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IoT-Based Gas Leakage Detection and Monitoring System

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Abstract

Gas explosions in Nigeria have contributed significantly to loss of lives and properties, with a rising trend over the past four years indicating a critical need for preventive solutions. This paper presents the development of an Internet of Things (IoT)-based system for the early detection and monitoring of Liquefied Petroleum Gas (LPG) leakages, aimed at reducing fire-related incidents in gas filling stations. The system is designed using an integrated circuit that incorporates gas sensors, an LCD display, a buzzer, and other selected materials, all connected to an ATmega328P microcontroller. Upon detection of gas leakage, real-time data is transmitted via GSM to a web-based application that handles data logging, analysis, and geographical tracking of gas stations. The web platform also serves as a tool for providing safety information and alerts to relevant stakeholders. Experimental results and performance evaluations indicate that the proposed system is effective in detecting gas leakages early, thereby enabling timely intervention and significantly reducing the risks of explosion. The system's deployment offers substantial benefits in terms of safety, economic loss prevention, and improved emergency response strategies within Nigeria's LPG distribution sector.

Keywords: Gas detection system, Internet of Things (IoT), Sensor, Microcontroller, ATMega328-p

INTRODUCTION

The frequent occurrence of gas explosions in residential areas and gas filling stations has alerted researchers for the urgent need for a reliable, real-time detection system. Such a system would align with the goals of the Environmental Protection Agency (EPA) in promoting environmental safety and public health. Gas leakages, whether in homes or industrial settings, pose significant threats; ranging from environmental hazards to loss of lives, property damage, and economic setbacks. Despite the growing number of incidents, findings from various feasibility studies reveal that both governmental parastatals and private individuals have made minimal efforts to implement proactive measures to address these recurring disasters.

Gas explosions have become one of the most devastating and tragic incidents in society,

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often resulting from the absence of proper gas detection equipment in residential buildings and gas plants. Public demand for a functional leakage detection system continues to rise, as citizens seek effective solutions to mitigate such life-threatening occurrences. In the Nigerian context, there remains a glaring technological gap in the monitoring, analysis, and reporting of Liquefied Petroleum Gas (LPG) leakages, both in households and commercial gas distribution centers.

A common misconception is that gas leaks are typically minor and do not pose serious dangers. Contrary to this belief, even a small leak can lead to catastrophic consequences if undetected. The critical need for an intelligent detection system is therefore undeniable. Relying solely on human senses to ensure safety in high-risk areas such as gas filling stations is insufficient. Given the potential for large-scale disasters, safety protocols must be reinforced with the use of modern technological solutions. This study, therefore, proposes gas leakage detection and monitoring system as a vital tool for improving safety standards and preventing explosion-related disasters in Nigeria's gas sector.

METHODOLOGY

This section details the methodological framework adopted in the design and implementation of an Internet of Things (IoT)-based gas leakage monitoring system. The system framework encompasses both hardware and software components, including circuit schematics, logical flowcharts, material specifications, and interaction mechanisms that collectively address the problem of gas leakage detection and timely alert dissemination.

Requirement Definition

The initial phase involved establishing the system's functional requirements. This included identifying the target gas—Liquefied Petroleum Gas (LPG), defining the deployment environment (residential and small-scale commercial gas stations), setting the required detection accuracy, desired response time, and specifying the user interface for data visualization and interaction. Safety, cost-effectiveness, and scalability were also considered in defining system goals.

Table 1. Recorded variation in LPG concentration, ambient temperature, and relative humidity.

S/N	Date	Concentration (ppm)	Temperature (ºC)	Humidity
1	2025-05-20	180.3	26.1	50
2	2025-05-21	190.5	26.5	40
3	2025-05-22	159	26.5	40
4	2025-05-23	160	26.5	37.4
5	2025-05-24	160	26.5	37.8

Hardware Design

The hardware unit of the system was developed around the ATmega328P microcontroller, integrated on the Arduino Uno development board due to its low power consumption and compatibility with various modules. The gas detection functionality was accomplished via the MQ-2 gas sensor, which the sensor is characterized with a high sensitivity to LPG, propane and methane.

Other key hardware components included:

1. LCD Display (16x2) – to display the levels of gas concentration in real-time.
2. Buzzer Module – for audible alerts in case of gas leakage.
3. GSM Module (SIM800L) – for sending SMS alerts to registered users and transmitting data to the server.
4. Voltage Regulator – to deliver steady input power supply to all the components of the system.
5. Breadboard and connecting wires – for prototyping and interconnections.

A complete schematic was developed using Fritzing and Proteus Design Suite for circuit simulation and layout testing before hardware assembly.

