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Development of a Gas Leakage Detection and Alert System for Enhanced Safety

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Abstract

This study aimed to design and develop a gas leakage detection and alert system to enhance safety in residential, industrial, and transportation settings. The system was developed using an MQ-5 gas sensor, Arduino Nano microcontroller, LED indicators, GSM module, and a 16x2 LCD display. Simulated gas leaks were introduced to test the system's performance under various environmental conditions, including humidity and temperature variations. The system demonstrated consistent performance in detecting hazardous gases like LPG and methane, triggering alerts within 2-5 seconds of the gas detection. It maintained accuracy across various environmental conditions, including humidity levels ranging from 30% to 90% and temperatures from 0°C to 37°C at Effurun region of Delta State. The system showed high robustness and adaptability to different operating conditions without compromising detection accuracy or alert response time. It seamlessly switched to battery backup during power outages, ensuring continuous operation for up to 6 hours. The developed system has significant implications for enhancing safety in various settings, including residential, industrial, and transportation. Its ability to detect hazardous gases and trigger alerts in real-time can help prevent accidents and minimize risks. The system's robustness and adaptability make it a reliable solution for gas leakage detection and alerting.

Keywords: *MQ-5 gas sensor, Arduino Nano microcontroller, LED indicators, GSM module, 16x2 LCD display.*

1. INTRODUCTION

The design and construction of gas leakage detection and SMS alert systems have become increasingly critical due to rising safety concerns associated with the use of flammable gases, such as Liquefied Petroleum Gas (LPG) [1-2]. These systems are essential in preventing accidents that could lead to property damage, injuries, or loss of life [3]. Gas detection is a crucial safety measure integrated into the safety systems of oil and gas facilities, as well as other industrial facilities [4]. The primary function of gas detection device is to detect combustible, flammable, and toxic gases, ensuring a safe working environment [5].

Gas detector comes in two forms: fixed type and portable type. Gas detection monitors oxygen consumption in underground areas, such as gold mines and coal mines, to prevent reduced oxygen levels that can cause dizziness, brain damage, or even death. It also plays a vital role in firefighting, enabling responders to identify potential hazards and take necessary precautions [6]. It can trigger warning or evacuation alarms, alerting operators to potential gas leaks and providing them with crucial time to evacuate the premises. By incorporating gas detection into safety systems, industrial facilities can ensure a safer working environment, mitigate risks, and protect lives [7]

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Several advances in sensor technologies and detection mechanisms already [8-13]. Sensor technology forms the backbone of gas leakage detection systems, with most designs relying on the MQ series of gas sensors, such as MQ-2 and MQ-5. These sensors detect gas concentrations and convert them into electrical signals that trigger alarms. Research has highlighted the sensitivity and cost-effectiveness of the MQ-5 sensor when used with microcontrollers for real-time gas monitoring [14]. The sensors operate by detecting significant changes in resistance of concentration of gases in the air. The change in the resistance is converted into voltage signals that can be processed by a microcontroller. Studies have demonstrated that incorporating multiple sensors, such as temperature and pressure sensors, can enhance detection reliability and minimize false alarms [15]. This multi-sensor approach ensures a more comprehensive analysis of environmental conditions, reducing instances of incorrect alerts.

More advanced systems have incorporated flame detection sensors alongside gas sensors to provide dual protection against gas leaks and fire hazards [16]. Additionally, the integration of artificial intelligence (AI)-based algorithms is gaining traction, allowing systems to analyse sensor data patterns and predict potential gas leaks before they occur. This predictive capability introduces a proactive safety approach, shifting the focus from reactive measures to prevention. Reliable communication systems are vital for prompt responses to gas leaks. Traditional systems utilize GSM modules to send SMS alerts to predefined mobile numbers upon detecting a gas leak. Research has demonstrated the effectiveness of combining microcontrollers and GSM modules for instant notifications, enabling swift action to prevent disasters [17].

The growing adoption of IoT-enabled systems has broadened alert coverage by sending notifications via multiple channels, including email and mobile applications [18]. This approach enhances the reach and speed of notifications, particularly in environments where rapid communication is essential. IoT integration also enables remote monitoring, allowing users to access real-time gas level data and system status through mobile applications.

In [19], the researchers failed to identify the machine learning algorithms that are most effective for predicting methane emissions. It focuses on using machine learning to calibrate metal oxide sensors for accurate methane mixing ratios, demonstrating good agreement with trace gas analyser results. This approach is more theoretical than practical.

