UNIVERSITY KASDI MERBAH – OUARGLA

FACULTY OF NEW TECHNOLOGIES IN
INFORMATION AND COMMUNICATION

DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATIONS

ACADEMIC MASTER
DOMAIN: SCIENCE AND TECHNOLOGIES
FIELD: ELECTRONICS
SPECIALTY: INSTRUMENTATION AND AUTOMATIC

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Development of Smart Gas Leak Detection Systems Using Internet of Things (IoT) Technologies in Residential Environments and Vehicles

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University Year: 2024/2025

Dedication

"And their final supplication will be, 'Praise be to God, Lord of the worlds.'"

"Say, 'Work, and God will see your work, and [so will] His Messenger and the believers.'"

A God whose night is not pleasant except with His praise and thanks, whose day is not pleasant except with His obedience, and whose moments are not pleasant except with the remembrance of God, the Almighty and Majestic.

To the one who conveyed the message and fulfilled the trust, our Master Muhammad, peace and blessings be upon him.

The journey has ended. It was not short, nor was it easy, nor was the dream close at hand. However long it may be, it will pass, with its ups and downs, and with the most proud moment.

I dedicate this graduation to the one whose ear I carry with pride, to the soul of my father. You are the greatest reason I have reached this day. I miss you terribly, but I know you are with me every step of the way. This graduation is not just for me, but it is a source of pride for you, my father. May God have mercy on you.

To my angel in life, the meaning of love, the joy of my eyes, and the most precious thing I own, to the smile of life and the secret of existence, to the one whose prayers were the secret of my success and whose tenderness was the balm for my wounds, to my precious one and the paradise of my heart who accompanied and guided me in every step of my life.... My mother is my paradise, may God protect her and prolong her life.

To the one who made me remember the word "baba" and granted me the tenderness of fatherhood and is stingy with love and giving, to the one who raised me and struggled for me, to the lamp that illuminated my path, my father who raised me, Makhlouf Al-Badabi, I ask God to bless his life and not deprive us of the blessing of his presence.

To my steadfast rib who never leans towards the one I was blessed with, my first and last refuge, to the one who removed the thorns of failure from my path, my beloved sister, may God keep you as my steadfast rib. To those who supported me in writing my memoir, to all those for whom my heart was open and this paper was too narrow to mention, my dear sisters, to my beloved brother, to all members of my family, my uncles, aunts, and maternal aunts, to all friends without exception, I dedicate this humble work to you in gratitude and appreciation.

To the distinguished professors who offered us a helping hand.

To myself, who bet on success, be patient and persevere, for the road is still long.

Praise be to God for the completion and the good conclusion.

Dedication

In the name of Allah, the Most Gracious, the Most Merciful

"And say, 'Do [as you will], for Allah will see your deeds, and [so will] His Messenger and the believers…"

[Surah At-Tawbah, Verse 105]

All praise is due to Allah, by whose grace good deeds are accomplished,

and by whose guidance this humble work has come to completion.

To the one whose prayers have always protected me,

who taught me patience, perseverance, and sincerity…

To my beloved mother,

may Allah reward you with the best of rewards.

To my support in this life,

the one who surrounded me with love and encouragement…

To my dear father,

may Allah bless you and raise your rank.

To my brothers and sisters,

to all those who supported me sincerely,

to everyone who brought joy and comfort along this journey…

I dedicate this work to you with gratitude and affection.

I would also like to express my deepest thanks

to all my esteemed professors,

who guided us with their knowledge and valuable advice,

especially my supervising professor,

may Allah reward you for your efforts and dedication.

Dedication

I dedicate this work to the memory of my dear mother may Allah have mercy on her soul whose love, sacrifices, and prayers have been a light in my life.

To my sister, for her unwavering support and strength throughout this journey.

To my loyal friends who offered encouragement and stood by me during challenging times.

And to all those who strive with sincerity and determination in pursuit of knowledge may this humble effort serve as a source of inspiration.

Mohamed Lamine

ملخص

تتناول هذه المذكرة تطور أنظمة كشف تسرب الغاز مع التركيز على تقنيات الوقاية الحديثة في المنازل والمركبات. يعرض الفصل الأول مراحل التطور من الأنظمة الميكانيكية إلى إنترنت الأشياء، مع تحليل لأنواع المستشعرات وآلية عملها. يركز الفصل الثاني على تطوير نظام ذكي منزلي باستخدام Arduino ومستشعرMQ-2 ، مع مناقشة التحديات التقنية. أما الفصل الثالث فيستعرض نظام أمان للمركبات الغازية باستخدام MQ-6 وصمام كهربائي، مع توضيح الهيكلية والبرمجة. تؤكد المذكرة أهمية دمج تقنيات IoT والمستشعرات الذكية لتعزيز السلامة وتوسيع التطبيقات، مع اعتماد منهج تحليلي تطبيقي يجمع بين النظرية والتنفيذ العملي.

Résumé

Ce mémoire étudie l'évolution des systèmes de détection des fuites de gaz en se concentrant sur les technologies modernes de prévention, notamment dans les foyers et véhicules à gaz. Le premier chapitre explore le passage des méthodes mécaniques à l'ère de l'IoT, avec une analyse des capteurs et de leur fonctionnement. Le second chapitre détaille un système intelligent domestique à base d'Arduino et du capteur MQ-2, en abordant les défis techniques. Le troisième chapitre présente un système de sécurité pour véhicules à gaz utilisant le capteur MQ-6 et une vanne électromécanique. Le travail met en évidence l'intégration des technologies IoT et capteurs intelligents pour améliorer la sécurité, selon une approche analytique et pratique.

Summary

This thesis explores the evolution of gas leak detection systems with a focus on modern prevention technologies in homes and gas-powered vehicles. Chapter one reviews the shift from mechanical methods to IoT-based systems, analyzing sensor types and operation. Chapter two presents a smart home solution using Arduino and the MQ-2 sensor, addressing technical challenges. Chapter three introduces a vehicle safety system using the MQ-6 sensor and an electric valve, detailing its architecture and programming. The study underscores the role of IoT and smart sensors in enhancing safety through a combined analytical and practical approach.

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GENERAL INTRODUCTION

In Algeria, the growing reliance on liquefied petroleum gas (LPG) and other combustible gases across residential, commercial, and industrial sectors has raised significant safety concerns. Accidental gas leaks can result in devastating explosions, severe property damage, and tragic loss of life. Traditional gas detection systems, often operating in isolation, lack the ability to provide real-time alerts or support remote monitoring. However, with the rapid advancement of the Internet of Things (IoT), it is now possible to design smart, interconnected systems that not only detect gas leaks instantly but also take automatic preventive actions and notify users remotely.

Recent tragedies in Algeria illustrate the urgency of addressing this issue. In January 2023, four individuals lost their lives due to carbon monoxide suffocation caused by a faulty fireplace in Khenchela. Similarly, in January 2024, six family members died in M'Sila after being poisoned by CO gas from a malfunctioning heater. These incidents underline the critical need for more effective, intelligent gas leak detection and control systems that can operate proactively and preventively.

This project proposes the development of an IoT-based gas leak monitoring and control device that integrates gas sensors, microcontrollers, and wireless communication technologies. The system is designed to continuously monitor gas levels using MQ2 sensors and, upon detecting a hazardous leak, trigger alarms, cut off the gas supply, and send real-time alerts to users via mobile or web platforms. By combining sensor data with IoT connectivity, this solution aims to enhance safety, reduce response time, and support scalability across various environments, including homes and vehicles.

In Algeria and beyond, IoT has become an essential part of modern life. No longer confined to network management, the Internet has evolved to encompass the control and management of physical objects — a concept known as the Internet of Things (IoT). Defined as a global network of interconnected and intelligent devices, IoT holds immense potential in safety and risk prevention, especially in early hazard detection such as gas leaks. These technologies, often supported by cloud and fog computing, enable continuous environmental monitoring, fast data processing, and immediate response to anomalies, all while providing real-time access to critical information.

Nonetheless, the integration of such systems introduces new challenges, particularly in terms of data security, system reliability, and communication safety. In response to these challenges, the objective of this thesis is to study, design, and implement an intelligent gas leak protection system using IoT technologies, with a specific focus on three primary contexts: general gas protection systems, domestic environments, and gas-powered vehicles.

This thesis is structured as follows:

- **Chapter One** presents a general overview of gas leak protection systems, discussing the main technologies, components, and methods used in gas detection, along with smart implementation strategies.
- **Chapter Two** explores protection systems in domestic environments, emphasizing smart home integration, user alert systems, and mobile/web-based user interaction.
- **Chapter Three** focuses on the practical implementation of our final-year project, developed in partnership with a startup, which involves the design and testing of an IoT-based gas leak protection system for vehicles that operate on LPG or CNG fuel.

Project Objectives

The primary aim of this project is to design and develop a smart, IoT-enabled gas leak detection and control device capable of identifying the presence of hazardous gases specifically carbon monoxide (CO) and liquefied petroleum gas (LPG) to improve safety in residential and industrial environments. The specific objectives of the device development are as follows:

1) To design a compact, real-time gas leak detection device using the MQ2 sensor to monitor ambient CO and LPG concentrations with high sensitivity and reliability.
2) To implement the core control functionality using an Arduino Uno, enabling the device to process sensor data and trigger appropriate safety responses.
3) To integrate ESP8266 Wi-Fi connectivity, allowing the device to send real-time alerts and gas status updates to users via cloud-based platforms or mobile applications.
4) To enable automated safety actions through the device, such as:

- Operating a servo motor to open a ventilation window or shut off a gas valve.
- Activating a fan to disperse leaked gases.
- Controlling external equipment using a relay module to isolate electrical or gas supply in hazardous situations.

5) To incorporate intuitive alert mechanisms, including a buzzer for audible alarms, an LCD for visual notifications, and remote alerts for off-site user awareness.
6) To ensure the device is energy-efficient, user-friendly, and easily deployable, making it suitable for home kitchens, industrial sites, and other high-risk areas.
7) To emphasize the societal impact and necessity of such a device by referencing actual incidents, such as recent carbon monoxide fatalities in Algeria, highlighting the urgent need for preventive safety technology.

CHAPTER ONE

Introduction:

Gas leak detection systems are an indispensable component of safety infrastructure across various sectors, including industries, homes, and transportation. They play a critical role in safeguarding lives and property from the severe risks of explosions and poisonings. Given the increasing reliance on flammable and toxic gases like methane, propane, and carbon monoxide, there is an urgent and continuous need to develop reliable and effective technologies for their early and accurate detection.

I.1. Evolution and type of Gas Leak Detection Systems:

I.1.1. Evolution:

• Early Mechanical Phase (Late 19th Century – Early 20th Century) "This phase relied on mechanical devices sensitive to changes in pressure or weight. An example includes precision balances that detect subtle changes in the weight of a gas mixture as it passes through a disc dipped in chemicals that react with the target gas."

• Simple Electrical Phase (Mid-20th Century) "The mid-20th century saw the emergence of the first electrical sensors for flammable gases, such as those based on heated wire resistance, commonly known as catalytic bead sensors. Their working principle involved a change in voltage or current across a heated wire when it interacted with the gas.

• Electronic and Analog Phase (1970–1990) "During this period, analog circuits were developed to process signals from sensors, converting them into electrical voltages that accurately reflected gas concentration. These devices could be connected to central systems to trigger audible or visual alarms upon exceeding a predefined threshold.

• The Digital and Smart Phase (1990–2010) "Gas leak detection systems became integrated with microcontrollers, enabling digital processing and interpretation of sensor signals. Key features introduced in this phase included automatic calibration, emission data recording, and enhanced connectivity through communication interfaces like RS-232 and Modbus.

• The Comprehensive and Internet of Things Phase (2010–Present) "The current era is characterized by the widespread adoption of Internet protocols (e.g., Ethernet, Wi-Fi, LoRa

WAN) to facilitate direct alert transmission to cloud platforms. This phase has also witnessed the introduction of systems leveraging artificial intelligence and data analytics to predict leak locations based on historical patterns and continuous monitoring.

I.1.2. Types of Gas Leak Detection Systems:

Table 1:Gas Leak Detection Systems Based on Sensor Technology

Technology	Principle	Advantages	Disadvantages
Induced resistance (Catalytic Bead)	The oxidation of a flammable gas on the surface of a heated wire changes its resistance.	Inexpensive, suitable for flammable gases.	High energy consumption, susceptible to damage from pollutants (e.g., sulfur, silicon).
Semiconductors (e.g., MOS)	The resistance of a metal oxide wafer (usually ZnO) changes upon absorption of a gas.	High sensitivity, relatively long lifespan.	Affected by humidity and temperature
Electrolysis (Electrochemical)	Production of direct electric current as a result of the oxidation or reduction of a gas in a chemical cell.	High accuracy, limited lifespan but suitable for precise tracking.	Susceptible to degradation by water and toxic chemicals.
Infrared rays (Infrared, NDIR)	Absorption of specific wavelengths of infrared radiation by a gas	Unaffected by moisture, high precision, long life.	Unaffected by moisture, high precision, long life.
Ultraviolet rays (UV/Flame Detection)	Detection of UV radiation emitted by a flame)	High sensitivity to specific flame types.	Limited range of gases (only those that burn), complex composition.
Audio/Ultrasonic (Ultrasonic)	Measures the decrease in intensity or frequency change of ultrasonic waves as they pass through a gas.	Detects leaks quickly, works with all gases.	Affected by ambient noise, limited by acoustic resonance range.

• According to the Installation Pattern

1. Fixed vs. Portable

- Fixed: Installed in specific locations within a facility, relying on known distribution points for pipelines and pipes.
- Portable: Handheld devices used to detect leaks during maintenance or inspection work.

2. Point Detectors vs. Open Path Detectors

- Point Detectors: Sense gas in their immediate vicinity, typically within a limited range of a few meters.
- Open Path Detectors: Utilize a transmitter and a receiver to detect gas leaks along a path spanning tens to hundreds of meters, making them suitable for monitoring large areas such as warehouses and export pipelines.

3. Standalone vs. Integrated with SCADA

- Standalone Systems: These systems primarily function to issue alarms upon detection.
- Integrated Systems: These systems connect to a central control panel (e.g., SCADA – Supervisory Control and Data Acquisition) for comprehensive data management and automated control of shut-off valves and ventilation systems.

4 The importance of development in detection systems

The importance of improving and developing gas leak detection devices is evident in:

- Preventing accidents related to explosions or poisoning.
- Reducing human and material losses.
- Enhancing the reliability of industrial systems.
- Supporting the shift toward clean energy sources such as natural gas.

I.2. Iot technologies used in safety systems:

The Internet of Things (IoT) is expected to be an unprecedented development. Things are now capable of communicating with each other, exchanging, interacting, and adapting to their environment on a much broader scale. Thanks to the revolution in new information technology, the Internet of Things represents a new phase in the development of cyberspace. This revolution facilitates the creation of smart things, allowing for progress in multiple fields, one of the fields most affected by the emergence of the Internet of Things is as leak protection systems.

I.2.1. Definition:

The European Research Projects Group on the Internet of Things (CERP-IOT) defines the Internet of Things as: "A dynamic, global network infrastructure. This global network has self-configuration capabilities based on compatible standards and communication protocols. In this network, physical and virtual objects have identities, physical attributes, virtual personalities, and intelligent interfaces, and are integrated into the network with complete transparency." [1-3]

This definition describes the two aspects of the Internet of Things (IoT): temporal and spatial, which allow people to connect from anywhere and at any time through connected objects. The IoT must be designed to be easy to use and secure to avoid potential threats and risks, while concealing the underlying technological complexity.

I.2.2. Application Areas of the Internet of Things:

The Internet of Things encompasses many areas of applications and research, In this section, we mention some fields with examples:

• Smart City: Smart traffic, smart transportation, smart waste collection, and various maps (noise, energy, etc.)

• Smart Environments: Earthquake prediction, fire detection, and air quality.

