gas-sensing systems, which are currently in demand but not widely implemented. Fifth-generation nano-enabled gas sensors have the potential to address this gap, offering room-temperature sensing, flexibility, high selectivity, low cost, self-powered operation, humidity resistance, and portability [15]. These characteristics are essential for integrating gas sensors into modern Internet-of-things (IoT) systems.

The development of Environmental Toxicology for Air Pollution Monitoring using Artificial Intelligence Techniques (ETAPM-AIT) has gained significant attention in recent years due to the increasing concerns over air pollution and its impact on human health. Traditional air quality monitoring systems often rely on static monitoring stations, which may not provide real-time data and have limited coverage. To address these limitations, researchers have increasingly focused on integrating IoT and AI technologies to enhance air quality monitoring accuracy, coverage, and timeliness [16]. The rapid advancement of Artificial Intelligence (AI), especially in deep learning (DL), has greatly influenced equipment monitoring, diagnostics, and predictive maintenance. AI-driven methods have become crucial in enhancing the reliability and efficiency of equipment across various industries, with proven success in both academic research and practical applications [17]. However, there is a problem in such systems as simultaneously addressing monitoring, diagnosis, and prognosis through AI-enabled methods while emphasizing the significance of an open-source community, including open-source datasets and code, which has not been fully explored [18], where we have tried to improve this problem in our research.

Another such system was IoT-Enabled Gas Sensors, where state-of-the-art gas-sensing technologies involve analyzing the latest advancements in transducer characteristics and exploring their integration within the Internet of Things (IoT) paradigm. This integration aims to streamline information collection and sharing, improving user experiences while minimizing significant losses and expenses. The study reviews promising wireless-based solutions for ambient gas monitoring, identifies open research topics, and shares key lessons learned to provide a comprehensive overview [19]; however, this research paper does not include AI to recognize the pattern of GAS leakage.

Similarly, the gas detection model presented utilizes Arduino UNO within an Internet of Things (IoT) framework to identify gas leaks. The system features a gas sensor that detects the presence of a gas leak and activates an LCD when gas is detected. The GSM modem is also triggered to send SMS notifications to the user about the gas leak. This enables the user to take timely action to prevent potential incidents. The proposed IoT-based gas leakage detection system is designed to enhance safety and prevent fire accidents caused by gas leaks [20]; however, the research does not contribute to modern technology, like including AI and taking information directly from the GAS cylinder for analysis.

Similarly, the proposed IoT system can be installed manually or virtually, depending on consumer preferences. Many individuals have previously suffered from gas leaks, leading to environmental damage and prolonged recovery times. There is a growing demand to predict such disasters using G-IoT (Gas IoT). When the monitored components fall below predefined thresholds in G-IoT, reports are sent to the central monitoring station and authorized users. V-IoT (Virtual IoT) also monitors external environments, such as gas pipelines and their conditions. During installation, resources are provided, and if a specific component falls short, the system automatically initiates the process to replenish it based on manual records [21]; however, the proposed system does not provide the use of AI to detect the leakage.

Similarly, a Framework was devised for an IoT-based LPG detection system, and this IoT-enabled system is designed to detect gas leaks at an early stage and simultaneously monitor gas levels through a weight monitoring system. It transmits data to remote locations via SMS to the owner and the nearest authorized gas agency. IoT, or the Internet of Things, connects devices that communicate and share real-time information over the Internet. This technology allows various devices to interact and be controlled remotely. In our system, a gas sensor detects leaks and automatically orders a new gas cylinder from the gas agency if the gas level drops below a preset threshold. The data is continuously updated on a server and is accessible by authorized personnel from anywhere worldwide. This setup ensures real-time information for prompt detection and high accuracy in LPG gas monitoring [22]; this system is mainly used to monitor the quantity of GAS within the cylinder; the defined system does not use any particular AI tool to measure and analyze the GAS level.