However, many IoT-enabled systems require stable internet connectivity, which may not always be available in remote or underdeveloped areas. This presents a gap in ensuring reliable communication in such locations, necessitating the development of alternative low-bandwidth communication solutions. Automation significantly enhances the safety and efficiency of gas detection systems by reducing human intervention. Many systems incorporate solenoid valves that automatically shut off the gas supply upon detecting a leak, minimizing the risk of explosions and fires. Advanced designs integrate with Building Management Systems (BMS), enabling coordinated emergency responses such as fire suppression activation and emergency service notifications [20].

In [21], the Extreme Gradient Boosting model using machine learning algorithm for predicting methane emissions was carried out, the model outperforms other models with a superior fit, minimal errors, and an accuracy of 95% in quantifying ground-level methane concentrations. However, implementation of the approach could be capital intensive.

In [22], the Smart Fault Detector Robo employs advanced gas sensors to detect harmful gases like methane and carbon monoxide, ensuring precise identification of potential hazards.

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While the paper does not explicitly mention flame detection sensors, it highlights the use of sophisticated AI algorithms for real-time data analysis, distinguishing normal fluctuations from threats. This capability enhances safety by enabling early identification of gas leaks and fire incidents, promoting a proactive approach to safety rather than merely reactive measures. However, the scheme cannot detect other gases other than the gases mentioned.

In [23], MQ-5 gas sensors feature high sensitivity to natural gas and LPG, utilizing a tin dioxide (SnO2) sensitive layer. Compared to other gas sensors, they offer rapid response but have low selectivity, limiting their effectiveness in mixed gas environments. However, when the target is to detect liquefied petroleum gas and carbon IV oxide, the MQ-5 serves the purpose very well. The choice of MQ5 sensors for this work is based on:

- Its ability to exhibit high sensitivity to methane and LPG, making them suitable for domestic and industrial applications.
- They provide a quick response, essential for timely detection of gas leaks.
- The sensor operates effectively within a concentration range of 300 to 10,000 ppm for methane and 200 to 10,000 ppm for LPG [18].
- MQ5 can be integrated with microcontrollers like Raspberry Pi for real-time monitoring and data logging [18].

While automation has advanced, there is still a gap in making these systems more accessible and affordable for smaller businesses and residential users. Furthermore, many systems lack redundancy features to ensure continued operation during power outages, posing a risk in critical situations. Addressing this issue involves developing low-cost, battery-powered systems with fail-safe mechanisms to maintain continuous functionality. However, many existing systems still lack these advanced predictive features, particularly in lower-cost models, limiting their capacity for early detection and intervention. Addressing these limitations is crucial for developing more effective and reliable gas leakage detection and SMS alert systems.

The authors in [24], developed automatic gas leakage detection system with 300 parts per million threshold value. Although the authors claim that the system works very well but they system cannot detect gas leakage whose ppm is 460ppm. Again, the work did not consider various environmental conditions.

This study ensures that with no reasonable concentration of the gases, the system does no operate.

2. METHODOLOGY

The system is designed to detect gas leaks using sensors. It processes the data through a microcontroller, and trigger both local and remote alerts. The core functionality revolves around the seamless interaction between hardware components (sensors, microcontroller, GSM module) and the software that controls them.

2.1 Materials and Method

Each component was carefully selected to ensure functionality, reliability, and cost-effectiveness. The components used are as shown in Figure 1: The LCD used is a 2x 16 character which means 2rows and 16 columns. It has 16 connector pins. It was designed by the manufacturer. Owing to the environmental variations in the concentration of the gases, the

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threshold setting for the gas detection was chosen to be 760 parts per million. Thermometer was used to obtain the temperature of the surrounding. The block diagram of the set-up is shown in Figure 1. Each component in the block diagram was connected to the circuit diagram as shown in Figure 2