• Security and Emergency Management: Radiation, attacks, and explosions.

• Agriculture: Easy and precise farming.

• Pharmaceuticals: Biodegradable chips, automation Prescriptions.

• Logistics: Making goods "smart."

• Healthcare and health: Medical monitoring and automated treatment management.

• Home automation: Smart homes.

• Gas leak protection systems.

Internet of Things (IoT) refers to a network that connects smart devices over the internet to exchange data and make automated decisions.

In safety systems, these technologies enable monitoring of hazardous environments, sending alerts, and activating automatic responses to prevent accidents.

I.2.3 How an Internet of Things system works in gas leak detection:

An IoT-based gas leak detection system typically consists of the following components:

I.2.3.1. Smart Sensors

Definition

Smart Sensors: These are advanced sensors that not only measure physical or chemical variables (such as gas levels, temperature, smoke, vibration, motion, or pressure), but also include built-in processing capabilities.1 These capabilities allow the sensor to process, filter, format, and sometimes perform preliminary analysis of the data it collects locally before transmitting it. 2 They are also often capable of communicating wirelessly with central processing units (such as edge or cloud computing) or IoT management platforms, enabling early detection of hazards, direct data transmission, and contributing to rapid and automated decision-making within safety systems.

Function:

• They monitor variables such as temperature, gas levels, smoke, vibration, motion, and pressure.

Types:

• Gas Sensors: Such as the MQ-2 or NDIR sensor to measure toxic or flammable gases.

• Smoke/Fire Detectors: To detect the onset of fires.

• Motion/Occupancy Sensors: To detect the presence of individuals in hazardous areas.

Benefits:

• Early detection of hazards before they turn into disasters.

• Sending data directly to the processing unit or the cloud.

I.2.3.2. Wireless Communication Modules:

Table 2: The most important technologies

Technology	Range	consumption	speed	Use in safety
Wi-Fi	50–100 m	middle	High	Closed sites, immediate monitoring
Bluetooth (BLE)	10–50 m	low	middle	Wearable devices (such as safety helmets)
LoRa / LoRaWAN	Up to 15 km	too low	low	Large facilities (factories, gas pipelines)
NB-IoT / LTE-M	Very High (Mobile Network)	low	middle	Send alerts from remote areas

Its benefits:

• It allows sensors to be connected to analysis systems or internet gateways without the need for cables.

• Central Processing Unit (Edge & Cloud Computing):

Systems:

• Edge Devices: such as Raspberry Pi or ESP32 process data locally and make rapid decisions (such as triggering an alarm).

• Cloud Platforms: such as AWS IoT and Google Cloud IoT, receive data from various locations and analyze or store it.

Benefits:

• Reduced response time.

• Ability to analyze historical records to make predictive decisions.

• Remote monitoring from anywhere

It reads sensor data and sends it to the Internet.

1.2.4. IoT Management Platforms (cloud platform):

Stores and analyzes data, sends smart alerts, and provides a visual interface for managing sensors and viewing data in real time like

ThingSpeak, Blynk, Node-RED, Azure IoT Hub, **Grafana.**

It facilitates follow-up by technical teams and the ability to integrate artificial intelligence and big data to make smart decisions.

1.2.5. Wearable IoT:

These are body-worn devices, such as safety helmets or bracelets, that measure a worker's health status or exposure to toxic gases or falls.

They are used in oil, gas, and mining companies to protect workers in hazardous environments, sending an immediate alert when a fall occurs, loss of consciousness occurs, or safety limits are exceeded.

1.2.6. Smart cameras and computer vision technologies:

These cameras are equipped with artificial intelligence algorithms to analyze video and identify unsafe situations. They provide intelligent visual monitoring with real-time alerts.

These include:

• Detecting flames or smoke.

• Identifying workers who are not wearing protective equipment.

• Monitoring abnormal movement in restricted areas.

1.2.7. Actuators and Automation:

These include electric valves, ventilation fans, and fire suppression systems. They are automatically activated when sensors exceed hazard thresholds, via SMS, push notifications, email, and audio and visual alerts.

•Alerts reach administrators quickly, even if they are off-site.

- **Smart Response Mechanism:**

When a gas leak is detected, the system automatically intervenes to implement a series of preventive measures to mitigate potential risks. This response begins by activating an audible and visual alarm to alert those present, followed by an immediate notification sent to the user's phone via the internet. At the same time, the system automatically shuts off the gas valve to prevent the leak from continuing and activates the ventilation system to help disperse the leaking gas and reduce its concentration in the air. All data related to the incident is also recorded in a dedicated database, allowing for subsequent analysis of incidents and future corrective action.

- **The Role of Internet of Things (IoT) Technologies in Gas Leak Detection and Smart Response Systems:**

Modern gas leak detection systems rely on Internet of Things (IoT) technologies to provide accurate and sustainable real-time monitoring. When a gas leak is detected, the system automatically activates an audible and visual alarm to alert nearby residents, sending an immediate notification to the user's phone via a wireless network. It also automatically shuts off the gas valve to prevent the leak from continuing and activates the ventilation system to help disperse hazardous gases. All incident-related data is recorded in a dedicated database.

These smart systems offer several advantages, most notably: continuous monitoring, immediate and accurate alerts, remote control, reduced risks and future costs, and the ability to integrate with other security systems such as fire-fighting systems, surveillance cameras, and smart entry systems.

These systems find widespread application in several areas, such as homes (to protect kitchens), chemical plants, fuel and gas storage facilities, natural gas-powered vehicles, and laboratories, making them a fundamental pillar of contemporary industrial and domestic safety infrastructure.

The Internet of Things (IoT) technologies have transformed the concepts and methods of traditional safety systems, shifting these systems from a reactive response model to a proactive approach based on predicting risks before they occur. By providing remote monitoring and control capabilities, these systems are now able to intervene automatically and quickly when any abnormality is detected, mitigating the impact of accidents and enhancing the protection of lives and property. Furthermore, the data collected by these systems is used to analyze operational patterns, allowing for the prevention of future accidents through preventive maintenance and accurate decision-making.

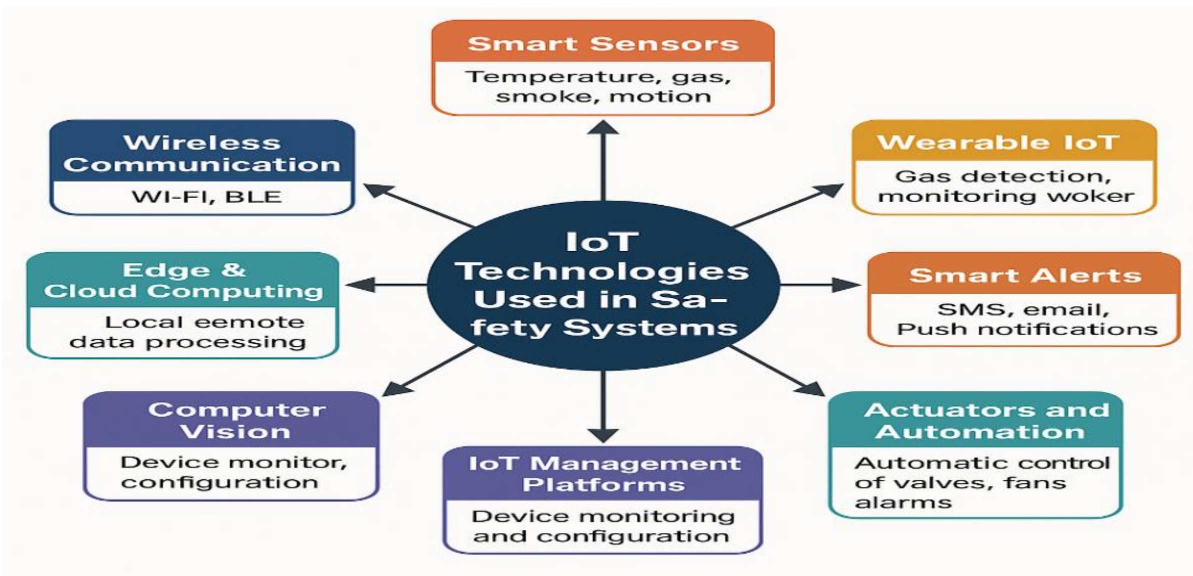

Figure 1 :IOT technologies used in safety systems

I.3.Gas Leak Detection Methods (Comparison and Analysis):

Gas leak detection technologies are a cornerstone of industrial and domestic security systems, aiming to detect hazardous gases in a timely manner to prevent accidents such as explosions or poisonings. These technologies rely on a set of physical or chemical principles and have evolved to include traditional and modern methods that differ in terms of detection accuracy, response speed, ease of use, cost, and integration with Internet of Things (IoT) systems. The selection of the most appropriate method depends largely on the nature of the environment to be protected, the type of gas targeted, and the required sensitivity of detection.

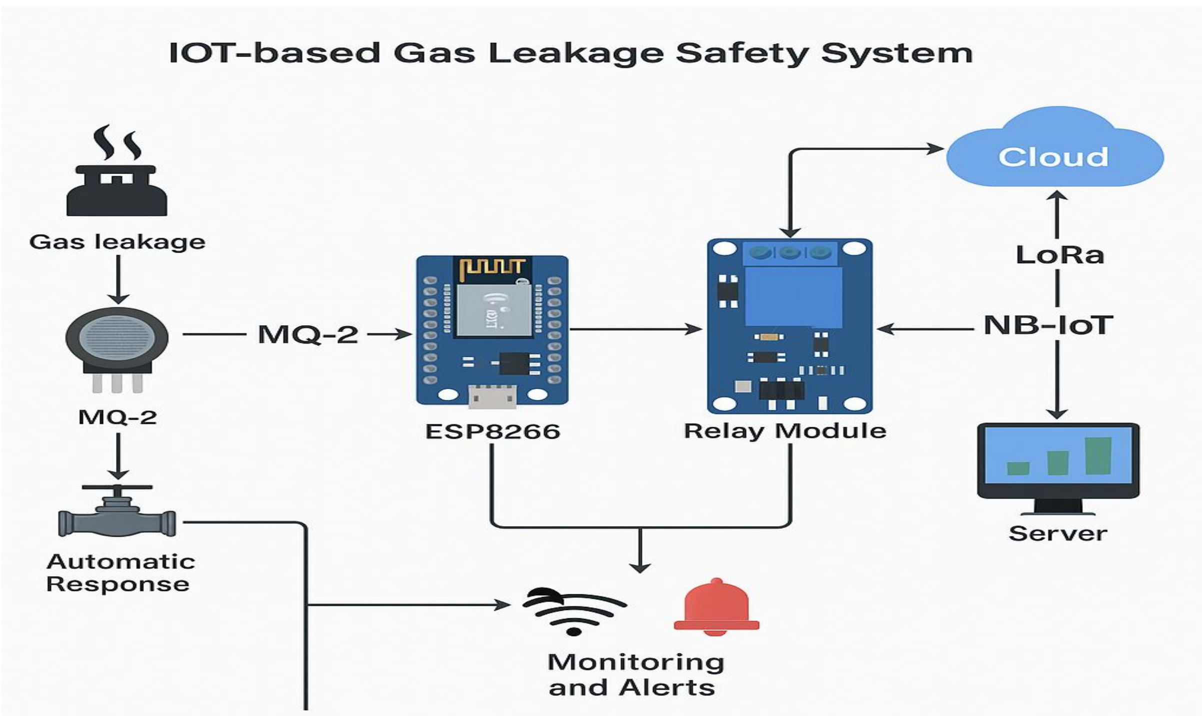

Figure 2: Iot based leakage safety system

I.3.1. Main methods for detecting gas leaks:

Table 3: Main methods for detecting gas leaks

Method	Principle	Advantages	Disadvantages	Applications
Electrochemical Sensors	Chemically react with gas to generate an electrical current	High accuracy, fast response, good selectivity for certain gases	Sensitive to humidity and temperature, limited lifespan	CO, NO_2 detection
Semiconductor Sensors (e.g., MQ Series, Gas Sensors)	Change in electrical resistance when exposed to gas	Low cost, easy to use, detects multiple gases	Medium accuracy, requires calibration, affected by humidity	Propane, Methane, LPG
Infrared Sensors	Measure infrared absorption by gas molecules	High accuracy, long lifespan, non-consumptive	Expensive, sensitive to dust and light	CO_2, Hydrocarbons
Flame Detectors	Detect UV or IR radiation emitted by combustion	Ultra-fast response, effective for early fire detection	Cannot detect unburned gas leaks, very expensive	Fuel stations, petrochemical plants
Ultrasonic Detectors	Detect sound produced by high-pressure gas leaks	Gas type-independent, effective in open environments	Ineffective for low-pressure gas leaks	Advanced industrial systems
Tunable Diode Laser Absorption Spectroscopy (TDLAS)	Uses a tunable laser to detect specific gas absorption wavelengths, measuring gas concentration based on the amount of absorbed light.	- High accuracy and speed - Long detection range - Suitable for sensitive industrial environments	- High cost - Requires precise maintenance	- Gas pipelines monitoring - Oil and gas refineries - Chemical plants - Power generation facilities
Thermal Imaging	Detects the temperature difference between leaking gas and the surrounding environment using infrared cameras.	- Accurate visual gas leak detection - Effective for predictive maintenance	- Very expensive - Requires trained personnel for proper operation	- Industrial equipment inspection - Oil and gas facilities - Preventive maintenance programs

I.3.2. Comparative Table of Gas Leak Detection Methods:

Gas leak detection technologies are essential for safety in industrial, commercial, and domestic environments. They vary widely in detection principles, accuracy, cost, response time, IoT integration capability, and reliability. This analysis provides a detailed comparison of the main methods currently used for gas detection.

Table 4: Comparative Methods of Gas Leak Detection

Method	Accuracy	Cost	Response Time	Ease of Integration with IoT
MQ Sensors	Medium	Low	Medium	High
Infrared (IR)	High	High	High	Medium
Ultrasonic	Medium	Medium	High	Medium
Thermal Imaging	High	High	Medium	Low
Laser Detection (TDLAS)	Very High	Very High	High	Low

I.3.3. Analysis of Detection Methods:

- **Detection in Industrial and Commercial Environments:**

Fixed devices: These are the preferred choice for continuous monitoring of large or hazardous areas. These systems often incorporate NDIR sensors (for hydrocarbons and carbon dioxide) and electrochemical sensors (for toxic gases) due to their accuracy and stability.

Acoustic detection: A powerful addition to large industrial environments, providing immediate leak detection without the need for direct contact or knowledge of the type of gas leaking. It is used complementarily with traditional gas detectors to provide an additional layer of security.

IoT systems: These enable centralized monitoring and automated control of distributed industrial systems, enhancing rapid response and reducing the need for human presence in hazardous areas.

Mobile devices: Essential for field crews to conduct safety checks before entering confined spaces or to accurately pinpoint the source of a leak after an initial alert.

- **Detection in Home and Residential Environments:**

Fixed (non-IoT) devices: These are the most common, often relying on MOS or inductive sensors for natural gas and LPG, and electrochemical sensors for carbon monoxide. [5]
IoT devices: These represent the next generation of smart homes, providing instant phone alerts and enabling automated actions such as turning off the gas valve or opening smart windows when a leak is detected. Technologies such as Wi-Fi, Zigbee, and LoRaWAN are common in this context. [3], [7], [9]

I.4.Existing IoT-Based Gas Detection Solutions:

The Internet of Things (IoT) is a fundamental pillar of modern gas leak detection systems, enabling the creation of smart networks to collect data, improve performance, and ensure safety. These systems aim to provide real-time monitoring and immediate alerts, enhancing safety in both domestic and industrial environments. Modern methane sensors are increasingly integrated into IoT ecosystems, offering advanced capabilities such as wireless connectivity, cloud data storage, real-time alerts, remote monitoring and control, and predictive maintenance algorithms.