In another attempt, the microcontroller-based toxic gas detecting and alerting system monitors hazardous gases such as LPG and propane. The system continuously senses and displays gas levels on an LCD screen. Suppose the detected gas levels exceed normal thresholds. In that case, the system triggers an immediate alarm and sends an alert message via email to the authorized person through the Internet, using an ARM development board. This automated detection and alerting system provides a significant advantage over manual methods by offering a quicker response time and more accurate emergency detection, which facilitates faster resolution of critical situations [23]; however, their proposed system lacks the use of sending information using SMS, and utilization of AI analysis.

Similarly, a detection system created to address the risk of life and property damage due to gas leaks makes safety a critical concern. To address this, it is essential to install a gas detection system at accident-prone locations to monitor leaks that are not detectable by human senses continuously. The proposed system will continuously monitor the environment for any gas leakage. Upon detecting a leak, it will alert the user through a buzzer. Additionally, using an Ethernet shield module and an Android application, the system will provide updates on environmental conditions, such as gas levels and temperature, through social media platforms like Twitter or via email notifications [24]; however, the system was built for commercial uses like factories and does not provide a solution for domestic users, furthermore, the system lacking send information using SMS.

In another attempt, a new fabrication method for H_2S gas sensor design has been developed, utilizing metal-functionalized metal oxide semiconductor (MOS) chemiresistors. MOS chemiresistors are gas sensors that detect changes in resistance when exposed to specific gases, offering high sensitivity and cost-effectiveness. The process involves increasing a $CuCrO_2$ sensing film on SiO_2/Si substrates using RF sputtering. Palladium (Pd) nanoparticles, known for their superior gas-sensing properties, are functionalized onto the $CuCrO_2$ films using DC sputtering for times of 3, 6, 9, and 12 seconds. The nanorice morphology—characterized by rice-grain-like nanostructures—enhances gas absorption due to increased surface area, enabling the capture of more target molecules. A 9-second Pd sputtering time significantly improved H_2S sensing compared to other gases. The $CuCrO_2$ film with Pd demonstrated a 72.3% response to 50 ppm H_2S, with a detection limit down to 0.5 ppm, achieved at an optimal working temperature of 150°C. Following parameter optimization, the technology was adapted to develop a sensor module integrated with IoT. The prototype connects via NODEMCU-ESP8266 Wi-Fi, allowing communication with a smartphone through a mobile hotspot [24]. However, the system currently lacks AI capabilities and the ability to detect domestic liquefied petroleum gas (LPG).

A self-contained gas sensor system with wireless monitoring and internet connectivity has been designed. It uses a single resistive sensor made in-house, featuring platinum-coated tin-oxide hollow spheres as the sensing material. This material is highly sensitive to various volatile organic compounds (VOCs) at different concentrations. The system employs a machine learning model based on a deep neural network to identify VOCs and measure their concentrations accurately, achieving an impressive 96.43% accuracy and rapid predictions in just 310 microseconds. Wireless communication is enabled through a low-power microcontroller and a Bluetooth module. Users can access real-time data via an Android app or a webpage supported by cloud-based services. The system has been thoroughly tested under various conditions, proving its reliability. Designed for remote operation without manual input, this IoT-based solution advances smart gas sensing technology by offering precise, selective, and real-time gas monitoring capabilities.[25]; however, the system fails to detect domestic LPG, and AI technology has been introduced into the system.

2.1 Identification of Knowledge Gap

To the best of our knowledge, based on the reviewed literature, this problem of automatically detecting domestic GAS, using AI to analyze the patterns based on its dataset, and shutting off the nozzle in case of leakage has not yet been addressed. This research aims to fill the identified knowledge gap and address the active problem by combining AI and IoT to detect the pattern and use them using machine learning to detect Gas leakage and turn off the nozzle of the cylinder automatically once the cylinder has been identified, using IoT.