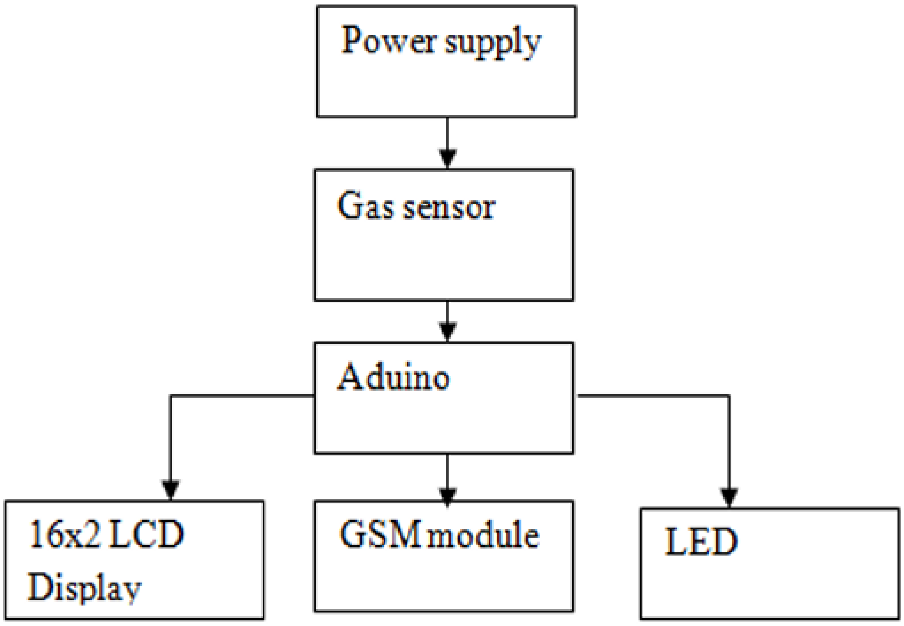

Figure 1: Block diagram representing the system architecture

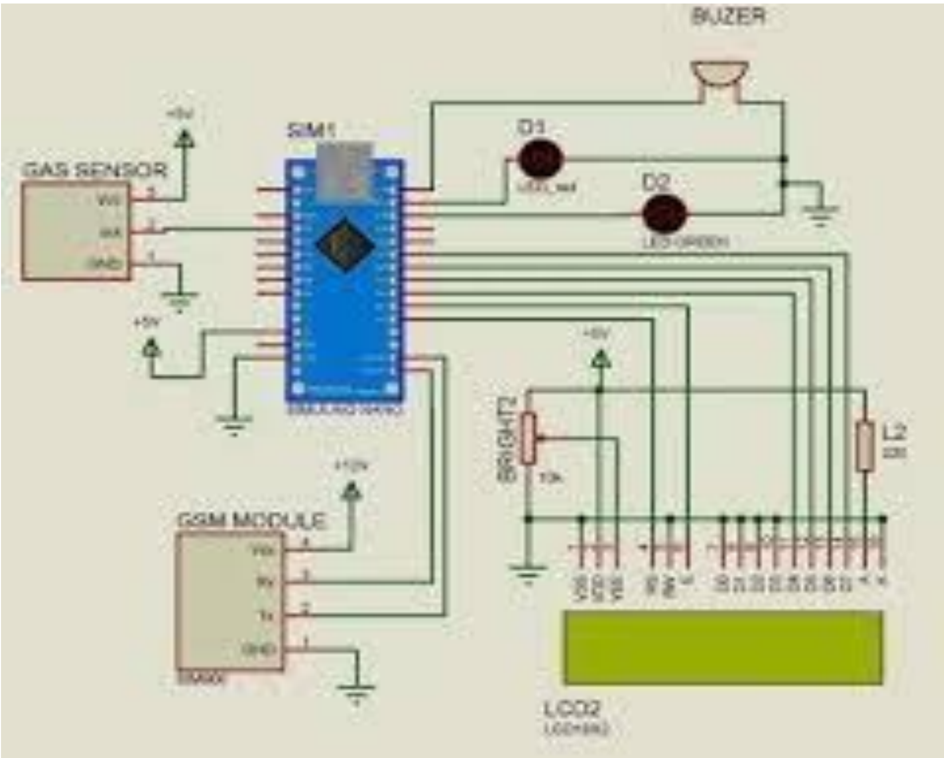

Figure 2: Circuit diagram of the gas leakage detection and alert system

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The circuit diagram of the gas detection and alert system illustrates the interconnection of various components that work together to detect gas leaks and send SMS notifications. At the heart of the system is the microcontroller, which acts as the central processing unit. It receives input from the gas sensor, processes the data, and triggers the appropriate output devices. The gas sensor, typically an MQ5, is responsible for detecting the presence and concentration of specific gases such as LPG, methane, and butane.

It converts the detected gas concentration into an electrical signal that the microcontroller can interpret. The microcontroller is programmed to monitor the sensor's output continuously. When the gas concentration exceeds a predefined threshold (760PPM), the microcontroller activates the output devices. These devices include a LED indicator, which provide immediate local alerts.

The LEDs flash to visually warn nearby individuals about the gas leak. The microcontroller also sends a signal to the GSM module, instructing it to transmit an SMS alert to predefined phone numbers (+2347040371456 and +2347088410181). This ensures that users who are not in the vicinity of the system are informed about the potential danger in real time.

The GSM module is connected to the microcontroller via communication pins, enabling seamless data exchange. It uses a SIM card to access mobile networks and send SMS notifications. The message content, recipient numbers and other configurations are predefined in the microcontroller's code. This integration ensures reliable communication between the hardware components and the user.