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Software Implementation

The software aspect was programmed using the Arduino IDE, with embedded C/C++ code for reading sensor data, activating alerts, and managing serial communication with the GSM module. The system logic was structured using flowcharts to handle various states such as normal, warning, and critical leakage levels.

For remote monitoring and data visualization, a web-based dashboard was developed using PHP for backend scripting and MySQL for data storage. Real-time gas data was transmitted via GSM to the server, where it could be accessed by stakeholders through a web interface. For mobile integration and quick alert access, platforms like Blynk IoT were considered as alternative frontends during prototyping.

System Integration and Testing

After assembling the hardware and deploying the software, all components were tested under controlled conditions. Test cases involved simulating different levels of gas concentration using LPG in a ventilated environment. System responsiveness, sensor sensitivity, accuracy of readings, GSM communication, and database logging were evaluated and fine-tuned.

Justification for Components

Each component used in the system was selected based on its reliability, availability, cost-effectiveness, and ease of integration. The MQ-2 sensor was selected for its distinct ability to sense various gases, while the ATmega328P microcontroller provided a robust platform for embedded applications. The GSM module enabled wide-range communication without reliance on local Wi-Fi infrastructure, making the system suitable for remote and underdeveloped areas. Figure 1 depicts the design flow chat, which consists of the proposed system's software and hardware components. The system's hardware is the physical components that form the building block.

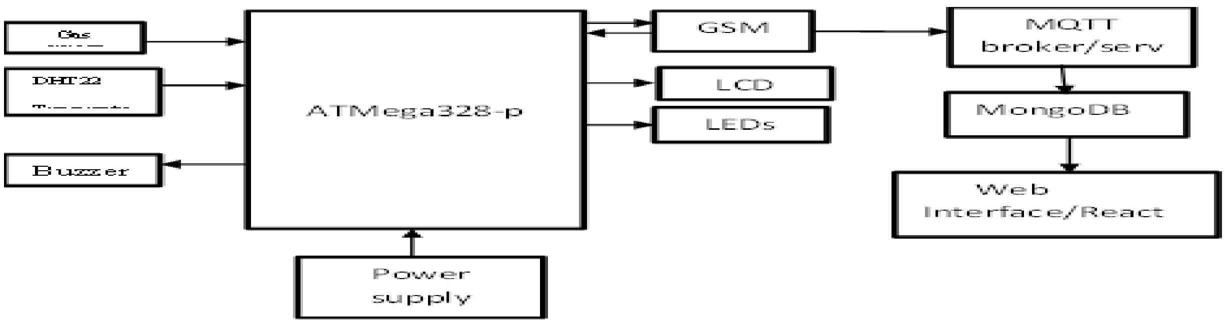

Figure 1. Design flowchart.

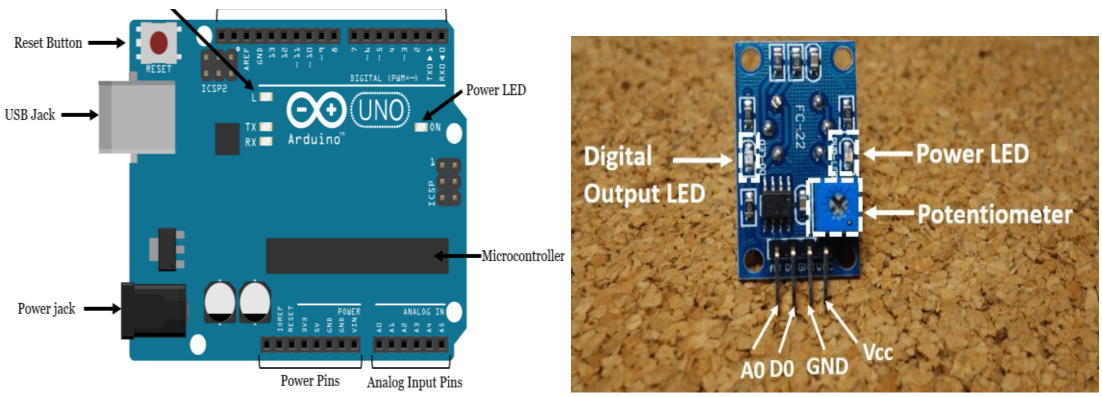

Figure 2. Arduino ATmega328p board and the MQ-5 pin diagrams.

Mode of Operation

The gas sensor module works by giving an output voltage that changes with respect to the concentration of gas present in the surrounding environment. Essentially, there is a direct relationship between the gas concentration and the sensor's output voltage:

i. When gas concentration increases, the output voltage rises.
ii. When gas concentration decreases, the output voltage drops.

