Improving Gas Safety Frameworks: A Comprehensive Examination of IoT Integrated System for Controlling Gas Leaks

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ABSTRACT
Gas leakage incidents pose significant risks in various settings, necessitating advanced solutions for prevention and rapid response. This paper introduces an Internet of Things (IoT)-enabled gas leakage control system that combines smart sensing and real-time communication to enhance safety measures. Leveraging gas sensors and IoT technology, the system swiftly detects gas leaks and triggers an integrated response mechanism. The approach integrates automated alerts, remote control, and data visualization through test messages, enabling users to monitor and manage gas leakage situations remotely. The system's architecture, sensor selection, communication protocols, and user interfaces are detailed. Extensive testing demonstrates the system's effectiveness in timely gas leak detection, alert dissemination, and remote control, showcasing its potential to mitigate hazards and optimize gas-related safety paradigms. The IoT-enabled gas leakage control system promises a proactive approach to gas safety management in various domains.

General Terms
The paper presents an IoT-enabled gas leakage control system for liquid petroleum gas, utilizing smart sensing, real-time communication, and Arduino technologies for proactive gas safety management.

Keywords
Gas, leakage, IoT, Arduino, sensor, detection

1. INTRODUCTION
Liquified petroleum gas (LPG) is extensively used in industries, homes, schools, and other sectors, contributing to economic growth and fulfilling domestic needs. However, while the use of gas brings numerous advantages, gas leakages can have disastrous and catastrophic consequences for human lives and the environment. The leakage of LPG, in particular, poses a significant threat. Inhaling this gas in excessive amounts can lead to fatalities, and gas leakages have caused the loss of lives and properties, as well as devastating fire accidents. Tragically, incidents of gas explosions and leakages have become alarmingly common, often due to the lack of proper gas monitoring and leakage detection systems. The increasing occurrence of gas leakages and explosions has created a pervasive sense of fear and vulnerability among individuals. Many people have lost their loved ones, properties, and homes due to these incidents. These occurrences highlight the absence of effective gas detection and monitoring systems in places where these incidents have taken place. The primary objective of this research is to design a system that effectively monitors and detects domestic gas leakages using an MQ5 gas sensor. Additionally, the research aims to develop a system that can detect smoke and provide timely alerts. An SMS-based alert mechanism will be established to notify specified mobile numbers in the event of gas or smoke detection. The research also aims to incorporate a sound alarm that activates upon gas leakage and ceases once the situation is under control. Furthermore, a 16x2 LCD module will be used to display the status of the gas leakage detection system. By addressing these objectives, this research endeavours to mitigate the significant risks associated with gas leakages, thereby enhancing public safety and minimizing the potential for disasters. Gas leakages pose significant risks to public safety, environmental sustainability, and industrial operations [1]. In recent years, the integration of the Internet of Things (IoT) has emerged as a promising solution for effectively detecting, monitoring, and controlling gas leakages [2]. By leveraging IoT technologies, real-time gas leakage detection, data transmission, and automated response mechanisms can be employed, enhancing safety measures and reducing the potential for disasters [3]. In the modern era, automated systems are increasingly preferred over manual methods. The concept of automation entails the ability to plan and schedule events for networked devices. Home automation allows remote control of household appliances via mobile smartphones, facilitating communication and data exchange between these devices. LPG serves as a widely accessible, clean, and portable energy source globally. Comprising hydrocarbon gases like propane, butane, and propylene, LPG is a combustible mixture used as fuel in heating appliances, kitchens, and vehicles. Gas sensors, functioning akin to a nose, play a vital role in such systems. These sensors promptly react to detected gases, alerting the system about changes in gas concentration. The objective is to identify leaks, notifying users who can subsequently employ a smartphone to control and deactivate the regulator using an IoT cloud application. The Raspberry Pi handles server and control functions, encompassing user authentication, equipment regulation, and security provision [4].

2. RELATED WORKS
Various gas leakage detection sensors are used in IoT systems to ensure accurate and reliable detection. Electrochemical, semiconductor, infrared, and ultrasonic sensors are among the commonly employed technologies. Each sensor type possesses distinct advantages and limitations, such as sensitivity, selectivity, and response time. Electrochemical sensors, for example, offer high sensitivity and selectivity, making them suitable for gas detection in diverse environments [5]. Effective deployment of gas leakage sensors within an IoT network is crucial for optimizing coverage and detection efficiency. Strategies such as sensor placement, coverage optimization,

and network topology design play a vital role in ensuring comprehensive and accurate detection. Sensor network deployment algorithms, including clustering and energy-efficient routing protocols, have been proposed to enhance the performance of gas leakage detection systems [6].