Additionally, an LCD module is connected to the system to display real- time information such as the gas concentration levels and system status. This enhances user interaction by providing clear and concise information about the current state of the system. The entire circuit is powered by a regulated power supply, typically a 12V adapter.

This ensures that all components receive stable and sufficient power for optimal operation. To protect the circuit from power fluctuations, voltage regulators are used to maintain a steady voltage output. Connecting wires and a Vero board are employed to establish secure connections between components, ensuring proper current flow and signal transmission. The components are housed in a durable enclosure to protect the system from physical damage and environmental factors.

2.2 System Integration

System integration is a crucial phase in the development of the gas leakage detection and SMS alert system. It involves combining all hardware and software components into a cohesive unit to ensure seamless communication, real-time data processing, and reliable alert generation. This phase focuses on the interaction between the microcontroller, sensors, GSM module, and output devices, ensuring that each component works harmoniously to deliver the desired functionality.

The hardware-software interface defines how the physical components interact with the software logic to perform specific tasks. This integration ensures that sensor readings are accurately processed, and appropriate actions are triggered. The flow chart for the gas detection system is shown in Figure 3.

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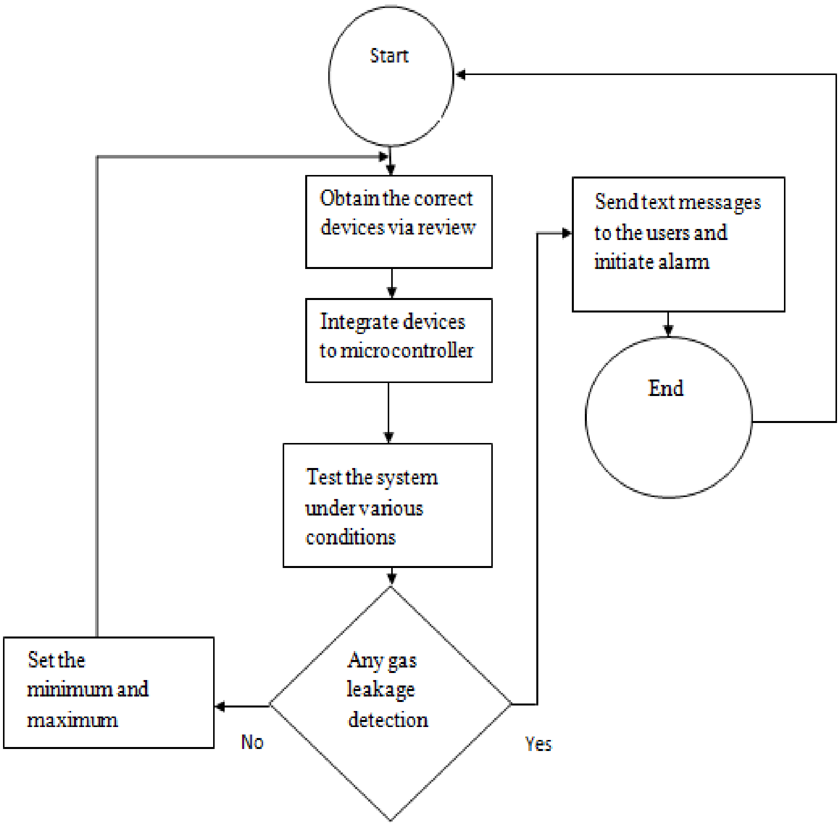

Figure 3: Flow chart of gas detection and alert system

3. RESULTS AND DISCUSSION

The Figure 4 shows the internal layout of the gas leakage detection system. This image highlights the placement of the gas sensor, Arduino Nano, GSM module, and LCD display within the enclosure.

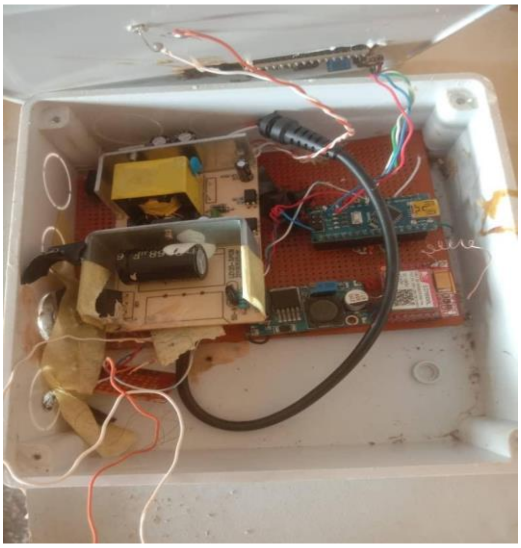

Figure 4: Internal view of the system components

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The components were housed in a robust plastic enclosure, designed to protect the system from environmental factors such as dust, moisture, and mechanical impact. Also, ventilation openings were strategically placed to prevent overheating, particularly near the gas sensor and microcontroller, to ensure reliable operation over extended periods. The enclosure was designed with access panels for easy maintenance, allowing users to replace or recalibrate components without dismantling the entire system. Figure 5 shows the fully assembled gas leakage detection system. The compact and durable enclosure ensures protection from environmental factors, while providing ventilation for reliable sensor performance