The sensor module provides two types of outputs: an analog output (AO) and a digital output (DO), each serving different purposes in the system.

The analog output (AO) delivers a continuous voltage signal that is proportional to the detected gas concentration. This signal can be connected to an analog input pin on the Arduino, allowing for precise measurement of gas levels. The analog results can be converted into gas concentration units, such as parts per million (ppm), with the right calibration and programming, this will give information about the amount of gas in the air.

On the other hand, the digital output (DO) acts as a simple threshold-based detector. It outputs either a HIGH or LOW signals which depends on whether the concentration of the gas has exceed a constant value or limit. The binary output is set as ideal for triggering alerts or automated responses, such as activating a buzzer, sending an SMS via GSM, or displaying a warning message. By combining both output types, the system can both detect the presence of gas leaks and shows the extent of the gas leakage, thereby enhancing the safety and responsiveness of the overall monitoring setup. The gas detection process begins with the proper interfacing of the MQ-5 gas sensor module with the Arduino Uno. In this setup, the digital output (DO) pin of the MQ-5 is connected to digital pin 7 of the Arduino to allow the microcontroller to receive high or low signals based on the presence of gas.

To power the sensor, a +5V output from the Arduino is linked to the Vcc pin (voltage at the Common Collector) of the MQ-5 module, ensuring the sensor operates within its required voltage range. Also, the GND pin (ground pin) of the sensor is connected to the GND pin (ground pin) on the Arduino to complete the electrical circuit and establish a common ground reference. When LPG or other combustible gases are present in the environment, the sensor detects the change in gas concentration and sends a corresponding digital signal to the Arduino. The microcontroller then processes this input and triggers appropriate actions such as activating an alarm (buzzer), displaying the status on the LCD, and sending alert data through the GSM module to a remote server or designated users. Figure 3 shows the connection of MQ-5 to Arduino using analog out pin. The connections are really straightforward, similar to how we used the digital out pin to interface MQ5.

The connections are really straightforward, similar to how we used the digital out pin to interface MQ5. Using this method, connect MQ5's analog out pin A0 to any Arduino analog pin in place of D0. The A0 pin of Arduino and the analog out pin of MQ5 are connected together as shown in the figure above. After correctly connecting Vcc (voltage at the Common Collector) and Ground as indicated by the circuit schematic, the wiring portion is complete. The software portion has now undergone a minor modification. To read sensor values, we require the Arduino's analogRead command rather than digitalRead.

A GSM module functions as a communication interface that combines a GSM modem—such as the SIM800 or SIM900—with a printed circuit board (PCB) designed to facilitate connectivity with various systems. It provides multiple output options, including TTL-level signals suitable for microcontrollers like Arduino and 8051, as well as RS232 output for direct interfacing with personal computers. Additionally, most GSM modules are equipped with dedicated pins or connectors for attaching external components such as a microphone and speaker, along with terminals for power input (commonly +5V) and ground. The exact configuration and features may differ depending on the specific model or manufacturer. The two goals of the GSM Module are to use the Arduino and GSM Module to send SMS to a designated cellphone number within the application and to submit the data to the Application Programming Interface (API) for data analysis. The entire system's circuit diagram is displayed in Figure 4.

RESULTS AND DISCUSSION

Results

A sharp peak indicates a potential gas leakage or spike in LPG level. The subsequent decline may suggest either automated mitigation, such as a ventilation fan triggered by an IoT system, or natural dispersion of gas. Lower humidity levels can lead to higher gas sensor sensitivity. This might explain the sharp reading increase, as dry air enhances sensor conductivity for certain gas types. As humidity dropped the concentration also stabilized, implying environmental balance or successful detection and response by the system. Since the temperature remained relatively constant (~26.5°C), it's unlikely to be the primary factor affecting LPG readings. However, maintaining a constant sensor temperature helps reduce false positives and ensures reading accuracy. This data reflects the fundamental and working principle of an IoT-based gas leakage detection system:

i. Real-time monitoring of gas concentration.
ii. Environmental calibration using humidity and temperature sensors.
iii. Automated alerts or actions (e.g. activating buzzers, sending SMS, or turning on exhaust fans) based on threshold readings (e.g. above 180 ppm).

By analysing environmental factors, the IoT system becomes smarter and more adaptive, minimizing false alarms and improving safety.

