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Development of Liquified Petroleum Gas Leak Detection System for Gas Stations

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ABSTRACT

Liquefied petroleum gas (LPG) plays a crucial role in the global energy supply due to its affordability, and relatively lower greenhouse gas emissions compared to other fossil fuels for cooking. However, gas leakages, particularly methane, presents significant safety, environmental, and economic risks. Gas stations, which serve as essential components in LPG distribution network, are prone to leaks caused by mechanical failures, corrosion, improper installation, and equipment malfunctions. In this research an LPG leak detection system has been developed and tested for leak and no-leak conditions. The system comprises a sensing unit, a control unit and a communication unit. The Atmega328P-PU which is the microcontroller processes the information from the MQ-5 methane sensor if there is a leak or not. This information is processed by the microcontroller and then is communicated to the personnel through the SIM800l module via a phone call in the event of a leak. The detection system has been configured with a gas concentration threshold of 270 ppm above which an alarm is triggered and communication established with an operator. Tests carried out on the system, under laboratory conditions, show that after 8 test trials each for leak and no-leak conditions, the system worked perfectively with 100% true positive and true negative respectively at a threshold of 270 ppm.

Keywords — **sensor, LPG, microcontroller, gas station, leak detection, environmental safety**

1. INTRODUCTION

Liquefied petroleum Gas (LPG) is a vital energy source that plays a crucial role in meeting the world's energy demands (Aldhafeeri et al., 2020). Composed primarily of methane, along with other hydrocarbons, LPG is utilized across various sectors, including residential, commercial, industrial, and transportation sector (Jones, P., Smith, L., & Walker, R. 2020).

Its widespread use in Nigeria as a source of cooking fuel is attributed to its affordability, abundance, and relatively lower greenhouse gas emissions compared to other fossil fuels (Brown, M. 2018). However, the extraction, production, transportation, and utilization of LPG come with inherent risks, one of the most significant being the potential for gas leakage.

Gas leak could occur in gas stations, storage facilities, processing plants, compressor stations, distribution systems, and end-use equipment (Roberts, L. 2017). Despite stringent safety measures and regulatory standards, gas leaks can occur due to a variety of factors, including mechanical failures, corrosion, excavation damage, equipment malfunctions, human error, and natural disasters.

2. LITERATURE REVIEW

The consequences of gas leakage are multifaceted and can have significant impacts on human health, the environment, and the economy (Johnson, T., & White, S. 2021). Furthermore, LPG is highly flammable, and leaks can pose significant safety hazards, including the risk of explosions, fires, and property damage (Anderson, C. 2020). Economically, gas leaks result in loss of revenue for gas companies due to product wastage, repair costs, regulatory fines, legal liabilities, and reputational damage (Taylor, M. 2016).

Sequel to these challenges, detecting and mitigating gas leaks have become imperative (Adams, A., & Green, B. 2019). This has led to significant advancements in leak detection technologies over the years, aimed at improving the accuracy, efficiency, and reliability of gas leak detection systems. Traditional methods, such as visual inspection, odorant detection, and acoustic surveys have been in use over the years but are also limited with their unique challenges (Desmet et al., 2017).

The development of sensor-based LPG leak detection system in gas stations is essential at these times for the safety and protection of operating personnel, the environment, conserving resources, thereby ensuring economic efficiency, promoting public health, complying with regulations, and fostering technological innovation in the energy sector.

Maicol K., (2017) investigated the best methods that can be used to detect leakages in gas stations. Several authors classified leak detection approaches based on inferential statistics and predictive approaches. Isehunwa et al., (2014) grouped leak prediction and detection into hardware, biological, and software-based approaches. The hardware-based leak detection approach uses special sensors such as acoustic, optical, and ultrasonic flow meters, etc. Though these methods are simple and accurate, the implementation cost is very high.

Chen et al., (2018), used a decision tree and multi-support vector machine to detect leak in gas stations. Sengupta et al., (2021) proposed an LPG leak detection system design that will sense gas leak using an MQ6 sensor and a buzzer for alerting personnel in the event of leak. However, the alert system used in this proposed work cannot alert personnel positioned beyond 50 meters from the gas leak.