Figure 5: External view of the system components

Before integrating all components into the final system, each element was subjected to rigorous testing to ensure it functioned correctly. The testing process was divided into individual component testing and full system integration testing. After verifying each component's functionality, they were integrated into a complete system. The microcontroller was programmed to process gas sensor data and trigger appropriate outputs. The integrated system was tested under simulated gas leak conditions.

When gas levels exceeded the threshold, the buzzer, LED, and LCD responded immediately, and SMS alerts were successfully sent to designated mobile numbers. The testing confirmed that all components worked in harmony, with no issues related to connectivity, power supply, or signal interference. The system's software was developed and uploaded to the Arduino Nano to manage the detection and alert processes. The software handled real-time sensor data processing, decision-making, and communication with output devices.

The code was written in C/C++ using the Arduino IDE, utilizing libraries for the LCD display, GSM communication, and I2C interface. Key functions included reading gas concentration data, comparing it to predefined thresholds, activating alerts, and sending SMS messages. The program operated in a continuous loop to ensure constant monitoring, with quick response times when gas levels exceeded the safe threshold. Initial testing revealed minor bugs, such as incorrect handling of SMS commands and delays in sensor data processing. These issues were resolved through code adjustments and optimizations. Validation tests involved simulating gas leaks to ensure the system responded as expected. The microcontroller

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accurately processed sensor data, triggered alerts, and sent SMS notifications without any noticeable lag. The final system operated reliably, with the LCD displaying real-time gas levels, the LED activating immediately upon detection, and SMS alerts consistently delivered.

This section presents the results of the performance testing conducted on the gas leakage detection and SMS alert system. The testing was designed to evaluate the system's reliability, accuracy, response time, and alert mechanisms under various conditions. The tests were carried out in controlled environments with different gas concentrations and simulated operational scenarios to ensure the system meets its safety and functional requirements. Figure 5 illustrates the system displaying the gas level as 'Normal' on the LCD screen during testing. This indicates that the gas concentration is within safe thresholds, showcasing the system's ability to monitor environmental conditions accurately.

Figure 6: LCD displaying 'Gas Level Normal' during testing

Once the gas concentration exceeded the threshold, the system was monitored to confirm the activation of the buzzer, LED indicators, and SMS alert. The LED activated within 2 seconds of detection, providing immediate audio-visual alerts. SMS alerts were successfully sent with an average delivery time of 5 seconds, ensuring timely notifications. The MQ-5 sensor's accuracy and sensitivity were evaluated to ensure reliable gas detection: The sensor readings were compared to a reference gas analyzer across different concentrations of LPG and methane. The average deviation was less than 5%, indicating high accuracy. The sensor showed high sensitivity to LPG and methane, with rapid response times.

However, the sensitivity decreased slightly in detecting lower concentrations, highlighting the need for regular calibration. False positives (detection when no gas was present) occurred at a rate of 2%. False negatives (failure to detect gas when present) were not found, indicating reliable sensor performance. The results are interpreted in the context of the study's objectives, highlighting the system's strengths and areas for improvement. Additionally, the system's performance is compared with existing gas leakage detection solutions, and the extent to which it addresses gaps identified in the literature is discussed. The system demonstrated a high level of accuracy in detecting combustible gases such as LPG and

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methane. The MQ-5 sensor consistently detected gas concentrations above the set threshold (760PPM) with high accuracy. This confirms the system's effectiveness in identifying hazardous gas levels and initiating safety measures promptly. The sensor's fast response time (within 2 seconds) further enhances the system's reliability in real-time applications, making it suitable for both residential and industrial environments. The combination of audio-visual alerts (LED) and SMS notifications ensures that users are promptly informed of gas leaks. The LED provided immediate local alerts, while the GSM module successfully delivered SMS notifications within an average of 5 seconds. This dual-alert mechanism enhances safety by ensuring that both on-site occupants and remote users are informed quickly, reducing the likelihood of accidents or delays in response.