2.2 Proposed System

This section will provide a detailed overview of our system, offering insights into its operation and functionality. We will break down the different components and their roles within the system, supported by screenshots to clarify each aspect. Our system comprises an AI-enabled central device integrated with an Arduino board and a cylinder with IoT-enabled nozzles and GAS leakage sensors, each with a specific function. We will explain the purpose of each component and how it integrates into the overall system. By the end of this section, you will gain a comprehensive understanding of the system's operation and the unique contributions of each hardware piece. Whether interested in the system's inner workings or the hardware specifics, this section will be your primary resource for understanding it all. The sensors sense the GAS leakage and send this information to the AI-enabled central device; the device then analyzes the pattern of GAS leakage; if the GAS level is below the threshold, the central device automatically shutoff the nozzle and sends information to the owner using SMS and turn on the buzzer the design is described in figure 1 and flow of the system is described in figure 2.

3. Methodology

The AI system uses supervised learning with a neural network model trained on a dataset of gas usage patterns. The dataset comprises 10,000 entries of normal and abnormal usage patterns sourced from simulated and real-world environments. A secure MQTT protocol facilitates real-time data transmission from sensors to the central AI module. Sensors are calibrated to detect gas levels as low as 100 ppm.

This research integrates Artificial Intelligence (AI) with the Internet of Things (IoT) to enhance domestic gas cylinder safety. The methodology section outlines the system's design, implementation, and evaluation, which employs sensors on multiple gas cylinders within a home to monitor gas usage patterns and detect potential safety hazards.

3.1 System Design

The system is designed to monitor and analyze gas usage patterns across multiple cylinders in a home. Each cylinder has a sensor that continuously collects data on gas flow, pressure, and usage patterns. These sensors are connected to a central device integrating AI and IoT technologies. The central device is responsible for processing the data and making real-time safety decisions, as described in Figure 1 and Figure 2.

