Industrial Hazard Monitoring: A Microcontroller-Based Gas and Fire Detection System

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In

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CERTIFICATE

This is to certify that the project titled **Industrial Hazard Monitoring: A Microcontroller-Based Gas and Fire Detection System** submitted by **Soumyadeep Bala (Enrolment No. 12021002002029), Sarnava Dey (Enrolment No. 12021002002032), Soumya Das (Enrolment No. 12021002002059), Satadhra Ghosh (Enrolment No. 12021002002033) and Diyaa Roy (Enrolment No. 12021002002024).** Students of UNIVERSITY OF ENGINEERING & MANAGEMENT, KOLKATA, as submitted for the partial fulfilment of requirements for the degree of Bachelor of Technology in Electronics & Communication Engineering, is a bona fide work carried out by them under the supervision and guidance of Prof. Prakash Bannerjee during 7th and 8th Semester of academic session of 2024-25. The content of this report has not been submitted to any other university or institute for the award of any other degree.

I am glad to inform that the work is entirely original and its performance is found to be quite satisfactory.

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TABLE OF CONTENTS

ABSTRACT

This project aims to create a cost-efficient and reliable fire and gas detection system based on a wireless mesh network of ESP8266 microcontrollers. Intended to provide safety in housing, industrial, or institutional environments, the system uses several sensor nodes—each mounted with an MQ-6 gas sensor, an infrared flame sensor, a buzzer, and an LED indicator—to monitor in real time potentially dangerous conditions like gas leakage or fire accidents. The mesh architecture of decentralized nature enables nodes to talk to one another and pass data efficiently, providing system reliability even during node failure or poor network coverage.

At the heart of the system is an ESP32-based gateway node that gathers data from all meshed nodes. The gateway essentially acts as a bridge from the ESP8266 mesh network to a local MQTT broker running on a local network. Sensor readings are collated, parsed, and published to structured MQTT topics, which facilitates robust and scalable interaction between devices and external interfaces.

In order to offer an intuitive user interface, the system uses Node-RED as the front-end dashboard platform. Locally hosted, the Node-RED dashboard displays real-time data from all sensor nodes, shows system alerts, and provides interactive controls like buttons to reset alarms or acknowledge alerts. This local hosting method makes the system work regardless of internet connectivity, making it extremely well-suited for application in offline or remote settings.

Furthermore, the system features a node tracking mechanism based on timeout logic. Each node is expected to periodically submit data, and in case of inactivity for a given time period, the node is declared inactive. The dashboard subsequently reflects the updated node's status and the last seen timestamp, with this furthering situational awareness as well as system diagnostics.

Overall, this project provides a robust and extensible solution for environmental hazard detection and alerting. Integrating mesh networking, local MQTT communication, and Node-RED visualization, it is an embeddable, real-time monitoring system with high reliability, scalability, and user-friendliness.

Keywords

- **Gas Sensor**
- **Leakage Detection**
- **MQ Series sensor**
- **Combustible Gas**
- **Toxic Gas**
- **Gas Concentration**
- **Real-time Detection**
- **Sensor Calibration**

INTRODUCTION

Gas leaks and fire accidents have in the past led to some of the most devastating disasters in industrial and residential settings. Not only do these accidents lead to loss of life and property, but they also have long-term effects on public health and environmental safety[1]. One of the worst industrial disasters in history is the Bhopal Gas Tragedy of 1984, which took place in Bhopal, India. The disaster struck when a huge amount of methyl isocyanate (MIC) gas leaked from the pesticide production factory of Union Carbide Corporation. The gas quickly moved into the residential areas in the vicinity, exposing hundreds of thousands of individuals to the poisonous fumes. More than 3,000 are estimated to have died instantly, with the final toll of deaths ultimately exceeding 15,000 due to complications arising from prolonged illness. Thousands more were afflicted with permanent disabilities, respiratory ailments, and neurological impairments. The Bhopal tragedy did not only uncover the effects of poor safety culture and absence of early warning systems but also reflected on the vital importance of having effective gas detection and real-time alarm systems in toxic environments.

Even in other more developed nations, such events have occurred. The California San Bruno pipeline explosion (2010) was caused by a rupture in a natural gas pipeline and caused eight fatalities and more than 35 homes to be destroyed. Eight fatalities and dozens of injuries resulted from the East Harlem gas explosion in New York in 2014 due to a suspected gas leak. These catastrophes are unambiguous evidences that gas accident occurrences are not geographically restricted and can strike anywhere if appropriate safety precautions are not taken.