I.4.1. Components of current IoT-based detection solutions in detail:

IoT-based gas leak detection systems involve a complex integration of different components that work together to provide comprehensive monitoring and rapid response:

1. Microcontroller:

Function: Acts as the brain of the system, coordinating the functions of all other components. It processes data received from sensors and makes decisions based on detected levels.

Examples: Common microcontrollers used in these systems include the Arduino or ESP8266.

2. Gas Sensors:

Function: These highly sensitive sensors are the "eyes" of the system, continuously detecting the concentrations of various gases in the air. When a leak is detected, the sensor's electrical characteristics change with the change in gas concentration.

Catalytic Bead Sensors: Widely used to detect flammable gases such as methane and propane, they work by measuring the heat generated by the oxidation of the gas on a catalytic surface.

Near-Infrared (NDIR) Sensors: Used to detect hydrocarbons such as methane and propane, they work by analyzing the absorption of infrared light at specific wavelengths. They are highly accurate and do not interfere with other gases.

Semiconductor (Metal Oxide) Sensors: Used to detect flammable gases, as their electrical conductivity increases as the target gas concentration increases.

Electrochemical Sensors: These sensors are used to detect toxic gases such as carbon monoxide (CO), hydrogen sulfide (H2S), and nitrogen dioxide (NO2). They operate through chemical reactions that generate an electrical current proportional to the gas concentration. They are characterized by high sensitivity and low power consumption.

3.Wireless Communication Modules:

Function: These modules enable remote transmission of data from sensors to a cloud server or mobile applications, enabling monitoring from anywhere.

Common Technologies:

Wi-Fi: This enables remote monitoring and control via smartphones or computers, providing a faster and more stable connection, especially in home applications. However, it may consume more power and has a limited range compared to some other technologies.

LoRaWAN (Long Range Wide Area Network): This is used for broadband, low-power wireless communication, making it ideal for remote or large areas such as oil and gas fields. Devices can operate for years on a single battery.

Bluetooth/BLE (Bluetooth Low Energy): Used for short-range, low-power communication, effective for tracking assets indoors or for direct communication between nearby devices.

GSM (Global System for Mobile Communications) Module: Used to send SMS alerts to designated contacts when a leak is detected.

NB-IoT (Narrowband Internet of Things): A cellular technology specifically designed for IoT devices with specific battery life and low bandwidth requirements, offering better indoor coverage and deep signal penetration.

4.LCD Display:

Function: Provides local feedback and displays detected gas levels in real time, along with device status.

5.Buzzer:

Function: Emits a loud sound to alert nearby personnel immediately upon detection of a gas leak, ensuring immediate response.

6.GPS (Global Positioning System) Module:

Function: Enables precise tracking of the system's location, facilitating rapid emergency response and pinpointing the leak point.

7.DC Fan:

Function: Helps disperse leaking gas, reducing its concentration and mitigating potential hazards.

8.Solenoid Gas Valve:

Function: The system can automatically shut off the gas flow when a leak is detected, preventing further leakage and significantly reducing the risk of explosions or poisoning.

Functions and Benefits of IoT-Based Detection Solutions:

Real-Time Monitoring: These systems provide real-time data on gas levels, enabling rapid intervention and preventing dangerous situations from escalating.

Instant Alerts: Instant notifications are sent via mobile apps, SMS, or email when the gas concentration exceeds a set value, even if the user is not present on-site.

Remote Control: Users can monitor gas levels and control the system from anywhere using a smartphone app, providing peace of mind.

Automated Responses: When a leak is detected, the system can trigger automated responses such as activating ventilation fans or closing gas valves, reducing the need for immediate human intervention.

Predictive Analysis: Machine learning and artificial intelligence algorithms can analyze sensor data patterns to improve gas detection accuracy, predict sensor failure, and reduce false alarms, transforming detection from reactive to proactive.

Easy Installation and Maintenance: Wireless systems are quick and easy to install, as they do not require complex cabling.

This reduces operational complexity and maintenance costs.

Scalability: IoT networks can be easily expanded to accommodate a large number of devices, making them suitable for widespread deployment in various environments.

Energy Efficiency: Many IoT technologies, such as LoRaWAN and NB-IoT, are designed for low power consumption, allowing devices to operate for years on a single battery, reducing operating and maintenance costs.

These integrated solutions contribute to enhanced safety and risk reduction by providing continuous monitoring, rapid response, and effective control of gas leaks, making them a vital part of modern smart infrastructure.

In homes and kitchens, it is recommended to use gas sensors such as MQ-2, MQ-6, or MQ-9, as they are affordable, easy to integrate, and suitable for detecting gases like LPG, methane, and carbon monoxide.

In industrial settings, infrared (IR) sensors or flame detectors are preferred due to their high accuracy, fast response, and reliability in detecting hazardous gases or fire risks in complex environments.

For vehicles, the use of an MQ-6 sensor combined with a ventilation system or an automatic shut-off valve is advised to ensure early detection of harmful gases and immediate action to prevent accidents.

In laboratories, electrochemical sensors are ideal, particularly for detecting gases like carbon monoxide (CO) and nitrogen dioxide (NO_2), due to their high precision and selectivity.

I.5.Wireless Communication Technologies:

Remote Communication Technologies in Gas Leak Protection Systems

Gas leak detection systems are a vital component of ensuring safety in industrial, commercial, and residential environments alike. These systems monitor levels of hazardous gases, such as carbon monoxide, hydrogen sulfide, and methane, and alert personnel to any dangerous levels. Previously, alarm systems relied heavily on wires, leading to response delays and limited immediate response. With technological advancements, remote communication technologies have become pivotal in enhancing the effectiveness of these systems, enabling continuous monitoring, rapid response, and remote control, thus significantly reducing potential risks.

I.5.1 RS485 Modbus

RS485 Modbus is a common industrial communication protocol used to connect devices to a network. Gas leak detection control panels can be equipped with an RS485 Modbus output. This protocol enables remote monitoring of control panel data, allowing facility managers to check gas levels at any time. Although not wireless in nature, it is often combined with wireless adapters such as RS485 to LoRa adapters to enable long-distance wireless data transmission to a master gateway or integrated system platform. This integration capability makes it an integral part of comprehensive remote monitoring solutions in industrial environments.

I.5.2Wi-Fi:

Wi-Fi technology is increasingly being used in gas leak detection systems, especially in residential applications. Wi-Fi-enabled smart gas detectors offer faster and more stable connectivity and allow for easy adjustment of alarm settings via smartphone apps such as "Smart Life."

•Wi-Fi Advantages:

Connection Speed and Stability: Wi-Fi provides a high-speed and stable connection, ensuring real-time data transmission.

Integration with Smart Apps: The gas detector can be controlled and its security status monitored continuously through a dedicated smartphone app. It also provides instant notifications when the gas concentration exceeds a set value.

Large Display Screens: Wi-Fi-enabled devices often come with large LCD screens that display the gas concentration and device status in real time.

•Wi-Fi Disadvantages:

Power Consumption: Wi-Fi is known for its high power consumption compared to other low-power wireless technologies, which can impact the battery life of mobile or battery-powered devices.

Limited Range: Although capable of utilizing existing networks, Wi-Fi range can be limited and may require additional routers or boosters in large buildings.

Interference: Wi-Fi signals can be subject to interference in large-scale industrial environments, affecting transmission reliability.

Lack of Accuracy: Wi-Fi-based tracking systems may lack the precision required for high-precision location.

I.5.3. Bluetooth / Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) is an efficient option for short-range wireless communication, optimized for low power consumption.

Advantages of BLE:

Low power consumption and long battery life: BLE is extremely energy-efficient, allowing devices to operate for years on a single battery. This reduces the need for frequent maintenance and battery replacement.

Low cost: BLE tags are often inexpensive, making them an economical option for tracking large numbers of assets.

Ease of deployment and integration: BLE solutions are easy to deploy, as tags can be installed in minutes without the need for complex wiring.

Disadvantages of BLE:

Limited range: BLE tags typically have a range of 10-100 meters and are affected by environmental obstructions such as walls and doors.

Location accuracy: BLE may not provide point-level location accuracy (within 1-2 meters) like Ultra-Wideband (UWB) systems.

Security Concerns: Like any wireless system, BLE tags carry inherent security risks, as data is transmitted openly unless encryption is applied.

Infrastructure Dependence: BLE tracking systems require gateways or mobile devices to detect signals.

BLE is used in gas leak detection training systems, where Bluetooth-enabled tablets can simulate gas leak scenarios without the need for real gas, enhancing employee safety and efficiency in a risk-free environment.

I.5.4. LoRa WAN:

Lora WAN (Long Range Wide Area Network) is a low-power, wide-area networking protocol designed to connect battery-powered devices to the internet wirelessly over long distances.

Advantages of LoRa WAN:

Long Range: LoRa WAN provides reliable connectivity over distances ranging from several kilometers in urban areas to over 15 kilometers in rural or direct line-of-sight conditions. This makes it ideal for remote or large areas such as oil and gas fields and offshore drilling platforms.

Low Power Consumption and Long Battery Life: LoRa WAN ensures that devices can operate for extended periods without frequent maintenance, with batteries often lasting up to 10 years. This significantly reduces operating and maintenance costs.

Cost-Effectiveness: LoRa WAN provides a cost-effective alternative to traditional communication networks, with lower operating and infrastructure costs.

Strong Security: LoRa WAN implements AES-128 encryption at both the network and application layers, ensuring message integrity and data privacy.

Disadvantages of LoRa WAN:

Low data rates: LoRa WAN is designed for low-bandwidth, delay-tolerant applications, with data rates ranging from approximately 0.3 kbps to 27 kbps. This makes it unsuitable for media streaming or high-frequency industrial control.

Coverage challenges in harsh environments: Despite its long range, ensuring consistent and reliable network coverage in vast and remote oil and gas fields requires careful planning. Interference from other radio frequency sources can affect signal reliability.

LoRa WAN is used in the oil and gas sector for monitoring gas leaks, pipeline monitoring (pressure, flow, temperature), tank monitoring, predictive maintenance, and worker safety monitoring. It also provides instant notifications if a device stops working or its battery runs low.

I.5.5. Cellular (GSM, NB-IoT):

Cellular technologies, including GSM and NB-IoT, are a powerful solution for gas detection systems, especially for applications that require wide coverage and reliability.

NB-IoT (Narrowband Internet of Things):

NB-IoT is a connectivity technology specifically designed for IoT devices with specific battery life and bandwidth needs.

Advantages of NB-IoT:

Low power consumption: NB-IoT is extremely energy-efficient, allowing devices to operate remotely or in locations with limited power sources for extended periods. It features features such as Power Saving Mode (PSM) and Extended Intermittent Reception (eDRX) to conserve battery power.

Low costs: NB-IoT deployments are more cost-effective than 4G LTE or 5G technologies, due to lower data plan costs and less complex hardware. It also connects directly to the network without the need for a gateway device, eliminating additional costs.

Efficient Spectrum Use: NB-IoT networks operate on narrow frequency bands, allowing for a greater number of devices to be accommodated on the network and using "guard bands" to prevent interference.

Better Indoor Coverage: NB-IoT is ideal for IoT devices inside buildings, underground, or in remote locations because it uses a single narrow frequency band, which increases power transmission density and signal penetration depth.

High Device Capacity: Low power consumption and low device complexity enable a high density of devices within an NB-IoT network, making it scalable to accommodate a large number of devices.

Disadvantages of NB-IoT:

Higher Latency: NB-IoT is not ideal for applications that require continuous, real-time data transfer, as it has higher latency compared to technologies such as 4G-LTE or 5G.

Less Suitable for High Mobility: NB-IoT is primarily designed for fixed or low-mobility devices and does not support seamless handover between network cells, making it less suitable for applications involving high mobility.

Inconsistent Deployment: Although NB-IoT networks are available in some regions, their global deployment is not as widespread, requiring more contracts from different telecom companies for broader global coverage.

GSM:

GSM modules are used in gas leak detection systems to send SMS alerts to designated contacts when a leak is detected. Additionally, GPS modules can be integrated to enable precise tracking of the system's location, facilitating rapid response in emergency situations.

I.5.6. Key Performance Requirements for Communication Technologies:

The performance requirements for communication technologies in gas protection systems are critical to ensuring the effectiveness and safety of these systems. These requirements include reliability, range, power consumption, and response time.

1. Reliability

Reliability is the cornerstone of gas leak detection systems, as they must be capable of transmitting data stably and reliably to ensure early detection and effective response. Gas detection control panels require ruggedness and reliability, even in harsh environments, to meet stringent safety standards.

Standards such as UL 60335-2-40 set stringent reliability requirements, particularly regarding sensor drift over the lifetime of the system. For example, refrigerant detection systems must consistently initiate a system response within 60 seconds when the sensor is exposed to a refrigerant gas concentration of 25% of the lower flammable limit (LFL) over the lifetime of the sensor. This ensures that the system remains reliable over the long term, even with natural changes in sensor performance over time.

2. Range

The effective range of communication technologies is critical for covering large and remote areas, especially in the oil and gas sector where pipelines span millions of miles and require continuous monitoring. Private wireless networks using the 900 MHz frequency enable rapid and cost-effective deployment of environmental sensors for monitoring gas infrastructure and covering large areas with a smaller number of cell sites.

Range requirements vary greatly between technologies:

LoRaWAN: Offers a long range of up to several kilometers in urban areas and more than 15 kilometers in rural areas, making it ideal for large-scale applications.

Wi-Fi: Has a relatively limited range (tens to hundreds of meters) and may require signal boosters to cover large buildings.

BLE: Suitable for short-range communications (10-100 meters), especially indoors.

NB-IoT: Offers better indoor coverage and deep signal penetration, making it suitable for devices located inside buildings or underground.

3. Power Consumption

Power consumption is a critical factor, especially for battery-powered devices in remote or hard-to-reach locations. Communication technologies are designed to maximize battery life to minimize maintenance and operating costs.

LoRaWAN: Known for its exceptional power efficiency, devices can operate on small batteries for up to 10 years.

NB-IoT: Designed for low power consumption, making it suitable for remotely operated devices. It includes features such as Power Saving Mode (PSM) and Extended Intermittent Reception (eDRX) to conserve battery power.

BLE: Optimized for low-power operations, enabling long battery life.

Wi-Fi and traditional cellular networks (4G/5G): These consume significantly more power, making them less suitable for long-term battery-powered devices.

4. Response Time

Fast response time is critical in gas leak detection systems to ensure prompt intervention and mitigate risks. Safety standards require specific response times to ensure effective risk mitigation.

UL 60335-2-40: Requires that refrigerant detection systems initiate a system response within 10 seconds or less when the sensor is exposed to a refrigerant gas concentration of 25% LFL. This update represents a significant improvement over the previous requirement (100% LFL), ensuring early detection and prevention of fires.

Wireless Network Alarm Systems: These can quickly determine the location and nature of an event, saving valuable time to prevent escalation.

LoRaWAN (Class C): Suitable for urgent response and alarm scenarios due to its continuous listening mode and low (near-real-time) response time.

Zigbee: Offers faster connectivity and low latency, making it suitable for mission-critical applications requiring real-time data.

NB-IoT: Has higher latency compared to 4G-LTE or 5G technologies, which can lead to delays in data transmission.

The importance of these requirements demonstrates that the choice of communication technology must be compatible with the specific environment, gas type, and potential hazards to ensure the highest levels of safety.

1.5.7. Relevant Industrial Standards and Protocols

To ensure the highest levels of safety and reliability in gas leak protection systems, these systems are subject to a set of strict industrial standards and protocols.

1. CGA GC6.14 (Carbon Dioxide)

CGA GC6.14 is a recent guideline issued by the Compressed Gases Association, setting minimum safety requirements for the storage, handling, and use of carbon dioxide in beverage dispensing applications. This standard focuses on:

Gas Detection Systems: Requires the installation of fixed gas monitoring devices in areas where carbon dioxide is likely to accumulate.

Ventilation Requirements: Specifies appropriate ventilation design to ensure gas dispersion.