The gas leakage detection and alert system demonstrated exceptional performance, accuracy, and reliability in detecting combustible gases, making it an ideal solution for residential and industrial environments. The dual-alert mechanism, comprising LED indicators and SMS notifications, ensures timely and effective notification of gas leaks, thereby enhancing safety. The system's robustness, adaptability, and resilience to environmental changes, including humidity and temperature fluctuations, underscore its reliability and effectiveness in various operating conditions. Furthermore, its ability to seamlessly transition to battery backup during power outages ensures uninterrupted operation for up to 6 hours, which is critical for maintaining safety in areas prone to power failures. Overall, this study successfully developed and tested a gas leakage detection and alert system that offers a reliable, efficient, and effective solution for enhancing safety in various environmental conditions. The gas leakage levels under different environmental conditions is shown in Table 1.

Table 1: Gas leakage level under various conditions

S/N	PPM	Buzzer	SMS ALERT	Signal response
1	460	OFF	NO	No gas leakage observed
2	760	OFF	NO	No gas leakage observed
3	1600	ON	YES	Gas leakage observed
4	2000	ON	YES	Gas leakage observed
5	2400	ON	YES	Gas leakage observed
6	2800	ON	YES	Gas leakage observed
7	3200	ON	YES	Gas leakage observed
8	3600	ON	YES	Gas leakage observed

From Table 1, the gas concentration is measured in part per million (ppm). The two scenarios or conditions that represent no gas leakage observed occurred at 460 PPM and 760 PPM. A concentration of 460 ppm signifies False Positives (FP) detection. It takes place when no reasonable concentration of the gases is to be detected. The False Negatives (FN) represents failure to detect gas when it is present. This scenario was not encountered, indicating reliable sensor performance as espoused in the Table 1 and Figure 1, and Figure, With the introduction of LPG and methane, butane, the overall concentration of the gases increased to 1600PPM leading to the dual alert mechanism.

3.1 Experimental data on gas distribution with temperature variation

The testing was first carried out in the morning with temperature variation from 23^0C to 28^0C. The experimental trial was validated in the afternoon when the temperature hovers from 33^0C to 34^0C. It took 150 seconds for the concentration of the gases to stabilize under different environmental conditions. The experimental trials on gas distribution were carried out when the temperature of the surrounding is low (morning) and high (afternoon). The gas

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concentration fluctuates from the range of 200PPM to 760PPM in the morning time and 460 to 760PPM in the afternoon time. As the concentration of the gases increased with gas lighter at 150seconds, the concentration becomes saturated and the variation of the concentration with time stabilized as can be seen in Figures 7 and 8.

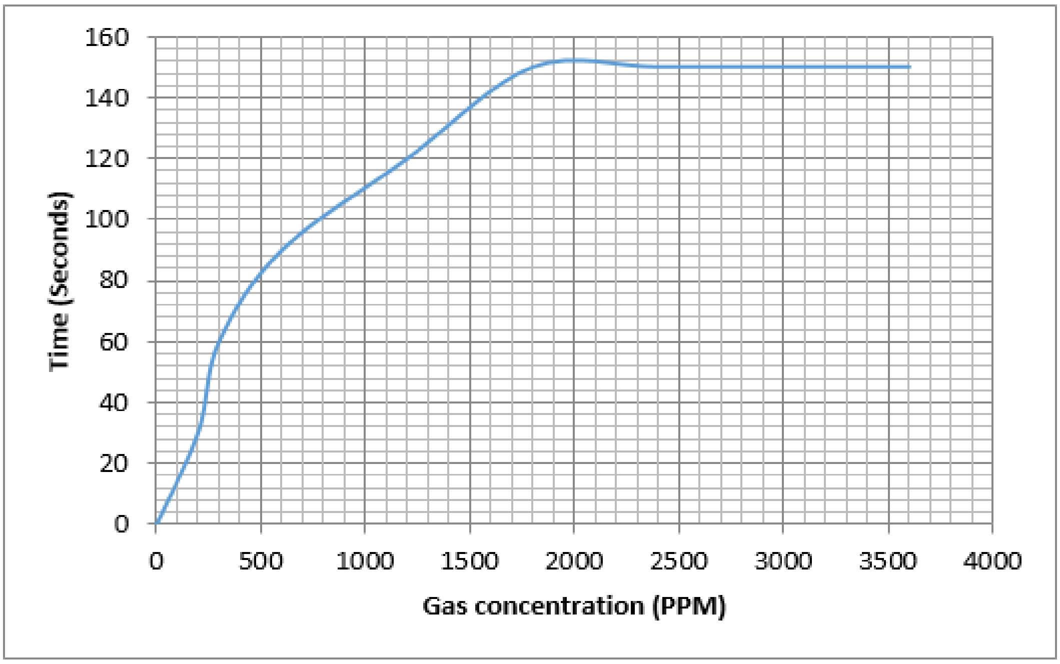

Figure 7: Experimental data on gas distribution flow rate with increase in temperature (morning)