To meet such challenges, this project suggests a real-time fire and gas monitoring system based on a wireless mesh network of ESP8266 microcontrollers with an integrated local MQTT broker and a Node-RED dashboard. Every sensor node in the network is fitted with an MQ-6 gas sensor that can identify liquefied petroleum gas (LPG) and other flammable gases, along with an infrared flame sensor to detect fires. Local audible and visible alarms are produced through buzzers and LEDs upon detection of unsafe conditions. The system employs a mesh topology, which provides strong communication among nodes through the ability to route data via multiple paths. This guarantees that even if one node fails or is disconnected, others can still communicate with the central ESP32-based gateway.

One of the main benefits of this system is its modular sensor setup. Depending on the environment type, various sensors of the MQ series can be exchanged—e.g., MQ-2 for smoke, MQ-4 for methane, or MQ-135 for air pollutant and CO_2 detection. This makes the system adaptable to certain applications, be it industrial facilities, laboratories, or homes.

The gateway node accumulates data from all mesh nodes and publishes them to a local MQTT broker, where the data is visualized in real-time by Node-RED, an open-source, flow-based development environment. Node-RED dashboard offers users an easy-to-use interface to see sensor readings, receive notifications, and reset alarm systems. Critically, since communication and processing are all localized, the system will function perfectly well without any internet connection—hence the system is particularly suitable for use in remote or mission-critical environments.

Through its blending of adaptability, real-time tracking, and decentralized communication, the system presents a scalable and dependable answer to enhance security and avoid catastrophes such as the Bhopal disaster from ever occurring again.

LITERATURE SURVEY

LITERATURE REVIEW

The increasing risks associated with fires and gas leaks have driven extensive research and development of fire alarm and gas leakage detection systems. These systems aim to ensure safety by providing early warnings and enabling swift responses to mitigate potential hazards. This literature review explores the existing studies, technologies, and methodologies implemented in such systems.

Early fire alarms relied on simple smoke or heat detectors to identify fire hazards. Ionization and photoelectric sensors were commonly used to detect particles in the air caused by combustion. Similarly, early gas detection systems used chemical or catalytic sensors to detect the presence of flammable or toxic gases like methane and carbon monoxide.

While these systems were effective in specific scenarios, their limitations included high false alarm rates and the inability to distinguish between different types of hazards. Moreover, traditional systems lacked real-time communication and integration with modern technologies, restricting their functionality

Author & Year	Technology	Main Findings
Babelle et al. (2021)	MQ-5 Sensor	Automatic Gas Leakage Monitoring System Using MQ-5 Sensor.
Ahmad et al. (2019)	Internet of Things (IoT).	A review advancement of security alarm systems using the Internet of Things (IoT).
Cavas M et al. (2019)	MQ-5 Sensor	The Various Types of sensors used in the Security Alarm system.
Arulanantha et al. (2020)	IoT gas leakage detector	Automatic gas leakage detection and management on IJETS.
Hussein et al. (2020)	Wireless sensor networks	A smart gas leakage monitoring system for use in hospitals.
S.Nazarov et al. (2020)	Convolutional neural networks	Fire detection using smoke and gas sensors.
Khan MM et al. (2020)	Gas leakage monitoring system	IoT gas leakage detector and warning generator.
M Mueller et al. (2013)	MQ-5 Sensor	Wireless sensor networks: Technology, protocols, and applications.
G Marph et al. (2015)	Vision-based fire detection	Adaptive background mixture models for real-time tracking.