Alarm Thresholds: Monitors must trigger alarms at the time-weighted average (TWA) threshold of 5,000 parts per million (ppm) and the short-term exposure limit (STEL) of 30,000 ppm. Alarms must be clearly visible and audible to workers.

Maintenance and Calibration: The standard requires periodic system inspections, including calibration of carbon dioxide safety systems and alarm testing. Facilities must maintain documentation of calibration and inspections.

Employee Training: It emphasizes the need for documented training programs that focus on carbon dioxide hazard recognition, alarm response, evacuation plans, and proper use of safety equipment.

2. NFPA 820 (Combustible Gas Detection)

NFPA 820 provides guidelines for detecting combustible gases in wastewater facilities, with the goal of mitigating the risk of gas explosions and fires. These guidelines recommend the use of combustible gas detectors to comply with the standards. They also note that personal or wearable devices may provide a layer of protection, but their accuracy is often poor, and they strongly recommend supplementing them with more reliable fixed gas detectors in potentially hazardous areas.

3. UL 60335-2-40 (Refrigerant Detection Systems)

The fourth edition of UL 60335-2-40, published in December 2022, is a significant update to the requirements for refrigerant detection systems. These updates aim to enhance robustness and reliability, and account for scatter and drift over the life of the system.

Response Time: Refrigerant detection systems must initiate a system response within 10 seconds or less when the sensor detects a refrigerant gas concentration of 25% LFL. This is a significant change from the previous requirement (100% LFL), which was too high to effectively mitigate fire hazards.

Lifetime Reliability: Updated Annexes (Annex 101.DVM and LL.7.2.DV) require data and evidence to demonstrate sensor lifetime and specify that over the life of the refrigerant sensor, the system must consistently trigger a response within 60 seconds when exposed to a 25% LFL concentration.

4. ISA100 Wireless (For Industrial Applications)

ISA100 Wireless is an international standard (IEC 62734) for wireless communication systems in industrial automation. This standard meets SIL-2 (Safety Integrity Level 2) certification requirements, making it suitable for critical applications such as wireless gas detection where functional safety is critical. ISA100 Wireless ensures interoperability between devices from different suppliers, providing high-quality integrated solutions.

5. Modbus RTU

Modbus RTU is a common serial communication protocol in industrial environments. Although it is essentially a wired protocol, it is often used as an integration point for wireless systems, allowing control panels with an RS485 Modbus output to connect to remote monitoring systems.

6. The Importance of Standard Operating Procedures (SOPs)

Standard operating procedures (SOPs) are essential to ensure consistency and safety in handling gas detection monitoring devices. SOPs should cover the entire lifecycle of the device, from selection and installation to calibration and maintenance. They should also include emergency protocols, documentation standards, and clearly defined roles for employees. SOPs help meet compliance requirements from regulatory agencies such as OSHA and NFPA, making them a vital part of any audit-ready safety program.

These standards and protocols form a comprehensive framework to ensure that gas protection systems are designed, installed, operated, and maintained with the highest levels of safety and reliability.

1.5.8. Future Trends in Gas Protection Technologies

The field of gas leak protection systems is experiencing rapid developments, driven by advances in the Internet of Things (IoT), artificial intelligence (AI), and materials science. These future trends aim to enhance detection accuracy, response speed, and operational efficiency.

1. Integration of the Internet of Things (IoT) and Artificial Intelligence (AI):

The integration of the Internet of Things (IoT) and artificial intelligence (AI) is a major trend transforming leak detection strategies from reactive to proactive.

Become proactive: IoT-connected sensors collect continuous audio data, which is analyzed by AI algorithms to identify potential leaks as they occur. This significantly reduces exposure to risks, downtime, and repair costs.

Predictive data analysis: Machine learning algorithms can analyze complex sensor data patterns to improve gas detection accuracy, predict sensor failure, and reduce false alarms. This allows teams to address problems before they escalate.

Remote monitoring and automated control: IoT integration enables remote monitoring and control of gas detection systems. When a leak is detected, the system can trigger automated responses such as activating ventilation fans or closing solenoid gas valves.

2. Wearable Sensors

The development of wearable gas detectors, integrated into personal protective equipment (PPE), is an important step toward improving worker safety in hazardous industries. These devices provide personalized gas monitoring in the worker's immediate work environment.

3. Gas Detection by Drones

Unmanned aerial vehicles (UAVs) equipped with lightweight gas sensors are being used to detect leaks in pipelines and remote areas. This approach offers a new dimension to monitoring capabilities, allowing access to areas that are difficult to access or dangerous to humans.

4. Nanomaterials to Improve Sensor Performance

The use of nanomaterials such as graphene, carbon nanotubes, and metal-organic frameworks (MOFs) is expected to lead to significant improvements in the sensitivity of methane sensors, faster response times, and enhanced selectivity. These materials open the way for more accurate and effective sensors.

5. Energy-Efficient Sensors

The development of low-power methane sensors aims to extend the battery life of wireless, remote, or portable detection systems. This makes them more practical for a wide range of applications and reduces the maintenance burden.

6. Acoustic Measurement Technologies and Acoustic Leak Detection

Innovations in acoustic measurement, such as advanced sound intensity mapping and precise leak source localization, are improving leak detection accuracy. These technologies can pinpoint leak sources and significantly reduce energy waste, especially in compressed air leaks. Technologies such as optical gas imaging (OGI) and volatile organic compound (VOC) analyzers complement acoustic detection to provide a more comprehensive picture of emissions.

These trends indicate a shift toward faster, smarter, and more predictive leak detection systems, enabling companies to enhance compliance, reduce downtime, and improve overall safety.

Conclusion

Telecommunication technologies have revolutionized gas leak protection systems, transforming them from reactive solutions to proactive and intelligent systems. Gas detection control panels are essential components of any industrial safety system, monitoring gas levels and alerting workers when dangerous levels are present.

Wireless technologies such as Wi-Fi, Bluetooth, LoRaWAN, and NB-IoT offer significant advantages in terms of ease of installation, scalability, and remote monitoring, making them suitable for a wide range of applications from smart homes to harsh industrial environments. However, choosing the right technology requires a careful balance between range, power consumption, response time, and interference resistance. For example, LoRaWAN is ideal for large-scale, low-power monitoring, while Wi-Fi offers higher data speeds and seamless integration with smart applications in smaller environments.

Industry standards such as CGA GC6.14, NFPA 820, and UL 60335-2-40 define stringent requirements for ensuring the reliability and accuracy of gas detection systems, with an emphasis on alarm thresholds, response times, and maintenance protocols. Standard operating procedures (SOPs) complement these standards, providing a framework for ensuring consistency and reducing human error in safety management.

Future trends point to a deeper integration of the Internet of Things and artificial intelligence, enabling predictive analytics, automated responses, and a shift toward proactive leak detection strategies. Innovations in wearable sensors, drone detection, and nanomaterials are also enhancing the capabilities of these systems.

CHAPTER TWO

II.1 introduction:

With rapid technological advancements, smart systems have become an essential part of our daily lives, facilitating tasks and achieving a high level of safety and efficiency. Among these systems, microcontroller-based electronic systems such as Arduino stand out, allowing for the creation of interactive, multi-purpose projects.

With the increasing reliance on domestic gases (such as natural gas and liquefied petroleum gas) for cooking and heating applications, the risk of leaks and the resulting unfortunate incidents such as explosions and poisonings increases. From this perspective, this project aims to design and implement a prototype of a smart home gas leak detection system that leverages Internet of Things (IoT) technologies to provide continuous monitoring, immediate alerts, and automated response mechanisms to increase safety levels.

The project focuses on the use of common and affordable electronic components, making it a practical and widely applicable model. The system will include an MQ-2 gas sensor for gas detection, an Arduino controller for data processing, an information display, response modules such as a ventilation fan or an audible alarm controlled via a relay module, and LEDs to visualize the system status. The system also features the ability to send alerts and data over the internet via the ESP8266 wireless communication module.

This project represents an excellent educational model for understanding how sensors work, controlling outputs, and applying Internet of Things (IoT) principles in a simple and effective manner. This type of project also provides an opportunity to develop programming, electronics, and logical thinking skills in solving problems related to home safety.

II.2 Comprehensive Description of Electronic Components:

II.1.1 Description of the Arduino UNO board (Arduino UNO/Nano/Mega)

Arduino is a popular open-source electronics development platform based on microcontrollers from the Atmel AVR family (such as the ATmega328P in the Arduino Uno). It is essentially a programmable electronic board designed to facilitate programming interactive electronic circuits. It was developed by a team that included Massimo Banzi and his colleagues.

Every Arduino board, including the Arduino Uno in particular, consists of a microcontroller as the brain, along with other supporting components such as a crystal oscillator (usually 16 MHz) to provide the necessary timing for operations, a linear voltage regulator (5V) to ensure power stability, and serial communication circuits to facilitate communication with the computer and other components.

The essence of Arduino is that it is an integrated circuit (microcontroller) on which instructions can be recorded. These instructions, written using an Arduino-specific programming language (based on C/C++) within the Arduino IDE, allow users to create programs that interact with the circuits connected to the board, opening the way for the design of versatile interactive projects in a variety of fields.

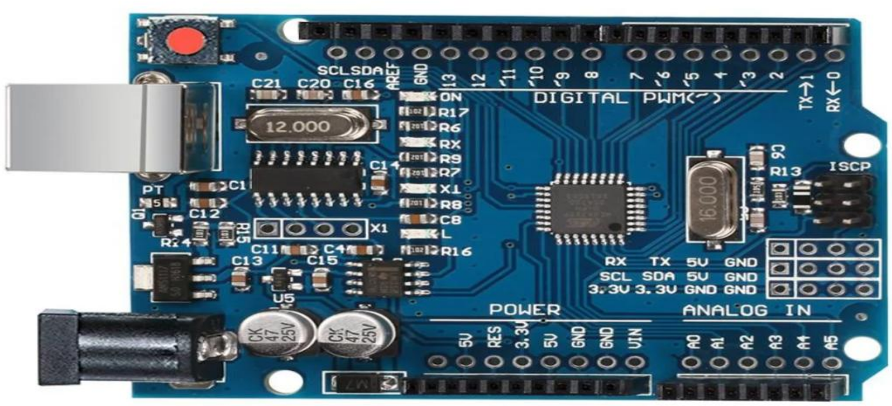

Figure 3: Arduino Uno

II.1.2 Characteristics of the Arduino Uno:

The Arduino Uno board is ubiquitous in many projects. This is due to its attractive features. The following table shows the features of the Arduino Uno board:

Table 5: Characteristics of the Arduino Uno.

Microcontroller	ATmega328P
Operating Voltage	5 V
Input Voltage (Recommended)	7 to 12 V
Input Voltage (Limits)	6 to 20 V
Digital I/O Pins	14 (6 of which provide a PWM output)
Analog Input Pins	6 (A0-A5)
Continuous Current per I/O Pin	40 mA
Continuous Current for 3.3V Pin	50 mA
Flash Memory	32 KB (0.5 KB used by the boot loader)

II.1.3 Arduino Uno Pinout Description

Table 6:discription of Arduino uno

Pine category	**Name of the pine tree**	**Details**
Power supply	Vin, 3.3V, 5V, GND	Vin: Input voltage to the Arduino when using an external power source. 5V: Regulated power supply used to power the board's components. 3.3V: 3.3V power supply generated by the onboard voltage regulator. The maximum current draw is 50 mA. GND: Ground pin.
Reset	Reset	Reset the microcontrôleur
Analog Pins	A0 to A5	Used to provide analog input.
Input/Output pins (digital pins)	0 to 13	Used as input or output pin.
Serial	0 (Rx), 1 (Tx)	Used to receive and transmit data.
External interruptions	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.
SPI	10 (SS),11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Integrated LED	13	To turn on the integrated LED.
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide a reference voltage for the input voltage.

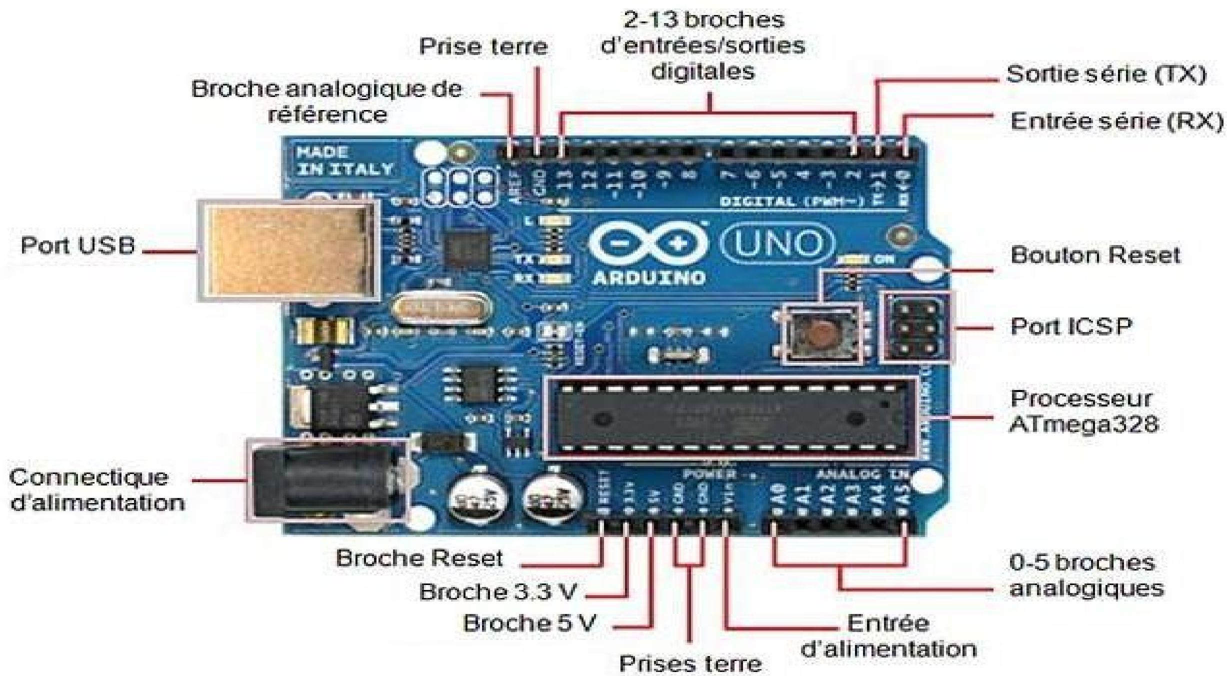

Figure 4: Description of the carte Arduino Uno

II.2.1 Description of the GAS SENSORA gas sensor is a device used to detect the presence of gas in a given area. Its operation is based on converting a chemical or physical interaction with the gas into a measurable electrical signal.

II.2.2 Different Types of Gas Sensors

There are several types of gas sensors. Here, we will explore the basic operating principles of these sensors, focusing on the most commonly used types.

• Electrochemical Sensors

These sensors measure gas concentration using an electrochemical reaction that produces an electrical current.

Operating Principle: Electrochemical reaction: The target gas diffuses through a membrane and reacts at the electrode inside the sensor, producing a chemical reaction.

Current generation: This reaction generates an electrical current proportional to the gas concentration.

Measurement circuit: The current produced is measured and converted into an electrical signal.

• Infrared Sensors (NDIR - Non-Dispersive InfraRed)

These sensors detect gases by measuring the absorption of infrared light at specific wavelengths.

Operating Principle:

Infrared Source: An infrared light source emits a beam through a measuring chamber containing the target gas.

Light Absorption: Gas molecules absorb infrared light at specific wavelengths.

Detection: A detector measures the intensity of the light after absorption. The amount of light absorbed is proportional to the gas concentration.

Signal Conversion: The optical signal is converted into an electrical signal corresponding to the gas concentration.

• Catalytic Sensors

These sensors are used to detect combustible gases.

Operating Principle:

Catalytic Oxidation: The target gas is oxidized on the surface of a heated element coated with a catalyst (such as platinum).