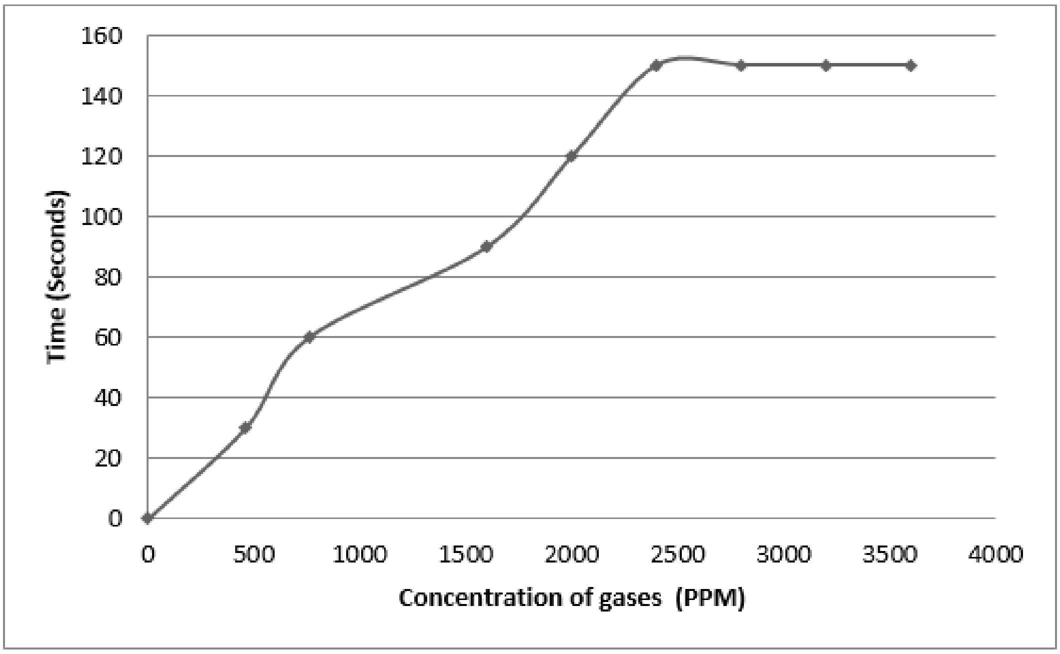

Figure 8: Experimental data on gas distribution flow rate with increase in temperature (afternoon)

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4. CONCLUSION

The experimental validation of the gas leakage detection system at various environmental conditions (28^{0}C in the morning and 34^{0}C in the afternoon) shows that the gas leakage detection and alert system work very well. The time of response of the systems to the presence of the specified gases and the response of the system to the low concentration of the gases demonstrated exceptional performance, accuracy, and reliability in detecting combustible gases.

This makes it an ideal solution for residential and industrial environments. The dual-alert mechanism, comprising LED indicators and SMS notifications, ensures timely and effective notification of gas leaks, thereby enhancing safety. The system's robustness, adaptability, and resilience to environmental changes, including humidity and temperature fluctuations, underscore its reliability and effectiveness in various operating conditions.

Furthermore, its ability to seamlessly transition to battery backup during power outages ensures uninterrupted operation for up to 6 hours, which is critical for maintaining safety in areas prone to power failures. Overall, this study successfully developed and tested a gas leakage detection and alert system that offers a reliable, efficient, and effective solution for enhancing safety in various environments.

References

1) Bibekananda J., Subit K. P., Raghuvar J., Sonali G., Renu S., "LPG Gas Leakage Detection System Using IoT", Materialstoday: Proceedings, Vol. 74, No. 4, pp. 795-800, 2023.

2) Gu Y., Huang B., and Zhu H., "Smart Gas Sensors towards Signal and Data Processing: A Review", IEEE Sensors Journal, Vol. 1, 2024. https://doi.org/10.1109/jsen.2024.3507195

3) Ahmed S., Rahman M. J., and Razzak M. A., "Design and Development of an IoT-Based LPG Gas Leakage Detector for Households and Industries", World AI IoT Congress (AIIoT), Seattle, USA, Jun. 7-10, p. 228, 2023.

4) Ekah U. J., Simeon O., and Etinamabasiyaka E., "Evaluating MQ Sensors in Gas Leakage Detection Systems", Journal of Scientific and Engineering Research, Vol. 11, No. 9, pp. 12-16, 2024.

5) Sai G. N., "Smart LPG Gas Leakage Detection and Monitoring System", 5th International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India, Jan. 23-25, p. 576, 2023.