Bairagi et al., (2024) developed an LPG detection system called SmartGuard. Upon detection of gas beyond an allowable level, an alarm is triggered and the gas supply is automatically shut off. However, the system can only alert users within a close range. Ashish et al., (2013) designed an LPG leak detection and cylinder rebooking system based on wireless sensor Network (WSN). The system also automatically alerts users when gas in air is detected.

An equation for gas leakage in a pipeline is presented in Equation 1. From Equation 1 a leak involves several factors, including the rate of leakage, the size and material of the gas station, pressure differentials, temperature, and environmental conditions.

$$Q = AC\sqrt{2}\frac{\Delta P}{P} \quad (1)$$

Where:

Q is the rate of gas leakage (in cubic meters per second)

A is the effective area of the leakage opening (in square meters)

C is a discharge coefficient that accounts for the shape and condition of the leakage point

ΔP is the pressure differential across the leakage point (in Pascals)

ρ is the density of the gas (in kilograms per cubic meter).

3. MATERIALS AND METHODS

The method employed in this research involves the development and testing of an LPG leak detection system for Gas station using a sensor-based approach. This system utilizes materials like an Atmega328P-PU microcontroller, an MQ-5 gas leakage sensor, a passive buzzer, an LCD 16x2 display, and a SIM-800L module as shown in the block diagram in Figure 1. The completed system is shown in Figure 2. Figure 3 shows the LCD display while in operation.

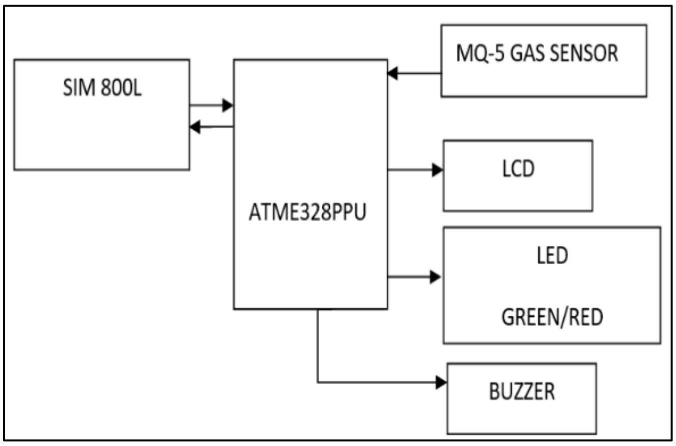

Figure 1: Block Diagram of a Sensor-based LPG Leak Detection system for Gas Station

Figure 2. LPG leak detection system

Figure 3. LPG leak detection in operation

The system employs a two-level feedback control design technique. The microcontroller, an advanced programmable electronic circuit, serves as the core of the system. The gas leakage sensor continuously monitors the gas levels in the environment and sends this data to the microcontroller, where it is stored in a register. This data is then compared to a predefined threshold level. For the purpose of this research a gas concentration threshold of 270 ppm is set.

Based on the compared results, the buzzer is activated or remains deactivated accordingly. A gas concentration level above the set threshold of 270 ppm, results in the automatic activation of the buzzer, while a gas concentration level below 270 ppm constitutes a no-leak condition. The system is also designed to send an alert message via the SIM-800L module to the process engineer, whether onsite or remote.

4. RESULTS AND DISCUSSION

The test on the system was carried out under laboratory conditions, using a 6 kg LPG cylinder as gas source. The evaluation process required carrying out a thorough assessment of its constituent parts to ensure proper operation. The intention of this thorough scrutiny was to ensure that the system could effectively detect gas leaks accurately under different conditions. The first thing done was to test the gas sensor using different concentrations of gases in order to calibrate its sensitivity and confirm its accuracy.

At the same time, there were also trials involving testing for communication modules within the system. In this case, one evaluated SIM800L module as a means of ensuring whether it could always make calls without any delay when gas leakage happens. It also involved determining if it was ready and response time of the module so as to ensure timely notifications.