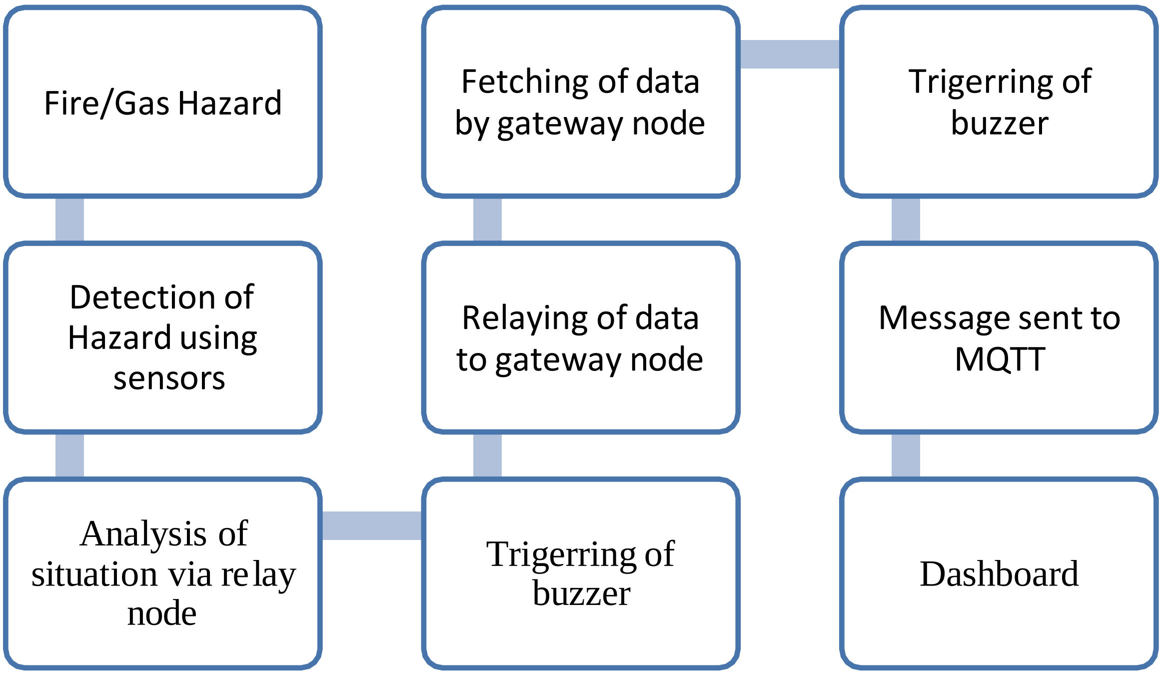

Fig : 1 Block Diagram

1.Start / Power On

The system boots up. Sensor and communication modules initialize. new

2.Detect Hazard Using Sensor Sensors detect abnormal gas concentration or flame. Analog or digital signal generated.

3.Analyze via Relay Node Sensor sends data to a relay node (microcontroller like Arduino/ESP32). Relay node processes data: Compares sensor value with safe threshold. Checks for sustained abnormal readings to avoid false alarms.

4.Relay node triggers buzzer or LED for local warning.

5.Relay node sends sensor status and hazard data to gateway node (e.g., Raspberry Pi or central ESP32)

6.Gateway Node Fetches Data Gateway node receives data via serial/Wi-Fi/BLE. Performs additional logic or filtering if needed.

7.Trigger Global Buzzer / System Alert Gateway can trigger a global alert system (e.g., sirens, automated gas valve cutoff). Ensures centralized response.

8.Send Data to MQTT Broker

Gateway node publishes the hazard data to an MQTT topic (like home/gas/status). Payload includes sensor data, location, severity level, etc.

9.Dashboard Receives Data Subscribed client/dashboard (e.g., Node-RED, Home Assistant, custom web app) fetches data from MQTT broker.

METHODOLOGY

The fire and gas detection system is developed based on the modular and scalable architecture based on ESP8266 microcontrollers, fire and gas sensors, and local MQTT-based communication architecture. The system is meant to identify the dangerous occurrences, forward the sensor data over a wireless mesh network, and display real-time data on an easy-to-use dashboard developed on Node-RED. This section describes the main elements of the system and their roles in providing correct detection, trustworthy communication, and efficient user interaction.

ESP8266 (D1 Mini)

The ESP8266 NodeMCU is a low-cost, Wi-Fi-enabled microcontroller utilized for sensor nodes as well as the gateway node in this project. It is designed to support TCP/IP protocols and comes with GPIO pins for connection with different sensors and output devices. Every sensor node is developed around an ESP8266 that reads out sensor data, processes threshold condition, and exchanges data wirelessly with other nodes utilizing a mesh network protocol. One of the ESP8266 modules is also used as the central gateway node, which collects sensor data from other nodes and publishes it to a local MQTT broker.

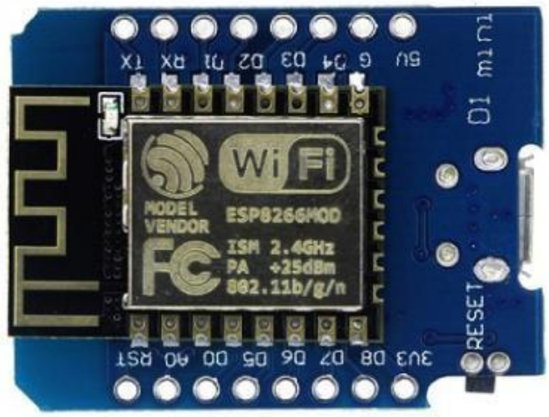

Fig.2 D1 Mini

Gas Sensor (MQ-6)

The MQ-6 is a semiconductor gas sensor for sensing combustible gases like LPG (liquefied petroleum gas), propane, and butane. It detects the change in conductivity due to the presence of gas molecules. The MQ-6 features a tin dioxide (SnO_2) sensing layer that changes its resistance when exposed to gases. It has a fast response time and operates over a wide detection range of 200 to 10,000 ppm for target gases[2]. The sensor requires a 5V power supply andhas both analog and digital outputs, making it compatible with microcontrollers like Arduino and ESP8266.The sensor sends out a higher analog or digital signal when gas concentration goes above a predetermined value, which is read by the ESP8266 to check if it should send out an alert.