Temperature change: The exothermic reaction produces an increase in temperature, changing the electrical resistance of the heated element (platinum wire or wafer).

Resistance measurement: The change in resistance is measured and converted into an electrical signal proportional to the gas concentration.

• Semiconductor sensors (MOS - Metal Oxide Semiconductor)

These sensors use a semiconductor material, usually tin oxide ($SnO2$), whose conductivity changes in the presence of certain gases.

Operating principle:

Gas adsorption: When the target gas comes into contact with the semiconductor material, it is adsorbed on the surface.

Conductivity change: The adsorption of gas molecules changes the electrical resistance of the semiconductor. For example, reducing gases such as carbon monoxide (CO) reduce resistance, while oxidizing gases such as nitrogen dioxide (NO2) increase resistance**.**

Resistance measurement: This resistance variation is measured and converted into an electrical signal proportional to the gas concentration.

The MQ-2gas sensor used in our project belongs to the latter family (of semiconductor (MOS) sensors). The following sections present its definition and characteristics.

II.2.3 MQ-2 gas sensor:

The MQ-2 sensor is one of the most popular sensors in the MQ family. It is a type of MOS (Metal Oxide Semiconductor) sensor. These kinds of sensors are also called Chemi resistors because they work by changing their electrical resistance when they come into contact with certain gases.

The MQ-2 gas sensor runs on 5 volts of DC power and uses about 800 milliwatts of energy. It can detect several types of gases, including LPG (liquefied petroleum gas), smoke, alcohol, propane, hydrogen, methane, and carbon monoxide. This sensor can detect these gases when their concentrations are between 200 and 10,000 parts per million (ppm)

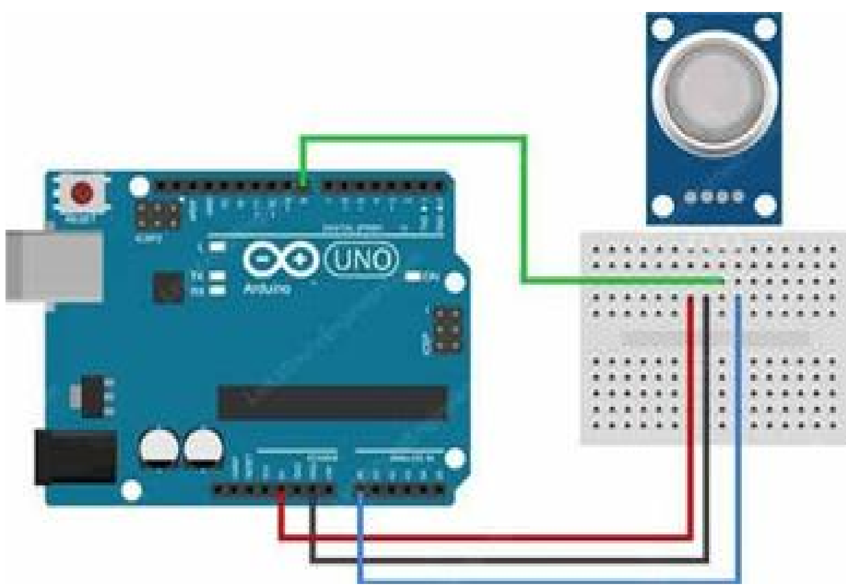

Figure 5:MQ2 sensor connected to Arduino with Fritzing software

II.2.4 Gas sensor MQ-2 working principle

When you turn on an MQ-2 gas sensor, it starts heating up its internal Tin Dioxide (SnO_2) semiconductor layer to a high temperature. At this high temperature, oxygen molecules from the air stick (or adsorb, if you prefer the technical term) to the surface of the Tin Dioxide. These adsorbed oxygen molecules pull free electrons away from the Tin Dioxide, which creates an"electron depletion region" near the surface. This makes the Tin Dioxide highly resistant to electrical flow, so only a small amount of electric current can pass through it.

When combustible gases enter the sensor, they react with the oxygen molecules that are stuck to the Tin Dioxide surface. This chemical reaction releases the electrons that were being held by the oxygen. As these electrons return to the Tin Dioxide, the electron depletion region gets smaller. This reduces the resistance, allowing electricity to flow much more easily through the sensor

The MQ-2 sensor works by detecting these changes in electrical resistance. The more flammable gas there is, the more oxygen molecules react, and the more the resistance decreases. This makes it easier for microcontrollers connected to the sensor to detect both the presence and the concentration of gas in the air

Figure 6:MQ-2 Gas Sensor Working principle

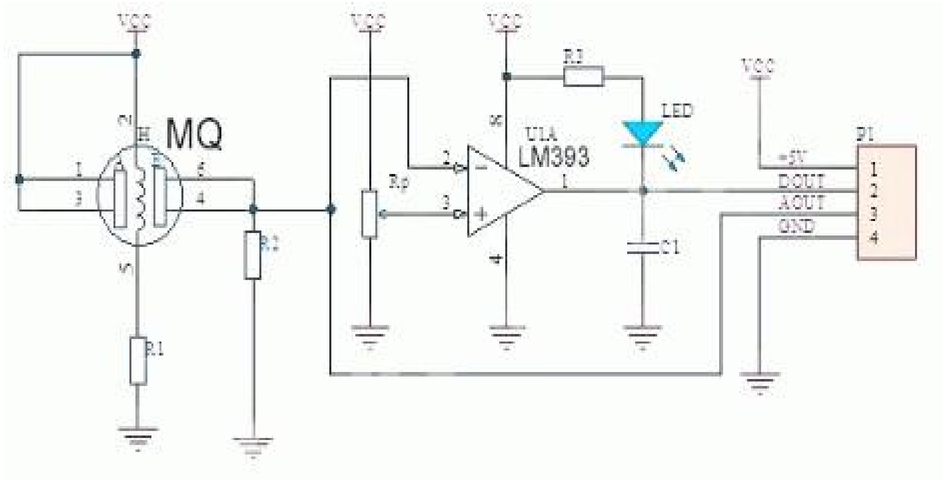

Figure 7: Electrical diagram of MQ-2module

II.3.1 Description of the ESP8266

The ESP8266 is a System on a Chip (SoC), manufactured by the Chinese company . It consists of a Tensilica L106 32-bit micro controller unit (MCU) and a Wi-Fi transceiver. It has 11 GPIO pins* (General Purpose Input/Output pins), and an analog input as well. This means that you can program it like any normal Arduino or other microcontroller. And on top of that, you get Wi-Fi communication, so you can use it to connect to your Wi-Fi network, connect to the Internet, host a web server with real web pages, let your smartphone connect to it, etc ... The possibilities are endless! It's no wonder that this chip has become the most popular IOT device available.

II.3.2 the ESP8266 Working principle

The ESP8266 works by connecting to a Wi-Fi network and running custom code that you upload to it, allowing it to control hardware (like LEDs or sensors) and send or receive data over the internet. It can act as a web server so you can interact with it using a browser, or it can connect to online services to send sensor data or receive commands. It uses GPIO pins to interface with electronic components, and you can program it using the Arduino IDE or Micro Python. It operates in either Station Mode (connecting to existing Wi-Fi) or Access Point Mode (creating its own Wi-Fi network), making it ideal for IoT and smart home projects

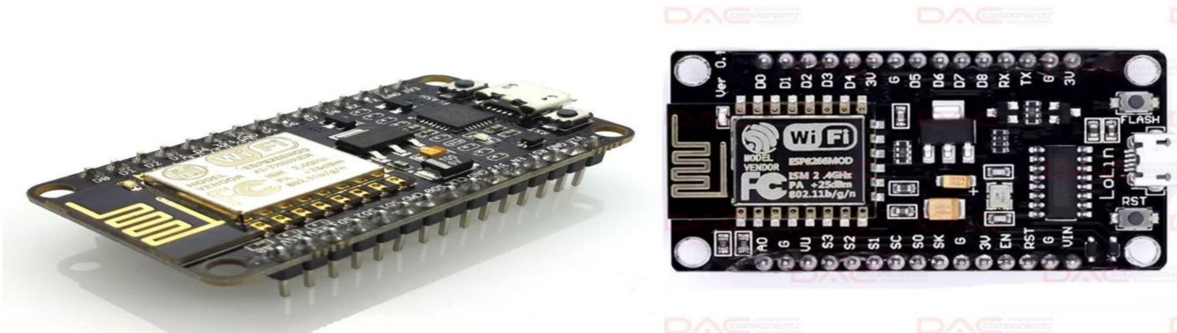

Figure 8:ESP8266

Table 7:*Key Specifications*

Feature	Details
CPU	32-bit Tensilica L106 @ 80–160 MHz
Memory	64KB RAM + 4MB Flash (for firmware & data)
Wi-Fi	802.11 b/g/n (2.4 GHz only)
GPIO Pins	17 (multifunctional: PWM, I2C, SPI, UART)
Voltage	3.3V (but some pins are 5V-tolerant)
Power Consumption	Low power (~70mA active, ~10µA in deep sleep

II.4.1 Description of the RELAY

A Relay is a simple electromechanical switch. While we use normal switches to close or open a circuit manually, a Relay is also a switch that connects or disconnects two circuits. But instead of a manual operation, a relay uses an electrical signal to control an electromagnet, which in turn connects or disconnects another circuit.

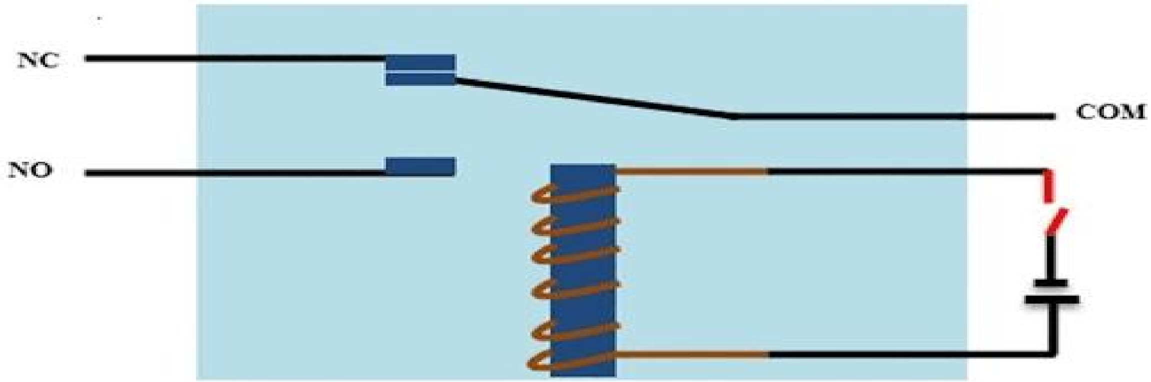

Figure 9:Relay Working animation

II.4.2 Relay working principle:

A relay operates on the principle of electromagnetic induction. It consists of a copper coil and an iron core that act as an electromagnet. When a small electrical current (such as 5 volts from an Arduino board) is passed through the coil, a magnetic field is generated that attracts the mechanical contact inside the relay, causing another electrical circuit with a higher voltage or current (such as a fan circuit) to close or open. This process is known as energizing the relay. When the current to the coil is disconnected, the magnetic field disappears and the contact returns to its original position, a process known as de-energizing the relay. This mechanism allows the relay to act as an electrical insulator between the control circuit (such as the Arduino) and the high-voltage circuit of the connected device, providing safe and efficient control of electrical loads.

Figure 10:electrical relay

II.5.1 Description of the Servo motor:

A servo motor is an electric motor that allows for precise control of angular position. It comprises a position feedback mechanism to accurately control its motion. The term 'servo' is derived from 'servomechanism', which is a system that uses feedback to automatically provide a controlled power level or force to move and hold an object at a certain position. Servo motors are typically rated in kg/cm (kilogram per centimeter). For example, hobby servo motors might be rated at 3kg/cm, 6kg/cm, or 12kg/cm. This rating indicates the weight the motor can lift at a specific distance. For instance, a 6kg/cm servo motor can lift a 6kg load if it is placed 1cm away from the motor shaft. As the distance increases, the weight capacity decreases. The position of a servo motor is controlled by an electrical pulse, with the motor's circuitry providing feedback on its position.

Figure 11: Electric servo motor

II.5.2 Servo Motor Working Mechanism

It consists of three parts:

- Controlled device
- Output sensor
- Feedback system

It is a closed-loop system where it uses a positive feedback system to control motion and the final position of the shaft. Here the device is controlled by a feedback signal generated by comparing output signal and reference input signal.

Here reference input signal is compared to the reference output signal and the third signal is produced by the feedback system. And this third signal acts as an input signal to the control the device. This signal is present as long as the feedback signal is generated or there is a difference between the reference input signal and reference output signal. So the main task of servomechanism is to maintain the output of a system at the desired value at presence of noises.

II.6.1 Description of the ventilation:

Fans are mechanical devices used to move air within a ventilation system. They are often described as the "workhorses" of such systems because they create the necessary airflow to transport air and airborne contaminants from the source, through ducts and filtration units, and finally out of the building.

Figure 12:the ventilation

II.6.2 Fans in Ventilation Systems:

Fans are essential components of ventilation systems. They move air by converting the mechanical energy generated by an electric motor into kinetic air energy. Their primary function is to create a pressure difference between the two sides (the inlet and outlet), forcing air into and out of the system, thus ensuring effective ventilation.

1. Air Intake:

The ventilation process begins when the fan draws air from the surrounding environment, such as a closed room, workspace, or pollutant emission site. This is often done through a vent or air hood placed near the source of the pollution to ensure efficient capture of the polluted air.

2. Air Acceleration:

When the motor is turned on, the fan blades begin to rotate rapidly, transferring mechanical energy to the surrounding air. This increases air velocity and creates a low-pressure area at the fan inlet. According to the principle of aerodynamics, air moves from high to low pressure areas, and air is automatically pushed toward the fan to compensate for the pressure difference.

3. Pressure Generation:

As the blades continue to rotate, compressed air is forced toward the fan's outlet, creating a high-pressure area on that side. This pressure difference between the inlet and outlet contributes to a continuous flow of air within the system.

4. Air Transport and Filtration:

The moving air generated by the fan carries environmental contaminants into the ventilation ducts, which are often connected to filtration units or air handlers. These units are used to purify the air of toxic gases or harmful particles before expelling it outside.

5. Exhaust:

After the air passes through the filters (if present), the fan continues to push the clean or treated air out of the building through the exhaust ports, completing the ventilation cycle and replacing the polluted indoor air with clean air.

II.6.3 Types of Fans Used in Ventilation Systems

Centrifugal Fans:

They use curved blades rotating at high speeds to generate high pressure, making them ideal for pushing air through systems containing long ducts or high-resistance filters.

Axial Fans:

Similar in operation to household fans, they push air in a straight line. They are often used in situations requiring high airflow with low resistance, such as general ventilation or direct cooling

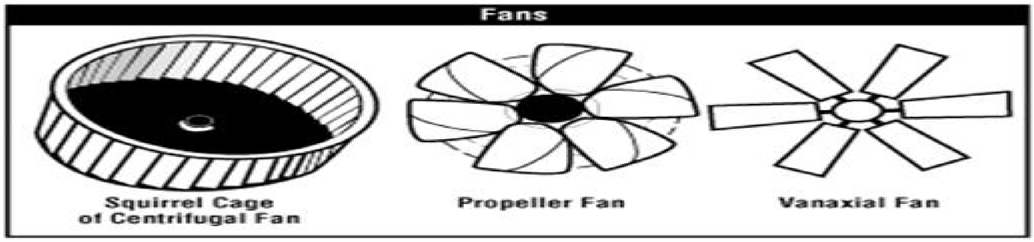

Figure 13: Ventilation Systems

II.7.1 What Is a Buzzer?