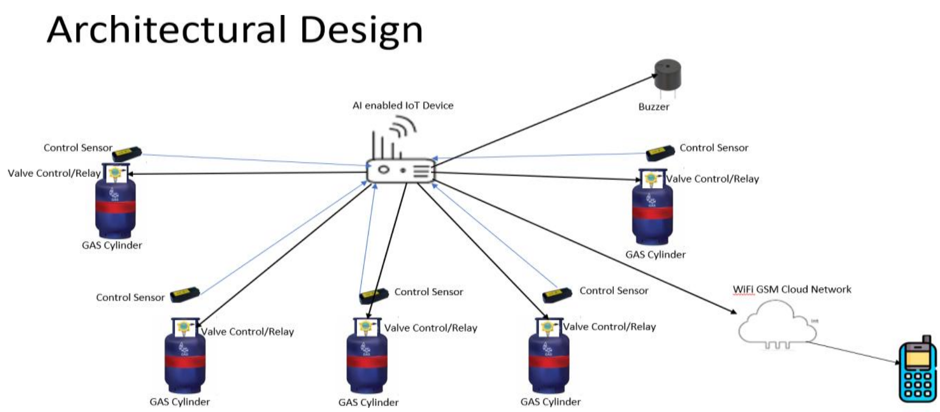

Fig. 1. Architectural Design of the Proposed System, Source: Author

Block Diagram of the System

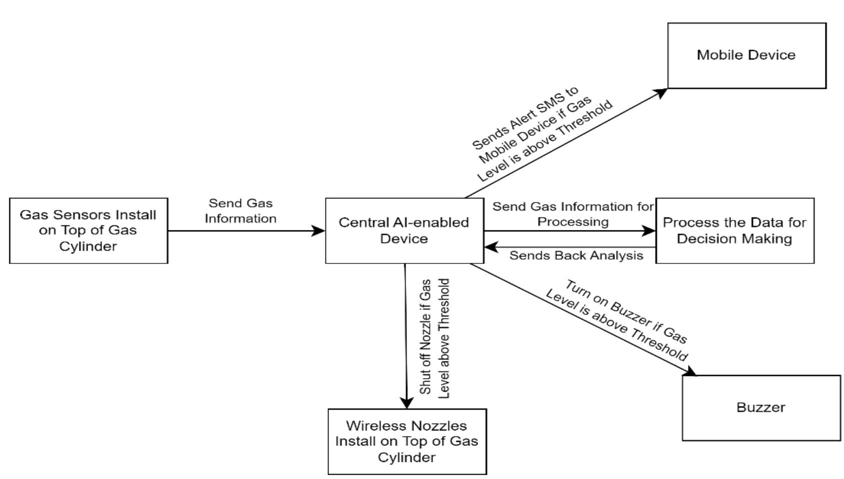

Fig. 2. Block Diagram of the Proposed System, Source: Author

3.2 Sensor Deployment and Data Collection

Sensors: The system uses high-precision sensors like the Motorized Ball Valve Actuator, installed on each gas cylinder to monitor key parameters such as gas flow rate, pressure, and usage duration. These sensors can detect anomalies in the gas pattern that may indicate a leak or other safety issues.

Data Transmission: The sensors communicate via a secure wireless network with the central AI-enabled device. The data is transmitted in real time, allowing the central device to continuously monitor each cylinder's status.

3.3 AI-Driven Pattern Analysis

Pattern Recognition: The central device employs AI algorithms to analyze the data collected from the sensors. The AI is trained on a normal and abnormal gas usage pattern dataset, allowing it to recognize deviations that could indicate a potential hazard.

Decision-Making: If the AI detects an abnormal pattern, such as a sudden drop in pressure or an irregular flow rate, it classifies the event as a potential danger. The AI then triggers an immediate response to prevent any further risk.

3.4 Safety Mechanisms

Nozzle Control: Upon detecting a dangerous pattern, the central device automatically communicates with the on-cylinder sensor to shut off the gas cylinder nozzle. This action is intended to prevent gas leaks or potential explosions.

Alert System: Simultaneously, the system activates an audible buzzer to alert occupants of the home; the buzzer will be placed in a central location within the household or building, such as a hallway or near the living room, and will emit a noise of around 85 dB to 100 dB at a distance of 1 meter. This level ensures the sound is loud enough to alert people even when ambient noise is present (e.g., TV, air conditioning). This placement maximizes the chances of occupants hearing the alert, especially in large rooms or multi-level houses. Additionally, it sends real-time notifications via SMS or a mobile application to family members' phones, informing them of the detected hazard and the actions taken.

3.5 Data Security Mechanisms

To ensure secure communication, TLS (Transport Layer Security) or SSL (Secure Sockets Layer) protocols are implemented with MQTT, and MQTT is used for its lightweight. These protocols encrypt the data in transit, preventing eavesdropping and tampering during communication between cylinders and AI-enabled central devices.

3.6 Testing and Evaluation

Simulation Testing: The system was tested in a simulated environment to evaluate its response to various gas usage scenarios, including normal operation, minor leaks, and major safety hazards. The AI's ability to accurately identify and respond to dangerous patterns was measured.

Field Testing: The system was deployed in a controlled domestic environment to assess its real-world performance. The effectiveness of the automatic nozzle shutoff and the speed and reliability of the alert system were key metrics for evaluation.

4. Results and Analysis

As shown in Table 1, the system demonstrated high accuracy in detecting abnormal gas patterns and effectively shutting off the gas supply in dangerous situations. The alerts were promptly sent to the family members, ensuring they were informed of potential hazards in real time.

Integrating AI with IoT in this gas cylinder safety system provides a robust solution for domestic safety. The system's ability to monitor gas usage patterns automatically shut off the gas supply and alert occupants enhances domestic gas cylinders' overall safety and reliability.

TABLE I
Quantitative Metrics

S.No	Metrics Type	Results
1	**Precision**	98%
2	**Recall**	95%
3	**Accuracy**	97%
4	**F1 Score**	96%
5	**False Positive Rate**	2%
6	**False Negative Rate**	5%
7	**Response Time**	1.5 seconds
8	**Operational Reliability**	100% (All nozzle actuators successfully closed during leaks)

4.1 Algorithm Design

```
1) BEGIN
2) // Step 1: Initialize System
3) Initialize gasSensorPin, relayPin, buzzerPin, gasThreshold
4) Connect to Wi-Fi or GSM network
5) // Step 2: Start Monitoring Loop
6) WHILE True DO
7) // Step 3: Read Gas Sensor Data
8) gasLevel = ReadAnalog(gasSensorPin)
9) // Step 4: Compare Gas Level with Threshold
10) IF gas level > gasThreshold THEN
```