Fig.3 MQ-6 Sensor

Buzzer (Piezoelectric)

The buzzer in this system is a miniature piezoelectric device that, when triggered, emits an audible sound. It is attached to the GPIO pin of the ESP8266 and is activated whenever the sensor readings exceed the set danger levels for gas level or fire detection. The buzzer is an instantaneous local alarm mechanism to alert nearby people of impending dangers. Its presence guarantees that even when users are not directly looking at the dashboard, they can still be notified of unsafe conditions in real time.

Fig.4 Buzzer

Flame Sensor (IR-based)

The flame sensor is an infrared (IR) sensor that senses light in the wavelength range normally emitted by fire. When there is a flame within its sensing distance, the sensor sends a signal to indicate the presence of fire. The signal is then processed by the ESP8266 to activate alarms and alert the central node.

Fig.5 Flame Sensor

Mesh Network Communication

A wireless mesh network is established using ESP8266 nodes to allow peer-to-peer communication between sensor nodes and the central gateway node. This topology ensures that data can still be routed through alternative paths in case any single node fails or becomes disconnected. The mesh protocol manages node discovery, routing, and data forwarding.

Local MQTT Communication

The central node acts as a bridge between the mesh network and the local MQTT broker. Once data is collected from all mesh nodes, it is published to specific MQTT topics. A broker like Mosquitto running on a local server or PC manages topic subscriptions and message distribution. This ensures lightweight and efficient communication across devices.

Node-RED Dashboard

Node-RED is used to build a real-time dashboard for data visualization and control. It subscribes to MQTT topics to display live sensor readings, alert statuses, and device health. The dashboard includes features such as hazard alerts, node status (active/inactive), gauge and reset buttons for alarm control. Node-RED flows are designed to handle both data logging and interactive user input, all hosted on a local server without needing internet access.

SCOPE OF STUDY

This research centres on the design and deployment of a localized fire and gas alarm system with a wireless mesh network of ESP8266 microcontrollers. The system is designed to sense environmental conditions, detect dangerous events like gas leaks and fires, and issue timely warnings via both local and remote interfaces. The project seeks to illustrate a flexible, scalable, and dependable alternative to traditional internet-based monitoring systems through the use of a local MQTT broker and Node-RED dashboard for control and real-time visualization of data.

The scope of the project covers:

- Deployment of ESP8266-based sensor nodes with gas and flame sensors designed to detect combustible gases (e.g., LPG) and fire.

- Deployment of a wireless mesh network that provides robust, peer-to-peer connectivity among nodes and a central gateway node independent of fixed network infrastructure.

- Support for a local MQTT broker to allow lightweight and efficient communication between the central gateway node and the Node-RED dashboard.

- Creation of a Node-RED-based user interface for alert notification, monitoring in real-time, control operations (e.g., alarm reset), and viewing node status.

- Use of buzzers and LED indicators on sensor nodes to give local prompt alerts when harmful conditions are found.

- Modular construction enabling straightforward replacement of gas sensors (e.g., MQ-2, MQ-4, MQ-135) depending on the particular application or target gas.

The system is intended for indoor and semi-outdoor settings like residential complexes, small industries, labs, and godowns where combustible gases such as LPG are routinely utilized. The research focuses on small- to medium-sized deployments, in which wireless mesh communication is able to sufficiently cover the area of monitoring without recourse to internet-based infrastructure. Everything within the system, such as the MQTT broker and Node-RED dashboard, runs within a local network and is able to function even where there is no or very little internet.

The emphasis is on developing an affordable and locally operated IoT-based safety system that provides consistent gas and fire detection with real-time notification via visual and audible signals, as well as a locally hosted user interface. The system is designed to be simple, accessible, and adaptable, making it ideal for communities or facilities that need independent safety solutions without relying on external resources.

PROPOSED SOLUTION

The solution proposed is a low-cost, locally administered fire and gas detection system with ESP8266-based sensor nodes networked using a wireless mesh network. Every node has flame and gas sensors, buzzers, and LEDs for local alarms. Sensor data is sent to a central node, which publishes to a local MQTT broker. A Node-RED dashboard gives live monitoring, danger notifications, and system management, all internet-independent. The system is scalable, modular, and suitable for settings such as homes, laboratories, and small-scale industries where safety monitoring is paramount.