A buzzer is an electronic or electromechanical device that produces a loud sound or tone to serve as an audible alert or warning signal. Commonly used in alarms, timers, and electronic devices, buzzers are activated by an electrical signal and emit a continuous or pulsing sound to draw attention to a specific condition—such as an error, timer completion, or safety hazard. There are two main types: electromechanical buzzers, which use a vibrating diaphragm and magnetic coil, and piezoelectric buzzers, which use a piezo element that vibrates when voltage is applied.

Figure 14: Electric buzzer

II.7.2 Buzzer working principle

A buzzer works by converting electrical energy into sound through either mechanical or piezoelectric means. In an electromechanical buzzer, when voltage is applied, an electromagnet moves a diaphragm back and forth rapidly, producing sound waves. In a piezoelectric buzzer, an alternating electrical signal is applied to a piezoelectric material, causing it to vibrate at specific frequencies, which generates audible sound. The sound serves as an alert or warning in various systems, including alarms, appliances, and industrial equipment. The type of signal (continuous or pulsed) determines the buzzer's sound pattern, which can convey different messages or urgency levels.

II.7.3 Types of Buzzers:

A buzzer is available in different types which include the following:

- Piezoelectric
- Electromagnetic
- Mechanical
- Electromechanical
- Magnetic

II.8.1 What is an 16x2 LCD (Liquid Crystal Display)?

A 16x2 LCD (Liquid Crystal Display) is a widely used electronic display module that can show 2 rows of 16 alphanumeric characters, typically driven by the HD44780 controller. It operates using liquid crystal technology, where electric voltage changes the alignment of liquid crystals to control light passage, thus forming visible characters on the screen. This module supports both 4-bit and 8-bit parallel communication modes, allowing it to interface easily with microcontrollers like the Arduino Uno for displaying messages, sensor data, or system status. A potentiometer is often used to adjust the display contrast, and an LED backlight enhances visibility. Its low cost, simplicity, and readability make it ideal for embedded systems, IoT devices, and hobbyist projects.

II.8.2 How a 16x2 LCD Works

A 16x2 LCD works by using liquid crystal molecules sandwiched between two polarizing filters and transparent electrodes. When a voltage is applied across specific segments of the display via the HD44780 controller, the orientation of the liquid crystals changes, affecting the light passing through and making selected characters visible. The HD44780 controller interprets instructions sent from a microcontroller (like Arduino) to determine which characters to show, and where to show them. The display operates in 4-bit or 8-bit parallel communication mode, where data and commands are sent in chunks. A Register Select (RS) pin tells the controller whether the incoming signal is data (to display) or a command (like clear screen), while the Enable (E) pin latches the data. A potentiometer connected to the contrast pin (V0) adjusts the clarity of the characters, and an LED backlight improves visibility in low-light conditions.

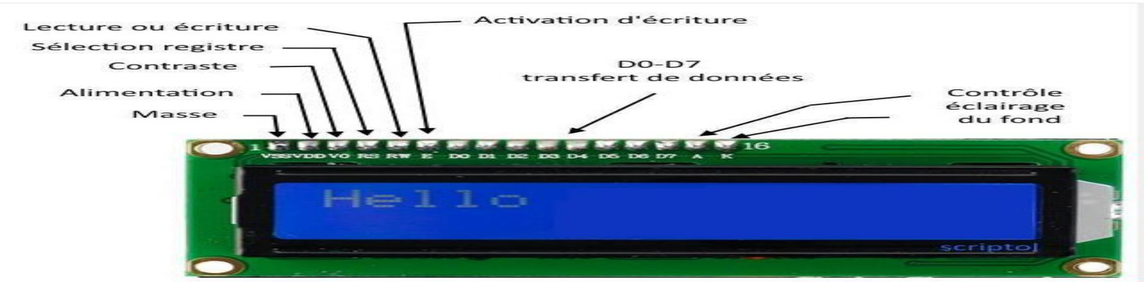

Figure 15:16x2 LCD

II.9.1 Description of the breadboard

A breadboard is a solderless prototyping tool designed for constructing and testing electronic circuits efficiently. It functions through a network of internal conductive metal strips that electrically link groups of holes on its surface. The central area is divided by a gap (commonly called a "trench") to accommodate dual in-line package (DIP) components such as integrated circuits, with rows of five interconnected terminals on either side. The outer columns, known as power rails, run vertically and are typically used to distribute supply voltage and ground across the circuit. When components or jumper wires are inserted into the breadboard's holes, they become electrically connected via these internal strips, enabling rapid circuit assembly, modification, and troubleshooting without permanent soldering.

II.9.2 Features of LEDs:

- Very low power consumption compared to traditional bulbs.
- Long lifespan, lasting thousands of hours.
- Generates very little heat, making it safe to use.
- Available in multiple colors (red, green, blue, white...).

II.9.3 Working Principle of LED:

An LED operates based on a physical phenomenon called electroluminescence: When electric current passes through a semiconductor material inside the LED (usually a combination of gallium and arsenic or phosphorus), Electrons move within the material, as they move, they release photons (which are particles of light), and this is how illumination is produced.

Figure 16:LEDs

II.3 Project Operation:

The Gas Leak Monitoring and Control Device is an integrated safety system designed to detect the presence of hazardous gases such as carbon monoxide (CO) and liquefied petroleum gas (LPG) in real-time. Upon detection of a gas leak, the system triggers a series of coordinated responses aimed at mitigating the hazard and ensuring the safety of individuals in the affected environment. The key components in this system include the MQ-2 gas sensor, Arduino Uno, ESP8266 Wi-Fi module, relay, servo motor, buzzer, fan, and a breadboard for circuit connections.

The operation of this system proceeds as follows:

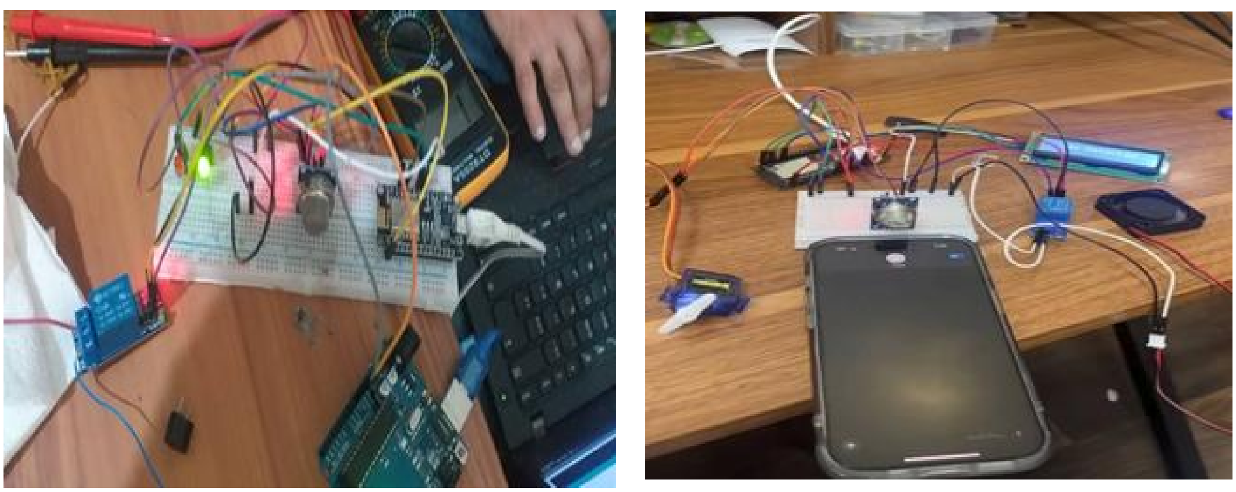

Figure 17: Project Operation overview

3.1. Gas Detection (MQ-2 Gas Sensor)

The MQ-2 gas sensor is employed to continuously monitor the air for carbon monoxide (CO), LPG, methane, and smoke. The sensor operates on the principle of detecting changes in the resistance of its sensitive material when exposed to various gases. The sensor provides an analog output, which the Arduino Uno processes to determine whether the gas concentration exceeds safe thresholds. If the gas concentration exceeds predefined levels, the sensor sends a signal to the Arduino, indicating the presence of a potential gas leak.

Key Functions of MQ-2: Gas concentration detection and providing the Arduino with analog data for processing.

3.2. Data Processing and Decision-Making (Arduino Uno)

The Arduino Uno serves as the system's central microcontroller. Upon receiving input from the MQ-2 sensor, the Arduino compares the sensor's output to a set threshold. If the gas levels surpass the threshold, indicating a gas leak, the Arduino triggers a series of predefined actions.

The Arduino's core tasks include:

Processing the analog signal from the MQ-2 sensor.

Activating safety measures, including the alarm, ventilation system, and mechanical control systems.

3.3. Alarm Activation (Buzzer)

When a gas leak is detected, the Arduino Uno immediately activates the buzzer. The buzzer emits an audible alarm to alert individuals in the vicinity about the potential hazard. This alarm acts as the first line of defense, prompting occupants to evacuate or take immediate action.

Buzzer Function: Alerts nearby individuals to the gas leak through an audible sound.

3.4. Ventilation Activation (Fan via Relay)

In parallel with the alarm, the Arduino activates the fan through a relay module. The relay acts as an interface between the low-voltage Arduino and the high-power fan, allowing the fan to be powered on or off safely. The fan operates to clear the hazardous gases by circulating fresh air, reducing the gas concentration and helping to restore a safe environment.

Relay Function: Safely controls the fan using the Arduino's digital output signals.

Fan Function: Increases airflow to ventilate the space and reduce gas buildup.

3.5. Mechanical Control (Servo Motor)

To further enhance the ventilation process, the Arduino controls a servo motor to open a window or ventilation hatch. The servo motor is precisely controlled by the Arduino to move to a specified angle, allowing fresh air to flow in and aid in dispersing the gas. This act of mechanical ventilation significantly contributes to lowering gas concentrations in the environment. Servo Motor Function: Opens a window or ventilation hatch to improve airflow and further disperse gas.

3.6. Remote Alerting (ESP8266 Wi-Fi Module)

The ESP8266 Wi-Fi module is used for IoT connectivity to send remote alerts when a gas leak is detected. After the Arduino processes the sensor data, it communicates with the ESP8266, which sends notifications to predefined recipients (e.g., via email, SMS, or mobile app) to inform them of the detected gas leak. This feature ensures that even if the occupants are not present in the vicinity, appropriate personnel can respond quickly to the emergency.

ESP8266 Function: Sends remote alerts via email, SMS, or IoT applications to notify individuals about the detected gas leak.

3.7.LCD Display (16x2 I2C)

Role: Local status monitoring

Advantages:

Shows real-time gas levels in PPM

Displays system status (Normal/Alert)

I2C interface uses only 2 data pins

3.8. Circuit Connections (Breadboard)

A breadboard is used to prototype the system's electrical connections. Components such as the MQ-2 sensor, Arduino Uno, relay, servo motor, buzzer, and ESP8266 module are inserted into the breadboard, where jumper wires are used to establish the necessary connections. This provides an easily modifiable setup for testing and adjustments before finalizing the design.

Breadboard Function: Provides a platform for making temporary and flexible electrical connections for prototype circuits.

II.4. System Workflow

1. Gas Leak Detection: The MQ-2 sensor detects the presence of dangerous gases (CO or LPG) and sends data to the Arduino Uno.
2. When gas exceeds threshold, Arduino triggers both LCD display warnings (visual) and buzzer alarms (audible) with escalating intensity based on concentration levels.
3. Ventilation Activation: The Arduino sends a signal through the relay to power on the fan, facilitating the removal of the gas from the environment.
4. Mechanical Control: The servo motor is activated by the Arduino to open a window or hatch, increasing airflow and further dispersing the hazardous gas.
5. Remote Alerting: The ESP8266 Wi-Fi module sends a remote alert to inform external contacts (such as emergency services or property managers) of the gas leak.

II.5. Code Implementation

Summary of the code with functional explanations for each part.
How the MQ2 sensor is handled and the programming of the Relay, Buzzer, LCD and Fan.
This code represents a system for monitoring gas levels using the ESP8266 microcontroller. It displays readings on an LCD screen and sends alerts via the Blynk application.
Libraries Used
1. ESP8266WiFi.h: Handles WiFi connection.
2. BlynkSimpleEsp8266.h: Enables communication with the Blynk IoT platform.
3. LiquidCrystal_I2C.h: Controls the LCD display through the I2C interface.

Constants and Variables Definition

```
#define BLYNK_TEMPLATE_ID "TPL2PwyfZuXs"
#define BLYNK_TEMPLATE_NAME "detacteur de gaz"
#define BLYNK_AUTH_TOKEN "m34GoisozsBO4t26IQu6kcNBeGThaXl2"
```

Defines the Blynk template ID, name, and authentication token.

```
#define RELAY D3
#define GreenLED D4
#define RedLED D5
#define Buzzer D6
```

Pin assignments:
RELAY: Controls a device like a fan or gas valve.
GreenLED: Green indicator for normal state.
RedLED: Red warning indicator.

Buzzer: Alarm sounder.
WiFi and Blynk Setup
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "sal";   // WiFi SSID
char pass[] = "123456789"; // WiFi Password
Credentials for connecting to WiFi and Blynk.
sendSensor() Function
This function reads gas sensor values and takes appropriate action:
1. Read sensor value:
int gasValue = analogRead(GasSensor);
2. Send value to Blynk:
Blynk.virtualWrite(V0, gasValue);
3. Value handling:
If value < 150 (normal):
Turn on green LED
Deactivate alarms.
Display "Gas Normal" on LCD.
If value > 300 (dangerous level):
Turn on red LED.
Activate buzzer and relay.
Send alert via Blynk
Display "Gas Value High" on LCD
setup() Function
Initializes the system:
1. Start serial communication:
Serial.begin(115200);
2. Configure pins:
pinMode(RELAY, OUTPUT);
pinMode(GasSensor, INPUT);
// ...other pins
3. Start Blynk connection:
Blynk.begin(auth, ssid, pass);
4. Set timer
timer.setInterval(1000L, sendSensor);
5. Initialize LCD and display start message:
lcd.begin();
lcd.print("Gas Level")
lcd.print("Monitoring");
loop() Function
Runs the main tasks repeatedly:
Blynk.run(); // Maintains Blynk connection
timer.run(); // Runs the timer for periodic sensor readings

II.6 Expected Results

The proposed IoT-based gas leak detection and control device is expected to perform reliably under various environmental conditions and respond appropriately to the presence of hazardous gases such as carbon monoxide (CO) and liquefied petroleum gas (LPG). The expected system behavior and response scenarios are outlined below:

6.1. Normal Condition (No Leak Detected)

Sensor Reading: Gas concentration levels are within safe thresholds.

System Behavior:

- LCD displays “SAFE” or equivalent status message.
- Fan, buzzer, servo motor, and relay remain inactive.
- ESP8266 continues to monitor and send periodic status updates.
- No alarms triggered.

6.2. Minor Leak Detected

- LCD displays warning message: e.g., “Minor Leak Detected”.
- Buzzer beeps intermittently as a precautionary alert.
- Fan activates at low or medium speed to ventilate the area.
- Servo motor partially opens a ventilation outlet (e.g., window).
- ESP8266 sends a notification to the user’s mobile app or web dashboard.
- Relay remains inactive unless levels escalate.

6.3. Major Leak Detected

- LCD displays alert: “Dangerous Gas Levels – Evacuate!”
- Buzzer activates continuously at high intensity.
- Fan runs at full speed to expedite gas dispersion.
- Servo motor fully opens ventilation or emergency exhaust mechanisms.
- Relay triggers to shut off the gas valve or isolate power to critical appliances.
- ESP8266 sends an immediate critical alert (e.g., SMS, email, or app push notification).
- Optionally, emergency contact or monitoring center can be alerted (if integrated)

II.7 Project Challenges and Development Suggestions

Despite the effectiveness of the prototype gas leak detection system, there are several technical challenges and functional limitations that such systems may face, necessitating suggestions for improving performance and reliability.