In addition, LCD display was checked on by allowing gas concentration levels into the sensor while reading from LCD screen. Similarly, alarm mechanisms like buzzer and call alerts found in this system were tested. Buzzer is activated when gas level exceeds setpoint while a phone call is made to notify the operating personnel through a designated phone number assigned on the program code. Table 3 shows some test readings for leak and no-leak conditions.

Table 3: Test-readings for leak and no-leak scenarios

Time Interval	Leak Data (Sensor > 270)	No Leak Data (Sensor ≤ 270)
1	435	210
2	785	229
3	880	224
4	1023	149
5	925	263
6	348	262
7	461	170
8	631	167

From the readings obtained, 8 leak readings were recorded which exceeded the 270 threshold and triggered the buzzer alarm and concurrently made a phone call. Also, a total of 8 readings on no-leak was recorded as shown in Figure 4.

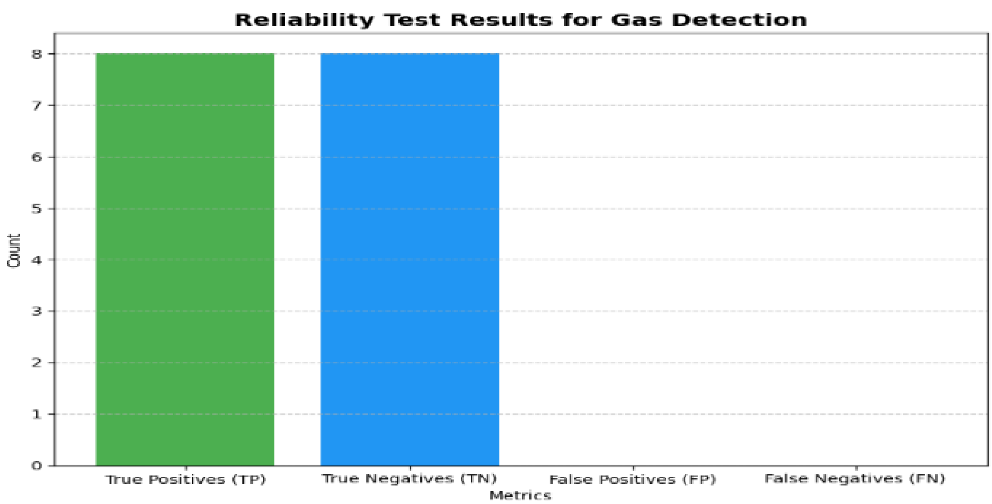

Figure 4. Graph of test readings

From the data in table 3, there are 8 total gas leak readings, all of which are above the threshold of 270 ppm. Every one of these readings triggered the alarm, meaning the detector responded accurately to each gas leak event. This is reflected in the graph where the "True Positives (TP)" value is 8. There were no false negatives (FN), indicating that the system did not miss any gas leak events. This shows that the gas detector's sensitivity is perfect, as it successfully identifies all leaks.

Similarly, there were 8 no-leak readings, all of which are below the threshold gas concentration of 270 ppm. None of these readings triggered a false alarm, as shown by the "True Negatives (TN)" count of 8 and "False Positives (FP)" being 0 in the graph of Figure 5.