Problem Statement

In many households, laboratories, and small-scale industrial settings, the risk of gas leaks and fire outbreaks poses a significant threat to both human life and property. Traditional detection systems often rely on standalone sensors with limited coverage, and many require internet connectivity to report hazards to cloud-based dashboards or mobile apps. In areas with poor or unreliable internet access, this dependency can delay critical warnings and compromise safety.

Solution

This project proposes a decentralized fire and gas detection system using ESP8266 microcontrollers arranged in a wireless mesh network. Each node is equipped with an MQ-6 gas sensor and a flame detection sensor, capable of identifying LPG leaks and fire within their vicinity. When a hazard is detected, the node immediately activates a buzzer and LED for local alerts, and sends the data to a central node over the mesh network

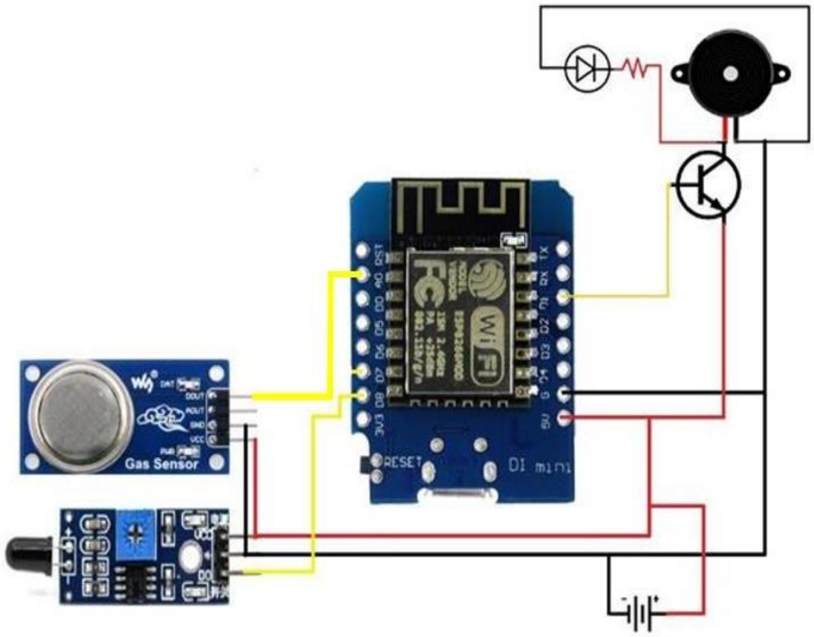

Fig.6 Circuit Diagram

WORKING PRINCIPLE

The intended system is capable of detecting combustible gases and fire in real time and notifying users both locally and remotely. It has a decentralized setup with multiple ESP8266 microcontrollers in a wireless mesh network for secure communication and sensor coverage. The system includes gas and flame sensors, alarm mechanisms (buzzers and LEDs), a local MQTT broker, and a Node-RED dashboard for visualization and user interaction.

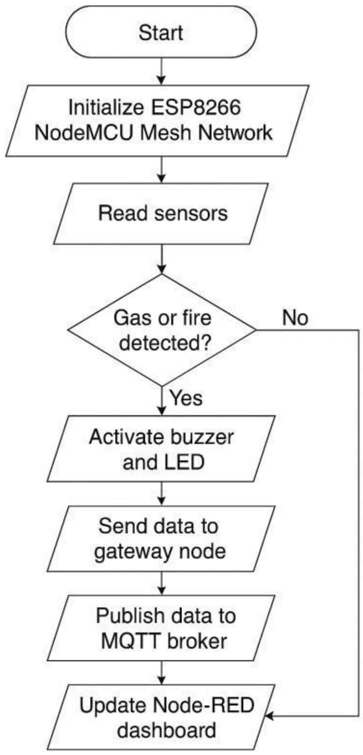

Fig.8 Workflow Diagram

The working process starts with the activation of ESP8266 nodes, which in turn initialize their onboard peripherals at once, such as the attached MQ-series gas sensors (e.g., MQ-6 for LPG) and flame sensors. The sensors are continuously sensing environmental conditions. The gas sensor sends an analog or digital signal depending on the air concentration of combustible gases, whereas the flame sensor senses infrared radiation emitted from a fire source.

Each ESP8266 microcontroller localizes the processing of sensor information and compares it with pre-configured safety levels. When gas concentration or flame level exceeds the threshold, the node takes two primary actions:

- It triggers local alarm mechanisms—usually a buzzer and an LED—to sound an immediate audio-visual warning at the location of risk.
- It transmits the data wirelessly via the mesh network to a specific central node (which is also an ESP8266) that acts as the communication gateway to the local MQTT broker.