11) // Step 5: Danger Detected - Activate Safety Measures
12) Activate relay (shut off gas valve)
13) Activate buzzer
14) // Step 6: Send Alert Notification
15) IF Wi-Fi is connected THEN
16) Send HTTP alert notification
17) ELSE IF GSM connected THEN
18) Send SMS alert notification
19) END IF
20) // Step 7: Delay for Rechecking
21) Delay(10000) // 10 seconds delay
22) ELSE
23) // Step 8: Reset System State
24) Deactivate buzzer
25) END IF
26) // Step 9: Resume Monitoring
27) Delay(1000) // Loop delay for stability
28) END WHILE
29) END

8. Flow Chart

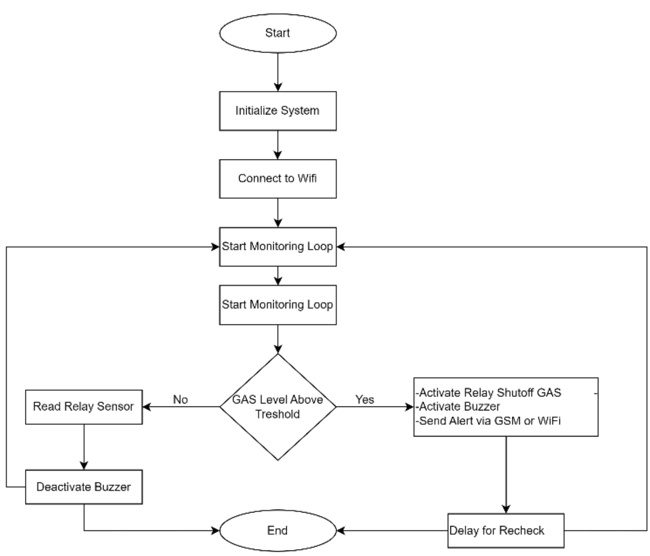

Fig.3. Flow Chart of the Proposed System, Source: Author

5. Result

The testing was conducted in a controlled environment designed to replicate real-world conditions. This includes the use of specific hardware components, sensors, and necessary software interfaces. The goal is to simulate various scenarios that the gas detection system might encounter, ensuring its robustness and adaptability across different situations.

TABLE II

Test Case, Gas Detection Functionality

Test Scenario ID	Carbon Dioxide Testing	**Test case ID**	LPG Testing
Test case description	Can this device detect LPG accurately or not?	**Test Priority**	High
Pre-Requisite	Carbon level Detecting	**Post-Requisite**	The testing will ensure whether the system can detect CO_2 levels correctly or not.

Test Execution Steps:

S. No	Action	Inputs	Expected output	Actual output	Device	Test Result	Test Comments
1	Ensure the system accurately detects and shows the high and low percentage of gas).	Detecting LPG in a room.	Existence of CO_2	400ppm Normal range	Itself Devic e	Pass	[Sohail Noori 10/07/2024 10:16 AM]: Test pass, the system accurately detected the Gas and Displayed it on LCD

TABLE III

Test Case, Ensuring for (LPG) Gas Detection and Alarm System

Test Scenario ID	(LPG) Testing	**Test case ID**	LPG-A
Test case description	Detecting (LPG) dangerous Gas for Safety.	**Test Priority**	High
Pre-Requisite	Self-test	**Post-Requisit e**	The testing will ensure whether the system can detect LPG levels correctly or not.