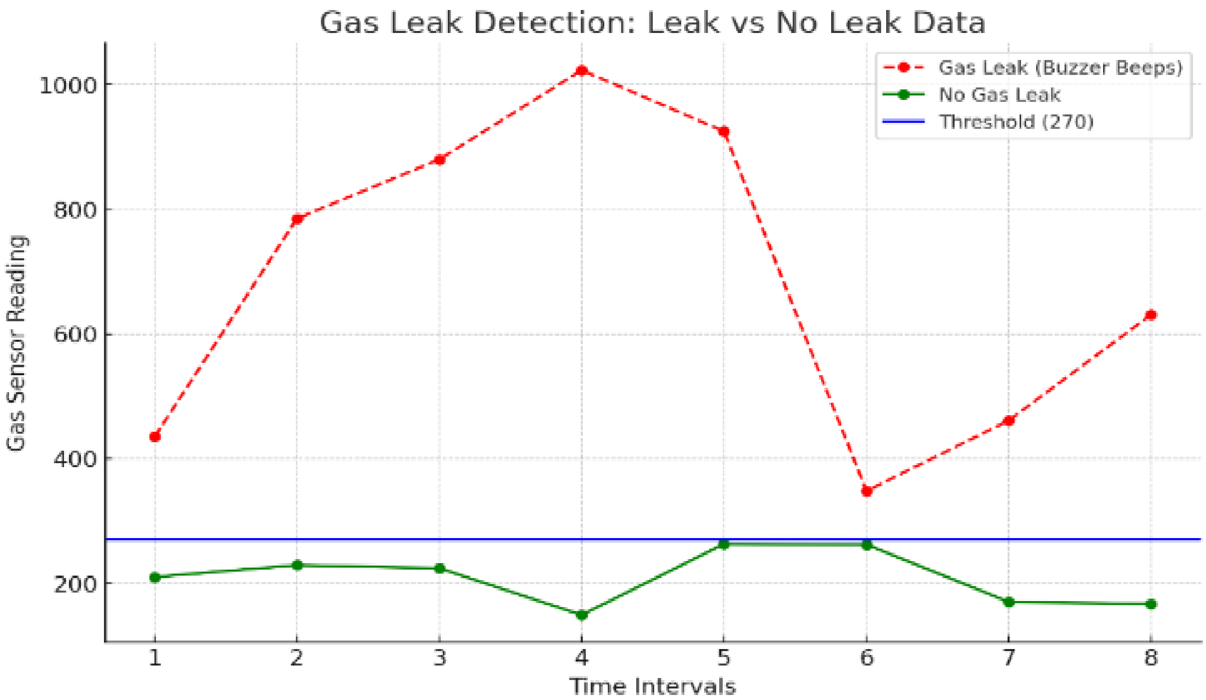

Figure 5: Reliability test graph of the LPG leak detector system

This indicates that the system has a high specificity rate, correctly identifying safe scenarios where no gas is leaking. The Sensitivity (True Positive Rate) is 100%, meaning the system accurately detected all gas leaks. The Specificity (True Negative Rate) is also 100%, showing that no false alarms were triggered in no-leak situations. The graph directly supports the analysis, as it highlights that the system has perfect reliability, with no false alarms or missed leaks in this particular test case. This suggests the gas detector is highly effective and trustworthy in detecting gas leaks and distinguishing between hazardous and safe conditions.

5. CONCLUSION

An LPG leakage detection system has been set up and thoroughly tested thus confirming its effectiveness and suitability to a number of crucial areas. The different tests conducted includes evaluation of gas sensor, communication module, LCD display, alarm systems, power consumption as well as connectivity protocols. Every part was subjected to rigorous testing to ensure that it can effectively detect the leakages of gases hence respond immediately. Calibration for sensitivity and confirmation of accuracy for the gas sensor demonstrated its ability to detect even slight leakages in gas station which is essential for safety.

Readiness and response time tests for SIM800L communication module have validated that it's capable of making alerting calls rapidly thereby ensuring timely notifications during gas leakage incidences. Further, the LCD displayed correct levels of gas concentration alongside calling alerts giving real-time information to operators. Buzzer alarms as well as telephone call alert systems were also tested and found to be reliable enough. It efficiently triggered whenever there was an over limit on gas levels while SIM800L module.

To improve the performance and applicability of a gas station leakage detector, regular sensor calibration is essential for maintaining sensitivity and accuracy over time. Incorporating multiple communication channels like Wi-Fi or LoRa alongside the SIM800L module can enhance alert reliability, especially in areas with poor cellular coverage. Expanded power solutions, such as solar panels or energy harvesting, could extend system lifespan, particularly in remote locations. Adding data analytics and machine learning would improve predictive maintenance through pattern recognition, and integrating GPS technology would allow for precise leak location tracking, enhancing response efficiency and the system's practicality.

AUTHOR CONTRIBUTIONS

Tare Caroline Gillow conducted the research; Perekebina Ebiarede analyzed the data and wrote the paper; all authors approved the final version.

CONFLICT OF INTEREST

"The authors declare no conflict of interest".

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