The mesh network supports sensor nodes' ability to connect with each other and pass messages even if out of range directly from the gateway node. The result is better coverage and a higher degree of reliability, especially in scenarios in which physical interferences or failures of nodes can otherwise cut short communication.

The gateway node in the centre accepts alert or sensor information from other nodes and publishes it to certain topics on a locally running MQTT broker. The broker distributes messages to subscribed clients, such as a Node-RED server on a local machine or Raspberry Pi.

The Node-RED dashboard subscribes to the MQTT topics and offers a graphical interface for real-time monitoring. It shows sensor values, system state, and alert messages. The dashboard can also feature control buttons to enable users to accept alerts, reset alarm states, or check node health (e.g., battery level or connection status).

Because the system can operate completely on a local network, it still functions perfectly well without internet connection. This is especially ideal for deployment in off-grid, low-resource, or safety-critical environments such as homes, labs, small workshops, and storerooms where internet-based systems might not be dependable.

The modular design of the system enables the exchange of sensors according to the type of target gas, providing flexibility in various applications. In general, the system offers a low-cost, scalable, and efficient solution for early fire and gas hazard detection to prevent accidents and save lives and property.

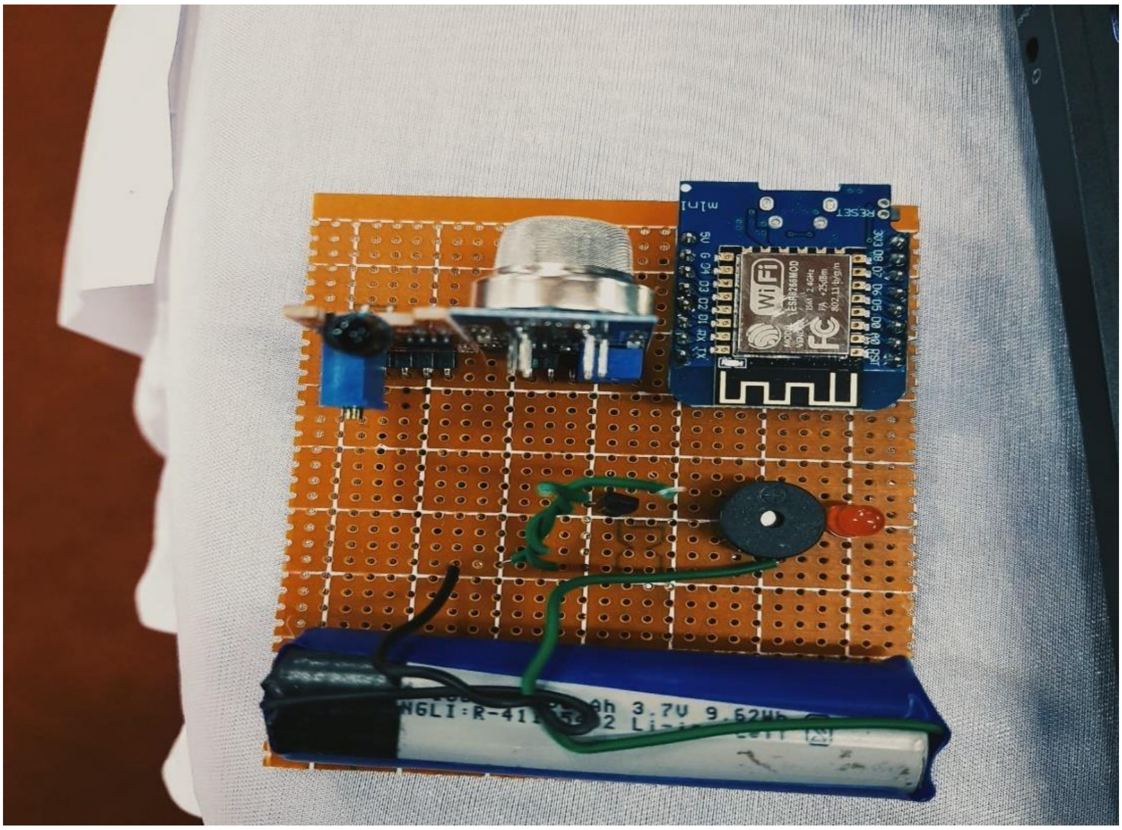

Fig 9 : Working setup of the model

RESULT AND ANALYSIS

The fire and gas detection system were effectively installed and tested in a testbed environment to analyse its real-time performance, network stability, and user interface responsiveness. The system was installed employing multiple ESP8266-based nodes, each being provided with MQ-6 gas sensors and flame detection modules. All nodes were set to establish a wireless mesh network to provide robust communication and redundancy.