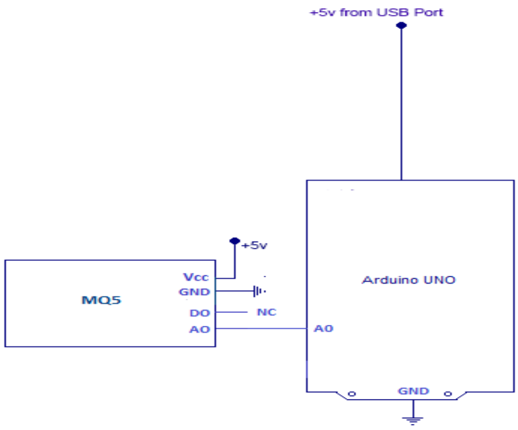

Figure 3. Connection of MQ-5 to Arduino using Analog out pin.

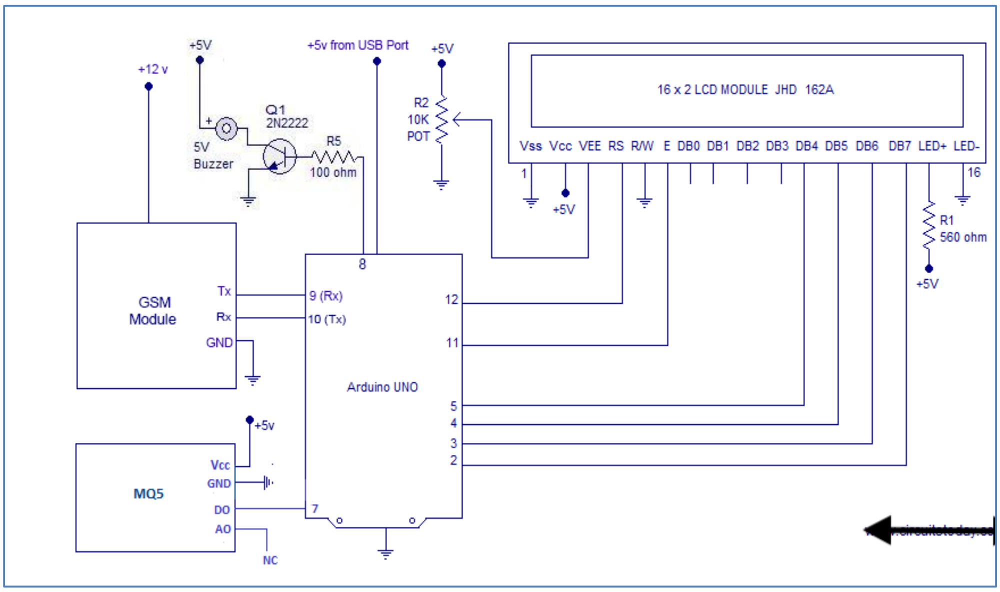

Figure 4. The entire system's circuit diagram.

RECOMMENDATION

To improve system accuracy and responsiveness of this device; incorporation of humidity and temperature correction algorithms should be brought into play in the microcontroller logic. Also set multiple threshold levels (e.g., warning at 160 ppm, danger at 190 ppm) to trigger graduated responses. However, using historical environmental data, like this, to train on predictive models or AI-enhanced detection systems in the future. Although the system faced some challenges and limitations during development, the integration of Internet of Things (IoT) technologies has proven to be highly effective for the rapid detection of gas leakages. This capability significantly reduces the risk of explosions by enabling timely intervention. The performance of the system demonstrates that the benefits of IoT adoption far outweigh its drawbacks.

To further improve the system's effectiveness, future iterations should focus on increasing sensor sensitivity and ensuring more stable internet connectivity to optimize real-time data transmission. Additionally, the system can be extended to incorporate machine learning algorithms, enabling it to analyze historical sensor data and detect patterns or anomalies related to gas concentration. This would pave the way for a predictive model capable of forecasting potential explosion risks based on multiple factors, including gas levels, pressure variations, and environmental conditions. As a contribution to ongoing research in smart safety systems, this paper reinforces the immense potential of IoT in improving hazard detection and prevention, particularly in environments such as gas filling stations where safety is paramount.

CONCLUSION

This paper presented the design and implementation of a real-time gas leakage detection and alert system using Internet of Things (IoT) technologies. By integrating hardware components such as the MQ-5 gas sensor, ATmega328P microcontroller, and GSM-based communication module, the system demonstrated effective detection of LPG leakages and prompt transmission of alert signals. This approach not only enhances the safety of gas filling stations but also contributes to the proactive prevention of fire hazards. The implementation results confirm the system's responsiveness and reliability in detecting gas leaks early enough to prevent potential disasters. Moreover, the modular and scalable nature of the design makes it adaptable to various settings, including residential, commercial, and industrial environments. This work reinforces the importance of embedding smart technologies in safety-critical infrastructures. With the growing risk of gas-related incidents in Nigeria and other developing countries, solutions like this represent a step forward in ensuring public safety and economic resilience.

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