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[9] added that IoT-enabled gas leakage control systems can trigger automated responses to mitigate risks. Actuators, such as solenoid valves, are employed to shut down the gas supply upon detection of a leak. Control mechanisms integrate gas detection systems with ventilation systems, fire suppression, and emergency response systems, providing comprehensive safety measures.

[10] discussed the broad importance of ambient gas detection across fields such as safety, pollution monitoring, and medical care. Gas leaks can have significant impacts, reaching communities or cities and causing environmental harm. The paper thoroughly examines advanced gas-sensing technologies, particularly focusing on transducer attributes. It also explores their integration into the Internet of Things (IoT) for efficient data collection and sharing. This integration seeks to improve user experiences and reduce costs. The study reviews wireless-based solutions for monitoring gases, identifies ongoing research areas, and concludes by sharing insights gained from the analysis.

In [11] focused on the challenge of detecting leaks in buried and unburied pipelines for liquids and gases, emphasising economic and safety concerns. Recent techniques have shown promise in real-world tests, offering cost-effective solutions with accurate leak detection and localization. However, many methods lack universal robustness and can fail under specific environmental conditions. The paper examines acoustic and infrared-based techniques commonly used for liquid and gas leak detection but acknowledges their limitations in certain scenarios. To address these limitations, alternative methods like ground-penetrating radar, temperature profiling, and photoacoustic sensing were proposed.

The study of [12] indicated a gas sensor to detect LPG (Liquefied Petroleum Gas) leaks. When gas concentration exceeds a certain level, a control system activates a ventilator, sends mobile alerts, and triggers an alarm. Two gas sensors (MQ5 and MQ6) were compared for effectiveness. Additionally, the system uses LED indicators, a buzzer, and an LCD display to show temperature and gas leakage status. The system's response time was crucial, and the research found that this device significantly enhances safety by minimizing the likelihood of gas leakage-related accidents.

2.1 Hardware Requirements

The project required a couple of hardware components listed as follows.

Arduino Board: Arduino serves as an open-source prototyping platform that combines user-friendly hardware and software. Arduino boards, as shown in Fig. 1, have the ability to interpret inputs such as light interacting with a sensor, a touch on a button, or even a message from Twitter. These inputs are then transformed into outputs, like setting a motor in motion, illuminating an LED, or even sharing content online. By sending a sequence of instructions to the microcontroller on the board, you can guide its actions. This is facilitated through the Arduino programming language, built upon wiring, and the Arduino Software (IDE), which is rooted in processing.

Focusing on the Arduino Uno model, it stands as a microcontroller board centered around the ATmega328 chip. Its features encompass 14 digital input/output pins (with 6 adaptable for PWM outputs), 6 analog inputs, a 16MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. This comprehensive configuration covers all necessary components to support the microcontroller. To initiate its operations, you can opt to connect it to a computer via USB or power it using an AC-to-DC adapter or a battery. ("Arduino Board Uno," 2016)

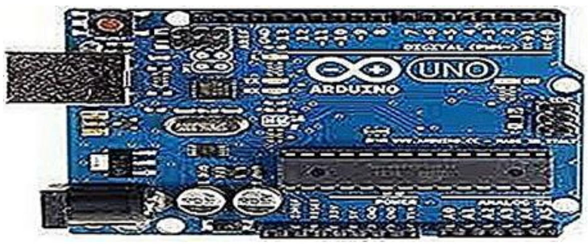

Fig.1. An Arduino UNO Board

Gas Sensor (MQ5) module: The Grove Gas Sensor (MQ5) module as shown in Fig. 2, proves valuable for detecting gas leaks in both home and industrial settings. It is capable of effectively detecting gases like H2, LPG, CH4, CO, and Alcohol. Its rapid response time and heightened sensitivity enable swift measurements. The sensor's sensitivity can be adjusted using the potentiometer. The sensor's sensitive material, SnO2, exhibits lower conductivity in clean air. However, when combustible gas is present, the sensor's conductivity increases proportionally with the rise in gas concentration. Utilising a simple electro-circuit, this change in conductivity is converted into an output signal corresponding to the gas concentration.

The MQ-5 gas sensor is particularly sensitive to Methane, Propane, and Butane, making it suitable for detecting both

Methane and Propane gases. This sensor can effectively identify various combustible gases, particularly Methane, offering a cost-effective solution suitable for a wide range of applications.