Whenever gas concentration or flame was sensed by any of the nodes, the buzzer and LED were instantly activated at the source node to give local audible and visual notifications. At the same time, the information was sent over the mesh to the central node, which then published the data to the local MQTT broker.

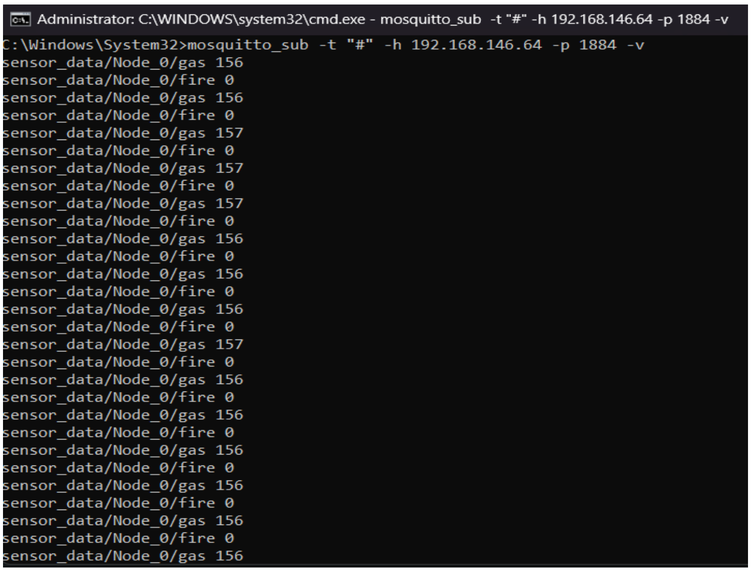

Fig.10 MQTT messages received from sensor nodes.

These MQTT messages were subscribed to by the Node-RED flow, which decoded and presented the values on a custom-built dashboard interface. The dashboard presented real-time sensor readings, active alert notifications, and enabled manual reset of warning states.

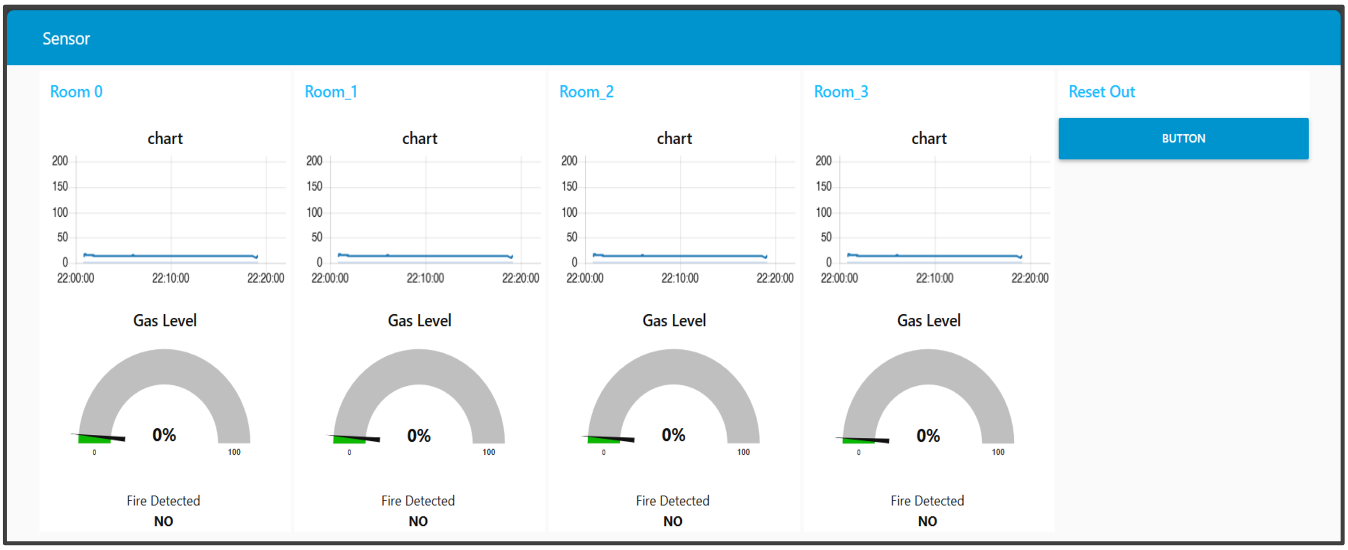

Fig 11 : Node-RED dashboard presenting sensor readings and alert

During testing, the system showed minimal latency in data delivery (less than 1 second from event to dashboard refresh), and the mesh network was still stable even with single nodes turned off or relocated. The module design of the sensors made it easy to swap between MQ-6 and other MQ-series sensors without code changes beyond calibration constants.