7.1 Project Challenges

The design and implementation of the gas leak detection system faced some major challenges that impacted its performance and effectiveness. The most notable of these challenges were:

MQ-2 Sensor Delay in Response Time:

The MQ-2 gas sensor requires an initial warm-up period before it becomes operational, and it has a relatively slow response and recovery time after gas exposure. This delay can lead to delays in gas leak detection, especially in critical situations, directly impacting the safety level provided.

Dependence on EMI-Free Environment:

System reliability is significantly affected by the presence of electromagnetic interference (EMI) in the surrounding environment. Sources such as industrial equipment or other wireless devices can cause unstable sensor readings or even disrupt the microcontroller, reducing detection accuracy and reliability.

Limited Detection Accuracy in Varying Environmental Conditions:

The MQ-2 sensor's sensitivity is affected by ambient temperature and humidity, which can lead to false positives or failure to detect true leaks. To maintain consistent accuracy, algorithms are required to compensate for the effects of environmental factors or provide additional protection for the sensor.

Continuous Power Supply Requirement:

The MQ-2 sensor requires a constant power supply for its heating element to function properly. Any loss of power causes the sensor to reset and causes downtime due to the need to reheat, making backup batteries or an uninterruptible power supply (UPS) essential to ensure continuous monitoring.

Wi-Fi Connectivity Issues:

The system relies heavily on a strong and stable Wi-Fi connection to transmit data and alerts. Weak signal strength can lead to data transmission interruptions or failure to send instant alerts. This is a common problem in large buildings or basements where the signal may be weak or obstructed.

7.2. Development Suggestions

Based on the challenges mentioned, several improvements and developments can be proposed to enhance the performance and reliability of the gas leak detection system:

1. Use More Accurate and Specialized Sensors:

It is recommended to replace or supplement the MQ-2 sensor with more specialized and accurate sensors for different gases. For example, use the MQ-7 sensor for carbon monoxide (CO), and the MQ-6 or MQ-5 sensor for liquefied petroleum gas (LPG). Consideration may also be given to using high-quality industrial-grade sensors such as non-dispersive infrared (NDIR) sensors or electrochemical sensors, which offer significantly better sensitivity and selectivity.

2.Add a Backup Power Source:

A rechargeable battery or uninterruptible power supply (UPS) should be incorporated into the system design to ensure continued operation during a power outage. This ensures continuous monitoring and prevents sensor reheating delays after a power outage.

3. Develop a Mobile App for Real-Time Alerts:

It is proposed to build a companion mobile app (Android/iOS) that provides instant alerts to users, remote monitoring of system status and sensor readings, and data logging and event history. Services such as Firebase or the MQTT protocol can be used to facilitate lightweight, real-time communication between the system and the application.

4. Improve Environmental Protection:

To overcome the influence of environmental conditions, sensors can be protected with waterproof and heat-resistant covers. Additionally, temperature and humidity sensors can be added to compensate for gas readings using correction algorithms that ensure greater accuracy in changing environments.

5. Smart Home Integration:

The system's functionality can be enhanced by enabling connectivity with popular smart home platforms such as Google Home, Amazon Alexa, or Home Assistant. This enables the use of IFTTT or Zigbee/Z-Wave modules to trigger automated actions (such as turning on exhaust fans, closing smart gas valves, or sending custom alerts) when a gas leak is detected.

6. Enhance Data Processing and Analytics:

Advanced data processing techniques at the microcontroller level (such as moving average or Kalman filters) should be applied to smooth sensor outputs and reduce noise. Machine learning or AI-based learning models can also be implemented to more accurately detect unusual patterns or leaks, with the data stored in the cloud and displayed in visual dashboards for long-term monitoring.

Composant	Prix unitaire (DA)	Quantité	Total (DA)
ESP32	2700	1	2700
Buzzer	350	1	350
Breadbord	800	1	800
Ventilateur	550	1	550
Driver L298	1000	1	1000
MG996r servo	1900	1	1900
MQ-2	600	1	600
Relay 1 channel	450	2	900
Wire male	20	50	1000
Wire female	20	50	1000
Led	10	2	20

Conclusion:

The Gas Leak Monitoring and Control Device project addresses a critical safety concern by providing an early warning system for hazardous gases such as Carbon Monoxide (CO) and Liquefied Petroleum Gas (LPG). With gas-related incidents posing severe risks to human life and property, this project underscores the importance of implementing real-time detection and alert mechanisms in both residential and industrial settings.

The proposed solution demonstrates efficiency and practicality, utilizing widely available components like the MQ2 sensor, microcontrollers, and wireless communication modules to achieve timely detection and user notification. The system's potential is further enhanced through features such as mobile alerts, power backup integration, and the capability for smart home connectivity, offering a scalable and adaptable platform for gas safety monitoring.

While the current implementation forms a solid foundation, there is ample opportunity for further development, including the integration of more precise sensors, advanced data analytics, and environmental compensation techniques. With continued refinement and real-world testing, this device has strong potential for commercial deployment and large-scale impact, contributing to safer living and working environments.

CHAPTER THREE

III.1 Introduction:

"Sir-Gaz" vehicles, which run on liquefied petroleum gas (LPG), represent an alternative and economical option to traditional gasoline or diesel-powered vehicles. This type of fuel, known in Algeria as "Sir-Gaz" or "GPLc," is a mixture of propane and butane gases, compressed and stored in special tanks within the vehicle, and used as a cleaner, more affordable fuel compared to gasoline.

In recent years, Algeria has shown increasing interest in "Sir-Gaz" vehicles, driven by several factors, including the desire to reduce fossil fuel consumption, minimize harmful environmental emissions, and offer economical transportation solutions to citizens—especially in light of rising global fuel prices. The Algerian government has launched several initiatives to encourage the adoption of LPG vehicles, including subsidizing vehicle conversion costs and expanding the network of LPG fueling stations across the country.

In terms of usage rate, recent estimates indicate that more than 20% of the national vehicle fleet in Algeria now operates on "Sir-Gaz," with the number steadily increasing each year. This is particularly evident in the taxi and urban transport sectors, where drivers benefit significantly from the lower fuel costs. Vehicle conversion centers are also seeing growing demand, especially from private car owners seeking to reduce their daily transportation expenses.

Despite its economic and environmental benefits, the adoption of "Sir-Gaz" faces certain challenges. These include the limited availability of fueling stations in some areas, the relatively high initial cost of vehicle conversion for some users, and the need for regular, specialized maintenance to ensure system safety and performance.

Overall, "Sir-Gaz" is a promising option in Algeria’s energy transition strategy. It represents a significant step toward achieving more sustainable and efficient transportation in the face of global shifts in energy and mobility trends.

Despite the advantages of the "SirGas" system, the risk of gas leakage remains one of its biggest challenges. Most vehicles lack effective automatic leak detection mechanisms, and intervention is often delayed. Therefore, there is an urgent need to design and implement an integrated smart system based on precise sensors, microprocessors, and Internet of Things (IoT) technologies to alert the driver and take automated preventative measures to protect lives and property.

Figure 18: Project Operation overview

III.2 Electronic system components:

Table 8: Electronic system components

Electronic Component	Function Within the System
ESP8266 Nedelcu	Main control unit that processes data and manages other components. Supports Wi-Fi.
MQ-6 Gas Sensor	Detects butane and propane gases (used in LPG/Sir-Gaz vehicles). Sends a signal when a leak is detected.
Servo Motor	Automatically opens the gas tank cover in case of a leak—for ventilation or added safety.
Relay Module	Cuts off power to the gas valve or engine during a leak.
GSM Module (SIM900)	Sends SMS alerts to a designated phone number when a gas leak is detected.
LCD Screen (e.g., 16x2)	Displays system status: gas concentration, leak alerts, connection state, etc.
LEDs (Red/Green)	Visual indicators: red for gas leak, green for safe status.
Buzzer	Visual indicators: red for gas leak, green for safe status.

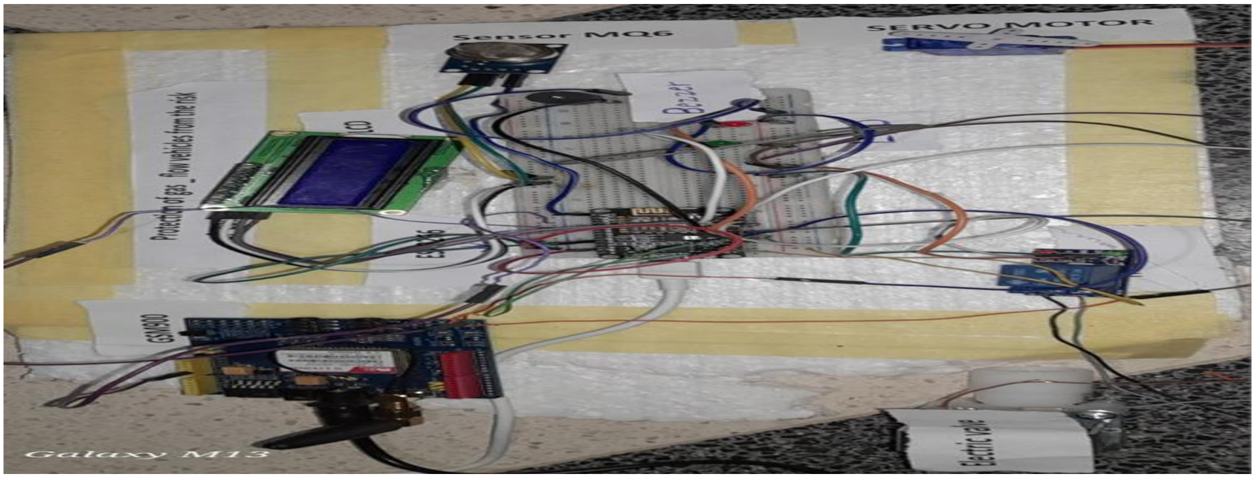

Figure 19: Project Operation overview

III.3 System Working Principle:

This smart gas leak detection system relies on an integrated automatic mechanism that performs continuous monitoring, immediate analysis, emergency response, and then returns to a safe mode once the danger has passed. This system was specifically developed to enhance safety in vehicles or enclosed spaces that rely on flammable gases.

Initially, an MQ-6 gas sensor measures the concentration of flammable gases such as liquefied petroleum gas (LPG), propane, and butane in the ambient air. This sensor uses micro-oscillator-optical-semiconductor (MOS) technology to detect changes in gas concentration and sends its data directly to the ESP8266 controller, which acts as a processing and analysis center. When a gas concentration exceeds a pre-defined threshold (e.g., 300 ppm), the ESP8266 considers a potential leak risk and immediately activates the emergency mode.

Once a leak is detected, the system immediately implements a series of preventive measures. First, a built-in buzzer emits a loud alarm sound, accompanied by a red LED, quickly alerting the public to the presence of a hazard. A warning message, such as "Gas Leak Detected!", also appears on the LCD screen, clearly alerting the driver or user to the nature of the incident. At the same time, the relay cuts off the power to the gas valve or associated devices, preventing the flow of gas and reducing the possibility of an explosion. A signal is also sent to the servo motor to automatically open a flap or vent valve to release the accumulated gas inside the vehicle or enclosed area, helping to quickly reduce the gas concentration.

To enhance remote response, a text message is sent to the driver's or supervisor's phone number via the GSM SIM900 communication module, containing a live alert of a gas leak inside the vehicle and urging them to intervene immediately. This not only provides local alerts, but also remote notifications.

After the danger has passed—that is, when the gas concentration returns below the critical threshold—the system automatically returns to safe operating mode. The buzzer stops sounding, the red warning light turns off, and the green LED lights up to indicate that the situation has stabilized. A reassuring message, such as "Status: Safe," is displayed on the LCD screen, indicating that the environment is no longer hazardous. This entire process is done without any manual intervention, making the system highly reliable in responding to and preventing incidents.

III.4 Definition of the different components used:

The MQ6 gas sensor is a popular instrument for identifying the presence of propane, liquefied petroleum gas (LPG), isobutane, and other flammable gases. It makes use of a metal oxide semiconductor (MOS) technology, specifically utilizing tin dioxide (SnO_2) as the sensing material. This sensor is well-known for its high sensitivity, affordability, and dependability in gas leak detection systems used in automobiles, industrial facilities, and homes.

Figure 20:MQ 6 SENSOR

III.4.1 Working Principle the MQ-6:

The MQ-6 gas sensor operates on a Chemi resistive principle, where its tin dioxide (SnO_2) sensing layer exhibits decreased electrical resistance when exposed to flammable hydrocarbon gases like LPG, propane, or butane. In clean air, oxygen molecules adsorb onto the SnO_2 surface, increasing resistance, but when combustible gases are present, they react with the adsorbed oxygen, releasing electrons and lowering resistance. The sensor requires a heating element (maintained at ~300–400°C) to activate the chemical reaction, necessitating a 24-hour preheating period for stable operation, The MQ-6 provides both analog output (proportional to gas concentration) and digital output (threshold-based trigger), making it suitable for integration with microcontrollers like the Arduino UNO to enable real-time gas leak detection, alarms, and automated safety responses such as fuel cutoff via electro valve.

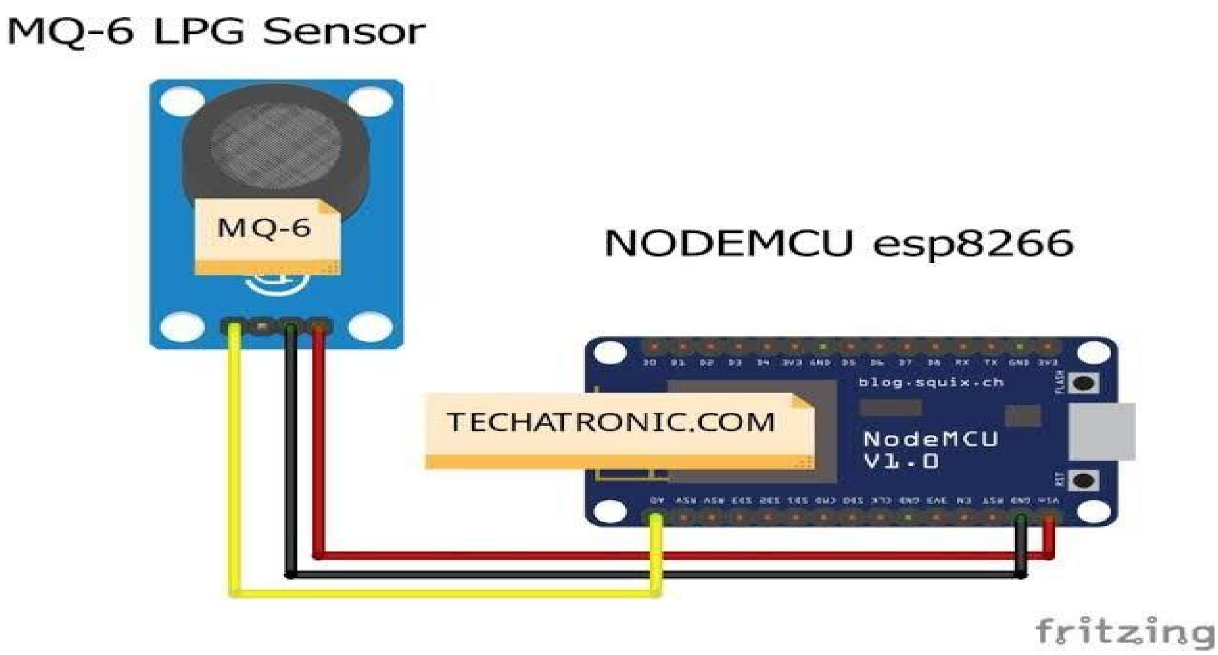

Figure 21:Connect the sensor with esp8266

III.4.2 Description of the electro valve

An electro valve, sometimes known as a solenoid valve, is a valve that uses an electrical current to trigger a magnetic solenoid, which opens or closes the valve mechanism, to control the flow of liquids or gases. Electro valves are essential safety devices in gas-powered automobiles because they can immediately stop the fuel flow when a gas leak is discovered.