Fig. 2. Gas Sensor (MQ5) module

Characteristics of mq5 gas sensor:

- Demonstrates remarkable sensitivity to a broad spectrum of combustible gases.
- Exhibits heightened sensitivity specifically towards Methane, Butane, and Propane gases.
- Presents rapid response capabilities.
- Encompasses a wide detection range for versatile applications.
- Ensures consistent and stable performance, boasting extended operational life at a minimal cost.
- Requires an uncomplicated drive circuit for efficient utilization.

GSM/GPRS module: The GSM/GPRS module as shown in Fig 3, serves the purpose of establishing communication between a computer and a GSM-GPRS system. The Global System for Mobile communication (GSM) architecture is widely adopted for mobile communication across many countries. Global Packet Radio Service (GPRS) is an extension of GSM that facilitates higher data transmission rates. This module comprises a GSM/GPRS modem integrated with a power supply circuit and communication interfaces (such as RS232, USB, etc.) for computer connectivity.

Fig 3 GSM Mobile

A GSM/GPRS modem falls under the category of wireless modem devices designed to enable computer communication with GSM and GPRS networks. Similar to mobile phones, it necessitates a SIM (Subscriber Identity Module) card for initiating network communication. Additionally, these modems possess an IMEI (International Mobile Equipment Identity) number, akin to mobile phones, for identification purposes. The functionalities of a GSM/GPRS modem encompass the following operations:

1. Receive, send or delete SMS messages in a SIM.

2. Read, add, search phonebook entries of the SIM.

3. Make, Receive, or reject a voice call

3. METHODOLOGY

Arduino Studio was used to create and program a gas leakage control system using Arduino microcontrollers. This IDE simplifies the process of coding, compiling, and uploading software to the Arduino board, providing a user-friendly interface. C was chosen for its efficiency, speed, and close-to-hardware capabilities. This allowed for precise control over the hardware, allowing for the development of the necessary algorithms, control structures, and communication protocols for the successful development of the system structure, as shown in Fig. 4.

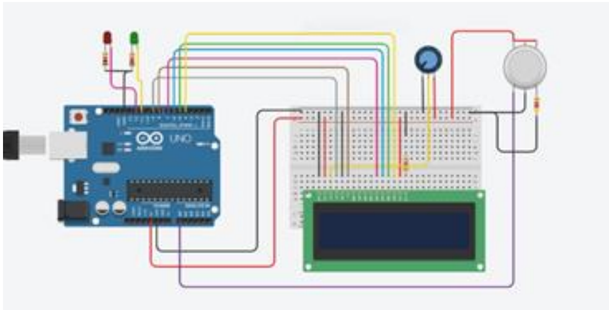

Fig. 4. Components soldered onto a breadboard

3.1 SYSTEM DESIGN

This section delves into the project team's chosen design approach for project execution. It outlines the techniques employed for requirement elicitation in comprehending the envisioned system, shaping derived requirement definitions, and utilizing a Unified Modeling Language (UML) use case diagram along with corresponding UML descriptions for the system. A system development methodology within the realm of software engineering acts as a structured framework for organizing, planning, and managing the information system development process.

System analysis is a defined process that involves gaining an understanding of the organization, investigating its needs, and modeling those requirements. To facilitate a comprehensive understanding of the methodologies underlying this project, this chapter centers on the methodology and system design procedures followed in constructing this system. Additionally, it covers requirement engineering, encompassing the methods employed by researchers for information gathering, as well as the software development processes intertwined with the relevant use case diagram

3.1.1 The Design Approach

The project team studied the existing manual mechanism of checking or detecting gas leakage though interviews and observations as the main requirement elicitation technique used. A quick prototype was built to identify and further ascertain the business requirements for the Arduino based or computerized gas detection system. As the project progressed, requirements were added to the requirement definition and grouped by requirement type.

3.1.2 Requirement Elicitation Techniques

The project team engaged the chief cook and staff (caterers) in the following requirement elicitation technique to better understand the requirements of the Arduino based or computerised gas detection system. And also for building mutual support for the project and establishing trust and rapport between the project team and the users. Gathering Information In gathering information from the staff of the Yaa Asantewaa catering department and Happy Gas Filling Station so as to create the requirements of the system, our group used both the interview and the observation method. Interviews are the most commonly used fact-finding technique that enables the collection of information from individuals face-to face, finding out facts, verifying facts, making users involved, identifying requirements and gathering ideas and opinions. Observation on the other hand, enables one to observe the study population's activities and attempts to be unobtrusive. In our information gathering, an interview was conducted at the premises of Yaa Asantewaa catering department and Happy Gas filling station, with the interviewees being some caterers. This was to find out what problems they face with the manual way of performing their day-to-day activities and their view of whether a system could be developed to automate some of the routine activities they perform. Each of the interviewees was interviewed for a minimum of 10 minutes, and all the information gathered was recorded in a note book. Simultaneously, the existing manual system was also observed on a frequent basis to know its drawbacks. This enabled the team to conduct critical analysis to come up with a proposed system that would solve the majority of their problems, if not all.