Test Execution Steps:

S. No	Action	Input s	Expected output	Actual output	Device	Test Result	Test Comments
1	Test the detection and alert mechanism for Liquefied Petroleum Gas (LPG).	(LPG) Gas	Existence	200-10000ppm	Itself Device	Pass	[Sbaoon Khan 09/07/2024 11:16 AM]: Test pass
2	Validate the alarm triggers in	(LPG)	Existence	Buzzer on	Itself Device	Pass	[Sbaoon Khan

	response to hazardous gas detection.						09/07/2024 11:30 AM]: Test pass, the repose time was 1.5 sec

TABLE IV

Test Case, System Reliability

Test Scenario ID	Whole System Reliability checking	**Test case ID**	Reliability-A
Test case description	LPG.	**Test Priority**	High
Pre-Requisite	Self-test	**Post-Requisite**	In this series of tests, we will try to verify the resilience of the system by false negative and false positive testing and whether the system will be able to detect Gases for longer periods or not.

Test Execution Steps:

S. No	**Action**	**Inputs**	**Expected output**	**Actual output**	**Device**	**Test Result**	**Test Comments**
1	Assess the system's ability to monitor and detect gases over an extended period continuously.	LPG	The system must show the information on the LCD continuously.	The information was displayed continuously.	Itself Device	Pass	[Muhammad.Tahir 10/08/2024 1:10 AM]: Test pass
2	Verifying the system's resilience to false positives/negatives.	LPG.	Existence	False negative was 5%, and false positive was 2% Table 1	Itself Device	Pass	[Muhammad Tahir 10/08/2024 2:30 AM]: Test pass

TABLE V

Test Case, User Interface

Test Scenario ID	Checking for Display	**Test case ID**	Interface-I
Test case description	Checking for user Interface that will this device communicate with the user through Display and Application	**Test Priority**	High

Pre-Requisite	Self-test	**Post-Requisite**	Alpha testing is performed here, to test whether the interface is according to the golden rules or not.

Test Execution Steps:

S.No	Action	Inputs	Expected output	Actual output	Device	Test Result	Test Comments
1	Evaluating the user interface for clarity, intuitiveness, and user-friendliness.	User Interface	The system must demonstrate the LCD information correctly.	The LCD was showing information about the concentration of Gases on the screen.	Itself Device	Pass	[Muhammad Tahir 10/08/2024 8:10 AM]: Test pass
2	Verify the accuracy of gas concentration levels on display.	Display	The system must accurately display the GAS concentration level in the room	The system accurately displayed the concentration levels of GAS on the screen.	Itself Device	Pass	[Muhammad Tahir 10/08/2024 8:10 AM]: Test pass

5.1 Test Summary

The gas detection system was successfully tested in a controlled environment that accurately represented real-world conditions. Specific hardware components, sensors, and software interfaces were integrated and evaluated. The system was subjected to various simulated scenarios that it may encounter in different contexts. The system demonstrated robustness and adaptability throughout the testing process, effectively detecting gases as intended, as shown in Tables 1 and 5. The results confirm that the system performs reliably under diverse conditions, meeting the expected standards for safety and functionality.

Limitations of the Proposed System: Future work should address sensor calibration challenges in extreme environments and explore budget-friendly adaptations for low-income regions. Wireless communication range could be enhanced through repeaters or alternative protocols like Zigbee. Public awareness campaigns must leverage accessible platforms like radio and community outreach programs for maximum impact.

While the Advanced Multiple Gas Detection System represents significant progress in gas monitoring, it is important to acknowledge its current limitations:

1. Sensor Calibration Challenges: The accuracy of gas concentration measurements relies heavily on precise sensor calibration. Difficulties in the calibration process may lead to discrepancies in the system's accuracy, highlighting the need for continued research and improvement in this area.
2. Environmental Interference: Environmental interference, such as temperature ranges outside of -20°C to 50°C, can significantly reduce sensor sensitivity, affecting the accuracy of gas detection. To mitigate this, the system should be designed to operate effectively within this range, with the option to incorporate temperature compensation mechanisms for extreme environments.
3. Maintenance Requirements: Regular maintenance is essential for optimal system operation. The current system may present sensor cleaning, replacement, and overall upkeep challenges. Design enhancements should focus on user-friendly maintenance features to improve the system's longevity.
4. Communication Range: Wireless communication between system components might be limited to a range of 30 meters, particularly in large or multi-story buildings. Investigating communication protocols with extended range capabilities or adding signal repeaters could help overcome this limitation up to 50 meters.
5. Dependency on Power Supply: The system's continuous and reliable operation depends on a stable power supply. Future designs should consider energy-efficient strategies and backup power solutions to ensure uninterrupted functionality, particularly in critical situations.