6) Rahmalisa U., Febriani A., and Irawan Y., "Detector Leakage Gas LPG Based on Telegram Notification Using Wemos D1 and MQ-6 Sensor", Journal of Robotics and Control, Vol. 2, No. 4, pp. 287-291, 2021.

7) Shah S., "IoT Based Smart Gas Leakage Detection and Alert System", 4th International Conference on Advances in Science & Technology (ICAST2021), Rochester, USA, Jun. 15, 2021, p. 4.

8) Garcia F. and Rodriguez L., "Wireless Communication Technologies in Safety Systems", Communications in Safety Technology, Vol. 10, No. 3, pp. 140-155, 2020.

Volume 64 | Issue 12 | December 2025
DOI: 10.5281/zenodo.18130066

9) Gupta A. and Sharma P., "Efficiency of MQ Series Sensors in Detecting Gas Concentrations", Sensors and Actuators, Vol. 25, No. 6, pp. 300-315, 2021.

10) Kumar R. et al., "Enhancing Safety with Flame and Gas Detection Systems", Safety Systems Review, Vol. 20, No. 1, pp. 89-102, 2022.

11) Naveen P. et al., Eds., "ATMEGA 328-Based Gas Leakage Monitoring and Alerting IoT System with SMS Notification", 9th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India, 2023, p. 1336.

12) Nguyen B. T. and Nguyen A. V., "IoT Application for Gas Leakages Monitoring", International Research Journal of Advanced Engineering and Science, Vol. 5, No. 4, pp. 51-53, 2020.

13) Palandurkar V. R. et al., "Smart Kitchen System Using IoT", International Journal of Engineering Applied Sciences and Technology, Vol. 4, No. 11, pp. 378-383, 2020.

14) Pooja B. M. et al., "GSM Based Gas Leakage Detection System", International Journal of Engineering Science and Computing, Vol. 10, No. 6, pp. 26130-26132, 2020.

15) Priya R. V. and Kowsalya G., "Detecting LPG Leakage and Automatic Turn Off Using Arduino Connected with PIR Sensor", Journal of Physics: Conference Series, Vol. 1717, pp. 1-4, 2021.

16) Rohan K. H. et al., "IoT Based Smart Gas Leakage Detection & Alerting System", Journal of Research Proceedings, Vol. 1, No. 2, pp. 1-10, 2021.

17) Shiyana A. and Deepa R., "SMS Based Gas Leakage Monitoring in Residential and Industrial Area", International Research Journal of Engineering and Technology, Vol. 4, No. 10, pp. 1025-1027, 2017.

18) Nagy A. S., Polanco Risquet A., Martínez de la Cotera O. L., and Carralero Ibargollen O., "Medición Simultánea de Gases con Sensores MQ", Vol. 41, No. 1, pp. 34-43, 2020. http://scielo.sld.cu/pdf/eac/v41n1/1815-5928-eac-41-01-34

19) Kiplimo E., Riddick S. N., Mbua M., Upreti A., Anand A., and Zimmerle D., "Addressing Low-Cost Methane Sensor Calibration Shortcomings with Machine Learning", Atmosphere, Vol. 15, No. 11, pp. 1313, 2024. https://doi.org/10.3390/atmos15111313

20) Luo R., Wang J., and Gates I. D., "Machine Learning for Accurate Methane Concentration Predictions: Short-Term Training, Long-Term Results", Environmental Research Communications, Vol. 5, 2023. https://doi.org/10.1088/2515-7620/acf0a3

21) Hungund B., Nair G. G., and Rathore P., "Quantifying CH4 and NO2 Emissions Using Satellite Measurements with Environmental Impact in Texas: A County-Wide Assessment for Oil & Gas Industry", 2023. https://doi.org/10.2118/215973-ms

22) Ghode S. S., Gedam S. K., Mahajan T. S., Nikalje P. R., Parate A. M., and Pathan A. F., "Smart Fault Detector Robo to Detect Gas and Fire", International Journal for Science Technology and Engineering, Vol. 12, No. 4, pp. 4480-4485, 2024. https://doi.org/10.22214/ijraset.2024.61011

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DOI: 10.5281/zenodo.18130066

23) Chakraborty U., Kaushik A., Chaudhary G. R., and Mishra Y. K., “Emerging Nano-Enabled Gas Sensor for Environmental Monitoring – Perspectives and Open Challenges”, 2024. https://doi.org/10.1016/j.coesh.2024.100532

24) Obokhai, K. A., Augustine, E. B., Omoregbee, H. O., Development and Testing of Automatic gas leakage detection system in cylinder using Artificial Intelligence. International Journal of Engineering and Emerging Scientific Discovery. Vol 10, No 1, 2025