3.1.3 Requirement Analysis

Requirement analysis is the process of analyzing the needs of end users, the organizational atmosphere, and any system presently being used to developing the functional requirements of a system that can meet the needs of the users. After the interviews and observations had been made, our group sat down and decisively analyzed the responses from the interview by taking each respondent into consideration and also every observed feature into proper accounts. The group, based on the responses given and the observations made came out with an outline of functional and non-functional requirements for the system. Functional requirements

- To detect LPG leakage
- Alarm notifications
- SMS /text message notifications

Major Use Case of Arduino based or computerized LPG leakage detection system This use case models the general interaction between the Arduino based or computerized LPG leakage detection system and the users (actors – The Gas filling station workers, The caterers) of the system. The use case diagram of LPG leakage detection system is shown in figure 5 and illustrated in table 1.

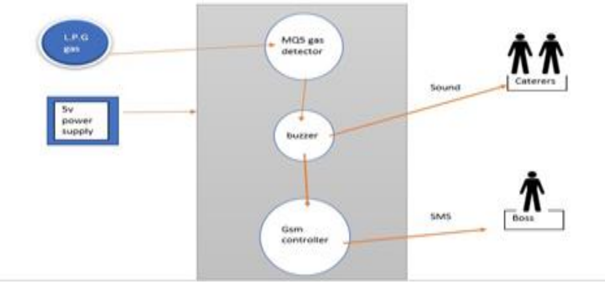

Fig. 5. A general Use Case Diagram for the LPG leakage detection system

Use Case Descriptions: The following presents the Use Case Descriptions for the major use cases, their scenarios, Use Case Descriptions: The following presents the Use Case Descriptions for the major use cases, their scenarios, the source and destination of data in the Arduino based or computerized LPG leakage detection system.

Table 1. Users of the System

System Actors	Activities
caterers	Receive beep/sound alert
LPG attendants	Receive beep/sound alert
Filing station manager/Chief cook	Receive sms notification

Users of the System System Actors Activities caterers. Receive beeps/sounds alert LPG attendants Receive beeps/sounds alert Filing station manager/Chief cook Receive sms notification. System Design System design is the specification or construction of a technical, computer-based solution for the business requirements identified in a system analysis. System design is concerned with establishing how to deliver the functionality that was specified in analysis while at the same time, meeting non-functional requirements that may sometimes conflict each other

3.1.4 Prototype Implementation of the System

The designed system was implemented as a prototype using both miniaturized devices and production ready devices. Environment was modelled to house the various components since the actual catering department and a gas filling station is impossible to carry along.

The electronic components such as resistors, female and male jumper wires, busser, button and sensors were hand soldered onto a breadboard using iron and lead as shown in figure 6

Fig. 6. The Arduino UNO and LCD screen connected together using a prototyping breadboard

3.1.5 Coding

```
void readSensorValue() {
  int value = analogRead(A0);
  value = map(value,1,1023,1,100);
  int sensorThres = 20;//threshold for minimum gas alert.
  int danger = 50;
  lcd.setCursor (0,0);
  lcd.print("Gas Value = ");
  lcd.print(value);
  lcd.print("%");
  lcd.print(" ");
  delay(100);
  if (value > sensorThres){
    lcd.setCursor(0,1);
    lcd.print("Gas Detected");
    digitalWrite(redLed, HIGH);
    delay(100);
    digitalWrite(greenLed, LOW);
    tone(buzzer,1000,200);
    SendMessage();
```

Fig. 7. Implantation in C

3.1.6 System Testing

Testing is the process of evaluating a system or its component(s) with the intent to find whether it satisfies the specified requirements or not.

Testing was performed on both the hardware components and software modules.

3.1.6.1 Unit Testing

Individual components were tested to verify they were working as expected. The gas sensor was tested as a unit component, but in connection with the busser, to check if it was working as expected.

In so doing, the busser was equally tested to check if it can produce the beep sound if and only if a target is reached.

Resisters and power buttons were also unit tested in order to ascertain that they were working well before they were used in the system. The power adapter that supplies power to the GSM module was unity-tested.

The Arduino board was tested with sample sketches that shipped with the Arduino IDE. Various subroutines of the sketch were also unit-tested. The subroutine for printing onto the LCD screen was tested to make sure it wrapped the output around the 16 x 2 screen correctly. Other subroutines, such as those responsible for capturing input from the sensors and switching the power button on and off, were also tested.