MQTT data analysis proved that sensor values were consistent in normal conditions and increased significantly during the gas introduction close to the MQ-6 sensor, correctly triggering alarms as intended. Flame detection also worked as intended, registering binary outputs when exposed to fire sources such as a lighter or matchstick.

Finally, the findings confirm the efficacy of the system in hazard detection, data communication on a local mesh network, and user feedback by both hardware indication and real-time software dashboard. The local MQTT broker guarantees internet independence, thereby making the solution robust and fit for safety-critical applications.

CONCLUSION

Fire alarm detection and gas sensing systems are instrumental in protecting life, property, and the environment. They serve as the initial line of defense by issuing advance warnings regarding fire danger or dangerous gases, which allow for taking prompt action before disaster strikes.

Fire alarm detection systems are created to sense preliminary signs of fire, including smoke, heat, or flame. They make use of sophisticated technologies such as optical sensors, ionization chambers, and thermal detectors to detect potential fire threats quickly. When detected, the system raises an alarm to inform occupants, trigger emergency procedures, and, in some instances, directly alert fire services. Through early mitigation of fire risks, these systems save lives, minimize property loss, and improve safety compliance in residential, commercial, and industrial environments.

Conversely, gas detection systems are also very important to identify the existence of toxic, explosive, or flammable gases. The MQ6 sensor is one of the sensors used to detect gases like LPG, methane, or carbon monoxide. Gas detectors quantify concentrations of gases in the air and inform users when levels become dangerous. Such systems are critical in chemical manufacturing, mining, and oil refinery industries, and in domestic environments to avoid gas leaks and explosions.

Fire alarm and gas detection systems together constitute an integrated safety network. Not only do they detect impending threats, but they also serve as precautionary measures by providing for automated responses, such as closing gas supplies or initiating ventilation systems.

In sum, spending on good fire and gas detection systems is crucial to safety and compliance. With advancing technology, these systems are getting smarter, more efficient, and more integrated into IoT networks, with even more safety and convenience in the pipeline.

In summary, fire alarm sensing and gas detection systems are necessary for ensuring safety and averting catastrophes. Fire alarms give early warnings of fire risks, while gas detectors detect harmful gases, minimizing risks related to explosions, poisoning, and environmental pollution. Both systems, collectively, form a strong safety network that guards lives, property, and the environment.

The continued evolution of technology, such as IoT integration, AI-based analytics, and enhanced sensor precision, continues to improve the reliability and efficiency of these systems. As safety becomes a more pressing issue in contemporary living and working conditions, investing in cutting-edge fire and gas detection systems is not only a regulatory obligation but a moral and practical imperative. By embracing these technologies, individuals and institutions can secure a safer, more secure future.

FUTURE SCOPE

One of the possible ways of improving the efficiency, precision, and scalability of gas detection processes has been seen as the integration of cloud and IoT technologies in gas leakage detection systems. Real-time monitoring, data analysis, and response to gas leaks are enabled through the integration of these technologies. Additionally, the implementation of cloud-based computing and storage enables the processing of data effectively and incorporating advanced machine learning and analytics algorithms for enhanced system performance The evaluation further highlights the need for addressing privacy and security concerns associated with the application of cloud-based gas leak detection technologies. Thus, subsequent research in this area needs to prioritize the development of plans that can effectively address these concerns and ensure the security and safety of these systems. The application of a gas leakage detection system through IoT and cloud technologies is recommended according to the literature review. The inclusion of a GPS module to determine the location of gas leaks should be included in the system, along with cloud storage for sensor data. Smoke leaking can also be found using a smoke sensor. A GSM module, Arduino microcontroller, fire sensor, and MQ-6Gas sensor should also be included in the system for optimal performance. In summary, there is great potential in revolutionizing gas leakage detection processes using IoT and cloud technologies and thus ensuring the safety and security of gas-based detection systems. Future research and development in this area have hope courtesy of the proposed gas leakage detection system, which utilizes IoT and cloud technologies

Improved Sensor Technology:

Creation of more sensitive, long-lasting, and multi-functional sensors that can detect more gases with greater accuracy and responsiveness.

Extension of Internet of Things (IoT) functionalities to facilitate real-time monitoring, remote control, and alarm through smartphones and other devices.

Here are some key areas where gas leak detection and sensors are expected to evolve in the future:

1. Integration with IoT and Smart Systems.
2. Advanced Sensing Technology.
3. Wireless and Battery-Powered Solutions.
4. Regulatory Changes and Standards.
5. Cost Reduction and Accessibility.
6. Emerging Gas Detection Methods.

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