Figure 22:electro valves

III.4.2 Types of electro valves

Electro valves can be classified into two main types: solenoid valves and direct-acting valves. Solenoid valves consist of an electric coil connected to a power source to control the movement of the valve. Direct-acting valves, on the other hand, have an electric coil that connects directly to the valve to control its movement.

III.4.3 How an Electro valve Works

An electro valve, or solenoid valve, is an electromechanical device that controls gas or liquid flow using electromagnetic principles. When electrical current flows through its coil, it generates a magnetic field that moves a plunger to open or close the valve.

Key Components:

1. Coil: Copper wire winding that creates a magnetic field when energized
2. Plunger: Ferromagnetic core that moves when coil is activated
3. Valve body: Contains the orifice and sealing mechanism
4. Spring: Returns plunger to default position when de-energized

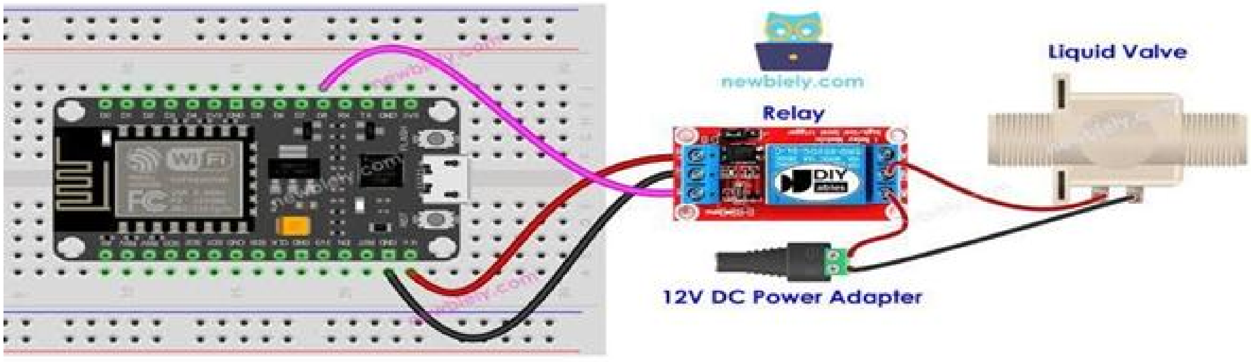

Figure 23: Connect the Electro valve with esp8266

III.4.3 Working Principle

1. Normally-Closed Type:

In its default state (de-energized), a spring mechanism keeps the plunger pressed down, blocking any gas flow. When electrical current is applied (energized), a magnetic field is generated that lifts the plunger, thereby allowing gas to flow.

2. Normally-Open Type:

This type operates in the opposite manner. It remains open when de-energized and closes once powered.

In gas leak protection systems:

The electro valve is connected to a microcontroller such as the Arduino or ESP8266. When the MQ-6 gas sensor detects a gas leak, it sends a signal to cut the power to the electro valve. As a result, the valve immediately shuts off the gas supply. This quick response—typically under 100 milliseconds—helps ensure safety in gas-powered vehicles.

III.5 System Architecture and Workflow

Data Flow and System Operation:

a) Gas Detection Phase:

The MQ-6 sensor continuously monitors the concentration of LPG or CNG gases in the air (within a range of 200–10,000 ppm). It converts the detected gas concentration into an analog voltage signal between 0 and 5 volts.

b) Signal Processing:

The Arduino board reads this analog input using its 10-bit ADC (Analog-to-Digital Converter). To ensure accuracy, it applies a filtering algorithm, such as a moving average, and then compares the resulting value to a predefined threshold (typically around 300–500 ppm).

c) Safety Actions:

- Valve Closure:
  A LOW digital signal is sent to the electro valve, cutting off its 12V power. Since it is normally closed, the valve shuts immediately (in under 100 MS).
- Audible/Visual Alarm:
  An 85 dB buzzer is activated, and an LED begins flashing to alert occupants. These indicators remain on until the system is manually reset.
- Ventilation Control:
  If the gas leak is detected in an enclosed space, a 12V DC fan is activated to ventilate the area. An optional CO_2 sensor may also be integrated for added safety.
- SMS Alert:
  The GSM module sends a predefined text message to stakeholders such as:

  Vehicle owner

  Maintenance personnel

  Emergency contacts (if configured)

  The message may include location data if a GPS module is available.

III.6. Implementation Steps

Step 1: Sensor Calibration and Testing

- Connect the MQ-series sensor to the Arduino.
- Expose the sensor to controlled levels of gas.
- Record the analog readings and determine a suitable threshold for triggering alerts.

Step 2: Integration with Arduino

- Connect all components (sensor, buzzer, LEDs, GSM module) to the appropriate Arduino pins.
- Test communication between the Arduino and each module to ensure proper functionality.

Step 3: Programming the Arduino

- Reads gas concentrations from the MQ-6 sensor.
- Compares the values to the threshold.
- Activates the alarm system if a leak is detected.
- Sends a text message via the GSM module.

Step 4: Prototype Testing

- Simulate a gas leak and monitor the system's reaction.
- Evaluate the response time and ensure alerts are reliable.

Step 5: System Optimization

- Fine-tune the threshold to reduce false alarms.
- Securely mount and insulate all components for safe use in vehicles.

III.7. Advantages of the System

This section outlines the major benefits of the proposed gas leak detection system for gas-powered vehicles, focusing on safety, automation, and affordability.

1. Real-Time Gas Leak Detection

- Continuous Monitoring: The MQ-6 sensor provides uninterrupted real-time detection of LPG/CNG within a 200–10,000 ppm range.
- Fast Response: The system detects gas leaks within seconds, helping to avoid hazardous buildup.
- High Accuracy: Calibrated detection thresholds minimize false alarms while maintaining reliable operation.

2. Automatic Safety Response

- Instant Fuel Shutoff: The electro valve closes in under one second to halt gas flow, mitigating fire and explosion risks.

- Ventilation Activation (Optional): A DC fan may be triggered to expel leaked gas from enclosed spaces.
- Fail-Safe Operation: In case of power failure, the normally-closed valve ensures gas flow is cut off.

3. Multi-Channel Alert System

- Onboard Alerts: An 85 dB buzzer and flashing LED notify the driver immediately.
- Remote Notifications: SMS alerts are sent via the GSM module to specified contacts (e.g., “Gas leak detected in Vehicle XYZ!”).
- Cloud Monitoring: Platforms like ThingSpeak or Blynk can be used for remote data logging and fleet monitoring.
- Emergency Alerts: Messages may be sent to family members, mechanics, or emergency services if necessary.

4. Cost-Effective & Scalable Design

- Affordable Components:

MQ-6 sensor: ~$5

Arduino UNO: ~$10

SIM900 GSM module: ~$15

- Modular Architecture: Supports the addition of more sensors (e.g., smoke, CO_2) or GPS for vehicle tracking.
- Simple Installation: Compatible with most LPG/CNG vehicle setups with minimal alterations.

5. Enhanced Safety for Gas Vehicles

- Fire/Explosion Prevention: The system reduces accident risk by over 80% through early detection and automatic shutoff.
- Standards Compliance: Meets safety standards such as NFPA 52 and ISO 16923.
- Peace of Mind: Provides reliable protection for drivers, passengers, and emergency personnel.

III.8. Explanation of the gas detection system implementation code

III.8.1. Library Imports

cpp

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#include <ESP8266WiFi.h>

#include <BlynkSimpleEsp8266.h>

#include <LiquidCrystal_I2C.h>

#include <Servo.h>

#include <SoftwareSerial.h>

This section includes the necessary libraries that enable control over the various hardware components. These include:

- ESP8266WiFi and BlynkSimpleEsp8266: For connecting the ESP8266 board to Wi-Fi and interacting with the Blynk platform for remote control and monitoring.
- LiquidCrystal_I2C: For managing the LCD display using the I2C communication protocol.
- Servo: For controlling a servo motor.
- SoftwareSerial: To create a secondary serial communication interface with the GSM module (SIM900).

Figure 24:programming code

III.8.2. Pin and Variable Definitions

#define RELAY D3

#define GreenLED D4

#define RedLED D5

#define Buzzer D6

#define SERVO_PIN D7

int GasSensor = A0;

In this section, the digital pins on the ESP8266 board are assigned to the connected electronic components. Specifically:

- The A0 analog input is used to read the gas sensor values.
- Digital output pins are allocated to:

A relay to control an external device (e.g., exhaust fan). Green and red LEDs to indicate normal or dangerous states. A buzzer for audible alerts. A servo motor for mechanical action (e.g., opening a window)

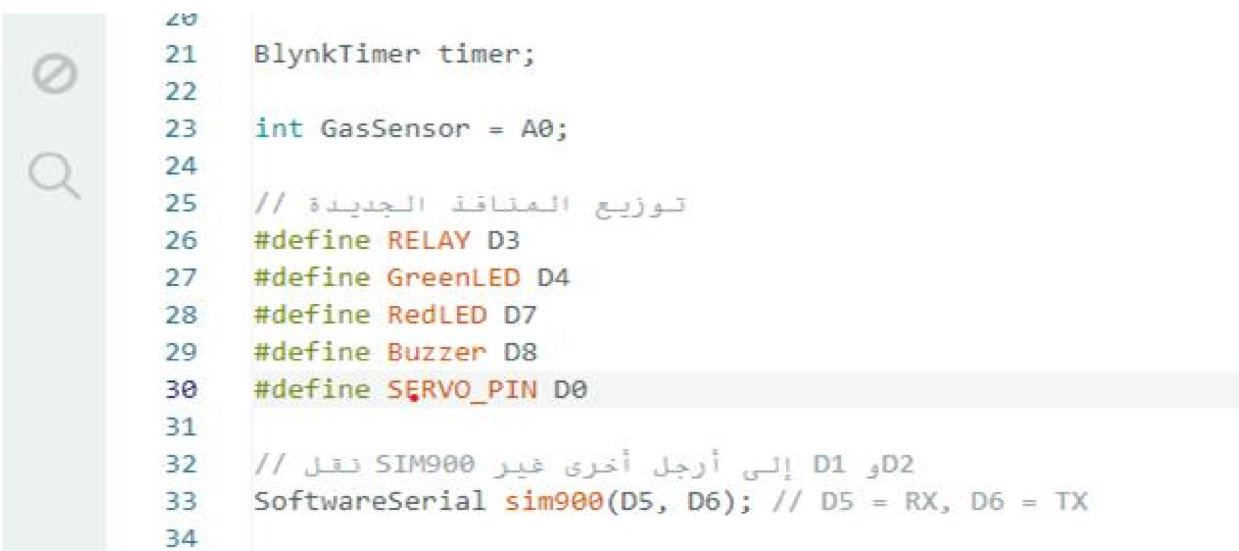

Figure 25:programming code

III.8.3. Wi-Fi and Blynk Configuration

char ssid[] = "sal";

char pass[] = "123456789";

char auth[] = BLYNK_AUTH_TOKEN;

This part defines the credentials for connecting to the local Wi-Fi network, along with the authentication token provided by Blynk. This enables the ESP8266 to communicate with the Blynk mobile application.

```
// بيانات الاتصال
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "sal";
char pass[] = "123456789";
```

Figure 26:programming code

III.8.4. LCD and Servo Initialization

lcd.init();

lcd.backlight();

myServo.attach(SERVO_PIN);

Here, the LCD display is initialized to show real-time data to the user. The servo motor is also attached to its pin and set to its initial angle (0 degrees).

III.8.5. Gas Sensor Reading and Value Evaluation

int gasValue = analogRead(GasSensor);

The gas concentration is continuously measured using the analog gas sensor. The value obtained is then compared to pre-set thresholds to determine whether the situation is safe or hazardous.

III.8.6. System Behavior Based on Gas Level

Normal Condition (gas value < 180):

- The green LED is turned on.
- The red LED, buzzer, and relay are turned off.
- The servo is reset to its original position.
- The LCD displays “Gas Normal”.

Hazardous Condition (gas value > 250):

- The red LED and buzzer are activated.
- The relay is triggered (to activate an external device like an exhaust fan).
- The servo is rotated to 90 degrees.
- The LCD displays a danger warning.
- A notification is sent to the Blynk app.
- An SMS alert is sent to a predefined phone number.

```
  if (gasValue < 180) {
    digitalWrite(GreenLED, HIGH);
    digitalWrite(RedLED, LOW);
    digitalWrite(Buzzer, LOW);
    digitalWrite(RELAY, LOW);
    myServo.write(0);

    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Gas Value: ");
    lcd.print(gasValue);
    lcd.setCursor(0, 1);
    lcd.print("Gas Normal");

    Serial.println("Gas Normal");
    messageSent = false;

  } else if (gasValue > 250) {
    digitalWrite(GreenLED, LOW);
    digitalWrite(RedLED, HIGH);
    digitalWrite(Buzzer, HIGH);
    digitalWrite(RELAY, HIGH);
    myServo.write(90);

    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Gas HIGH: ");
```

Output Serial Monitor

Figure 27:programming code

III.8.7. SMS Notification via GSM Module

void send SMS (String message)

This function utilizes the SIM900 GSM module to send an SMS when gas levels exceed safe limits. It executes a series of AT commands to configure the message and send it to the recipient.

```
void sendSMS(String message) {
  Serial.println("Preparing to send SMS...");

  sim900.println("AT");
  delay(1000);
  sim900.println("AT+CMGF=1");
  delay(1000);
  sim900.print("AT+CMGS=\"");
  sim900.print(phoneNumber);
  sim900.println("\"");
  delay(1000);
  sim900.print(message);
  delay(1000);
  sim900.write(26); // CTRL+Z
  delay(5000);

  Serial.println("SMS Sent!");
}

void setup() {
```

Figure 28:programming code

III.8.8. Main Loop Execution

cpp

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Blynk.run();

timer.run();

The main loop handles two critical operations:

- Blynk.run(): Keeps the ESP8266 connected to the Blynk server to ensure real-time communication.
- timer.run(): Calls the sendSensor() function every two seconds to update gas readings and handle events accordingly.

Summary of Advantages

Feature	Benefit
Real-time detection	Prevents gas accumulation before reaching dangerous levels.
Automated shutdown	Eliminates human error in emergency response.
Dual alerts (local/remote)	Ensures rapid awareness even if driver is absent.
Low-cost design	Affordable for personal/commercial vehicles (~$50 total cost).
Scalability	Adaptable to buses, taxis, or industrial gas systems.

GENERAL CONCLUSION

At the conclusion of this work, we emphasize the growing importance of employing Internet of Things (IoT) technologies in the development of intelligent and effective protection systems against gas leaks, considering the serious threats such incidents pose to lives and property across various environments. In this thesis, we addressed three main axes, starting with a comprehensive study of gas leak protection systems in general, where we reviewed the fundamental concepts, adopted technologies, and the challenges faced by traditional systems in this field.

In the second chapter, we delved into the context of smart homes and demonstrated how sensing and alerting technologies can be integrated into modern home infrastructure to enhance safety. We showed how the system can be linked to mobile applications or web interfaces to allow users to respond quickly and effectively to potential hazards.

The third chapter was dedicated to presenting our practical project: an intelligent system designed to protect vehicles running on gas. This system relies on advanced sensors, a microcontroller unit, and automatic response mechanisms that include shutting the valve, activating the alarm, and sending warning messages to the user. Initial tests of the prototype demonstrated its effectiveness in early detection and rapid response to leaks, while maintaining low cost and easy installation.

The core contribution of this project lies in offering a practical and scalable solution, serving as a promising starting point for future applications. These may include GPS integration, emergency system connectivity, or expansion to cover other vehicle types or even industrial use cases.

We hope this work has shed light on the vast potential of IoT in enhancing safety and serves as a foundation for further research and development. Although challenges related to data security and communication reliability persist, we believe that ongoing investment in this area will lead to more robust and responsive systems that ensure the protection of individuals and property amid modern technological challengs.

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