After assembling the components together and loading the sketch onto the microcontroller, the entire system was tested. Following are the test cases used:

The system must monitor and detect domestic gas leakages and smoke in the environment.

The system must set up an SMS-based alert mechanism that sends SMS (alert messages) to a specified mobile number when gas or smoke is detected.

The system must produce a sound alarm upon gas leakage and stop the alarm once gas leakage or smoke is under control (gas presence in the atmosphere is within normal range).

The system must show the status of its current state on the LCD screen.

The system passed all the test cases listed above.

3.1.6.2 Case Study of How the System Works

The system is turned on using the ON/OFF button using energizer battery of 9Volt except the GSM module. The GSM module is then powered by plugging in its adopter to a power source which gives or supply power to the GMS module. While the power button is turn on, a green light pops up signifying there is no amount of gas substances in the atmosphere other than that, the red light shows. The LCD screen displays the gas value in percentage and “You are safe” whiles the green button is still on at this stage as shown in the image below.

The system then initializes. The initialization process sets up the entire system by specifying output and input pins appropriately and also a way to delay the actual start of the working loop of the system. This has the advantage of protecting the system components such as the mq5 gas sensor, buzzer and GSM module from power fluctuations.

The status of the system is then shown on the LCD screen. The current state of the system is displayed on the screen so that the user can know what is going on. The figure above in figure.

4. RESULTS AND ANALYSIS

A gas cylinder or a gas lighter is now turned on. And as the gas keeps on releasing into the atmosphere, the system senses the gas in the atmosphere and displays it on the screen according to a percentage. As soon as the reading reaches a threshold displayed on the screen, the green button switches from green to red, signifying danger. And the alarm starts blowing, and a text message is triggered and sent to whoever is responsible. The moment the level of gas leakage in the atmosphere is reducing, the percentage value also reduces, the alarm diminishes, and a “You are safe” message is displayed to the users, as shown in Fig. 8 and 9 respectively.

When the gas sensor identifies the presence of gas within the room's atmosphere, it transmits a signal to the Raspberry Pi. Subsequently, the system implements the appropriate actions. This sequence is visually presented in a step-by-step manner on the output display, as illustrated in figure 9

Fig. 8. Screen showing the gas level in the atmosphere in normal and safe

Fig 9 provides a clear illustration of the process. when the gas sensor detects gas, the output screen displays the message "gas detected" and subsequently initiates a call to the user. upon cessation of the gas leakage, the screen indicates "gas leakage stopped." additionally, the figure displays the status of all devices within the system.

Fig. 9. Text message received after a gas leakage is detected

5. CONCLUSION

This paper presents an IoT-enabled Gas Leakage Control System designed to mitigate risks associated with gas leakages, particularly in domestic settings. The system uses smart sensing and real-time communication through Arduino technologies, gas sensors, and GSM/GPRS modules to enhance safety measures and provide a proactive approach to gas safety management. The system's architecture, sensor selection, communication protocols, and user interfaces are detailed. Extensive testing validates its effectiveness in detecting leaks, disseminating alerts, and providing remote control. The system's reliability and effectiveness are highlighted.

Looking ahead, there is a notable emphasis on integrating machine learning algorithms to differentiate between normal environmental conditions and occurrences of gas leakage. This deliberate integration seeks to efficiently decrease false alarms and refine response mechanisms for peak effectiveness. Furthermore, there is a strong interest in utilizing geospatial data and mapping technologies for accurate localization of gas leakages, particularly in extensive environments like industrial complexes or smart cities. Investigating intelligent response mechanisms, including the incorporation of components like solenoid valves to swiftly stop gas supplies during leaks, will be a pivotal area of research.

The evaluation of gas sensors involves various tests to assess their sensitivity and specificity, including gas testing, threshold calibration, and IoT communication protocol comparison. Real-time response testing simulates gas leakage scenarios, while remote monitoring and control features are evaluated. SMS alert system reliability is investigated, and audio feature testing evaluates gas leak response efficiency. User interfaces and experiences are tested for readability under different conditions and feedback. System robustness is assessed through stability testing and environmental variability, ensuring accurate gas detection capabilities. Reliability is also assessed through prolonged stability tests and user feedback.

6. ACKNOWLEDGMENTS

We express our gratitude to the reviewers for their thorough examination of the paper as well as their valuable comments and suggestions that significantly enhanced the quality of the manuscript. Also, our gratitude goes to Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, Valley View University, Accra, Ghana, and the Coordinating Director of Sekyere East District Assembly (SEDA)

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