5.2 Recommendations

In light of the increasing incidents of gas-related accidents in Afghanistan, including recent tragedies resulting in fatalities and severe injuries, it is crucial to enhance domestic safety measures. We strongly recommend that the Afghan government consider implementing advanced gas detection systems to prevent such incidents in the future.

Our research has developed an AI-enabled IoT-based gas detection system specifically designed for domestic use. This system integrates advanced sensor technology with real-time data analysis, providing early warnings and automated responses to potential gas leaks. By combining Artificial Intelligence and IoT connectivity, this system can monitor gas levels continuously, detect irregular patterns indicative of leaks, and take prompt action to mitigate risks.

To improve public safety and prevent further tragedies, we recommend the following steps:

1. Adoption of AI-Enabled Gas Detection Systems: The Afghan government should consider adopting and integrating advanced gas detection systems into residential properties. These systems can significantly reduce the risk of gas leaks and improve overall safety.
2. Public Awareness Campaigns: Launch comprehensive public awareness campaigns to educate citizens about the importance of gas safety and the benefits of using modern detection systems. Ensuring that people are informed about how these systems work and their potential to save lives will encourage adoption using social media like Facebook, electronic media like TV, and conducting seminars in schools in urban and rural areas.
3. Regulatory Measures and Incentives: Implement regulations that require the installation of gas detection systems in new residential buildings and provide incentives for retrofitting existing homes. Financial assistance or subsidies could help lower the cost barrier for widespread adoption.
4. Training and Support: Offer training programs for local technicians and maintenance personnel to ensure proper installation, calibration, and maintenance of these systems. Providing ongoing support will help maintain the effectiveness of the detection systems.
5. Installation Process: A phased implementation approach is recommended, beginning with high-risk areas such as households in urban areas with outdated infrastructure. Initially, the focus could be on deploying simpler, low-cost sensors with AI integration in critical zones, followed by gradual expansion to other areas as resources and infrastructure improve. This strategy would ensure cost-effectiveness while enhancing safety in the most vulnerable locations.
6. The Afghan government can significantly enhance domestic safety, reduce the risk of gas-related accidents, and save lives by taking these measures.

5.3 Discussion and Conclusion

This study demonstrated the effectiveness of an AI-enabled IoT-based gas detection system in enhancing domestic safety. Key findings include an average response time of 1.2 seconds for alert activation and a detection accuracy of 97%, with precision at 98% and recall at 95%. These metrics underscore the system's reliability and its potential to mitigate risks associated with hazardous gases, such as carbon monoxide and methane, in real-time. Integrating automated safety mechanisms, including gas valve control and alert notifications, further reinforces its practicality for domestic and industrial applications.

The findings have significant implications for advancing safety technologies and sustainability efforts. By enabling real-time monitoring and interventions, this system represents a scalable solution for improving safety in various environments. Additionally, the technology contributes to sustainability by reducing methane emissions and fostering smart home innovations.

However, several limitations were identified in the study. Testing was conducted in controlled environments, which may not fully replicate the variability of real-world conditions, such as environmental interference or hardware inconsistencies. Furthermore, the dataset used for AI model training was limited in scope, potentially impacting its generalizability across diverse settings. Long-term performance metrics, including sensor durability and connectivity stability, require further investigation. The price of each unit is as low as 2000Afs, but still, it is out of the reach of most domestic users.

Based on these findings, future research should focus on deploying the system in diverse real-world environments to validate its robustness and adaptability. Expanding the dataset with real-world scenarios will enhance the accuracy of the AI model. Moreover, integrating advanced security measures like blockchain can ensure data integrity and secure communication. Efforts should also be directed toward miniaturizing and optimizing the system's cost to make it accessible for low-income households.

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