IoT-Based Automatic Gas Leakage Detection and Fire Protection System

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Abstract—Gas Leakage and its fatal effects are a great concern throughout the world, especially in developing countries like Bangladesh. Every year lots of people died and countless damages to assets occur due to the fire caused by the gas leakage. Not only that but gas leakage and explosion are also very harmful to the climate. Thus, a system to detect gas leakage and preventive measures is of utmost importance. In this project, we design and implement an intelligent IoT prototype to detect gas leakage, and the fire caught by gas leakage. Our goal is to minimize the effect of gas leakage by taking some protective measures. When the gas sensor, detects the gas leakage, the solenoid valve shuts off the gas line, and the exhaust fan starts to run. Again, when the flame sensor detects a fire, the sucker throws the fire extinguisher balls at the fire. The GSM SIM module notifies the user by sending a message to his smartphone. The buzzer sounds when a mishap occurs and the LCD monitor always shows the status of the system. In this way, we have efficiently designed and implemented a low-cost and intelligent gas leak detection and fire suppression system.

Keywords—gas leakage, gas and fire detection, Internet of Things, intelligent system, smart IoT prototype, sensors and actuators

1 Introduction

Gas leakage is a commonly observed problem that causes malicious effects on the environment and human health. The gases in a cylinder may leak in a gas or liquid form. If the liquid leaks, then it quickly evaporates and forms a relatively large cloud of gases that would drop to the ground, since it is heavier than air. Gas cylinder vapors can run for a long distance along the ground and can be collected in drains, floors, or grounds. When the gas approaches a source of ignition, it may burn or explode. The burning gases release carbon dioxide, a greenhouse gas [1], [2]. The reaction also produces some carbon monoxide [3]. Greenhouse gas has severe environmental and health effects. It causes climate change by trapping heat, and it also contributes to respiratory diseases from smog and air pollution. Excessive carbon dioxide in the ambiance increases the greenhouse effect. More thermal energy is trapped by the atmosphere, causing the earth to become warmer than it would be naturally [1]. This increase in the Earth's temperature is known as global warming.

Gas is an essential need of every household; its leakage could lead to a disaster. Gas leakage and explosion is one of the deadliest accidents in the world [4] that happened mostly in developing countries like Bangladesh. The accident can be occurred by gas leakage or cylinder blast. Blasting the cylinder may cause a large fire accident where a lot of people may lose their lives and also get injured. In Bangladesh, there have been many incidents because of cylinder blasts, many people injured and killed by the cylinder explosions. Last year about 350 people in Bangladesh are dead from gas explosions [5]. The blast in a mosque in Narayanganj's Paschim Tallah is the latest example of such a tragic accident. At least 24 people have succumbed to their burn injuries and many more are dead. Therefore, if we can make a system that prevents gas explosions, we can save people's life. Thus, in this project, we want to make an IoT-based intelligent system that detects gas and fire accidents and takes protective measures as well [6].

When gas leaks inside the chamber, room, or kitchen, the gas sensor detects gas leakage. The system informs the owner about the incident by sending a notification. The system shut off the gas supply and throws the leaked gas out of the chamber by an exhaust fan installed in a kitchen or gas cylinder chamber at the hotel or any other place. Unfortunately, if there catches fire, the system can automatically throw a fire extinguisher ball to extinguish the fire and send a notification to the owner about the accident.

The rest of the paper is organized as follows. Section 2 illustrates different existing IoT systems and the motivation of this project. Section 3 describes the requirements and system overview of this project. System design and implementation are carried out in Section 4. Section 5 presents the performance, reliability, and survey result of the system. Some related future works are outlined in Section 6. Finally, Section 7 concludes the paper.

2 IoT systems review and motivation

2.1 Related works

Lee et al. [7] design an electronic nose system to identify mixed explosive gas leakage. The authors implement a gas pattern recognizer leveraging a neuro-fuzzy network. The authors in [8] present an efficient gas sensing technique that minimizes the response time of the system. They find the optimum composition for achieving the highest sensitivity of the tin oxide (SnO2) layer toward the tested gas. In [9], the researchers develop an IoT-based system that detects the LPG (Liquefied Petroleum

Gas) gas leakage as well as evacuates the leaked gases. The researchers also integrate an alerting system such as sending an SMS and activating a buzzer for the household. Nonetheless, they ignore the fire protection system.

As communication technology advances unprecedentedly, many consumers are fascinated with the home automation system. Omran et al. in [10] present a home automation system that controls many home appliances (doors, windows, freezer, etc.) as well as can regulate home ambiance (humidity, temperature, and other household conditions). However, they do not consider the house protection system such as gas leakage and fire accident.

The Internet of things for smart cities is one of the emerging and challenging research domains. Sharma et al. [11] develop an early fire detection system leveraging image processing to save the cities. The system can also detect forest fires with 95 to 98 percent accuracy. In [12], the authors implement an intelligent fire recognition system using IoT Technology with an automatic water sprinkler. The system also connects a GSM modem for notification purposes.

Yépez and Ko in [13] implement an innovative fire protection system that integrates blockchain technology to verify the record of fire risk events. They also provide Android and iOS apps for house owners to communicate with their devices. Muhammad et al. in [14], design a novel fire detection method for uncertain surveillance environments (due to fog, smoke, snow, etc.). Their method is based on the convolutional neural network (CNN) which provides better accuracy than existing systems.

In the above-cited articles, references [7]-[10] focus mainly on gas leakage detection whereas, references [11]-[14] focus primarily on fire detection systems. Again, some articles integrate a notification system or include an app with the IoT system. In addition to those articles, some researchers in [15]-[19] also partially implement the gas leak and fire detection mechanism. However, neither of those covers both the gas leakage and fire protection system together. In this regard, our designed system comes forward that focuses on both gas and fire protection as well as integrates an app and an alerting mechanism.

2.2 Motivation

Every year a huge number of accidents occur by gas explosions and we lose many people. WHO (World Health Organization) [20] estimated that moreover 1.3 million children are getting orphans every year around the world by the gas explosion. Fire accidents cause a lot of damage to the economy. Therefore, we want to design and implement a system that minimizes the effect of gas explosions.

In this project, we want to create an LPG gas or smoke detector that uses an MQ-4 gas/smoke sensor and sends an SMS to the user when gas leakage is detected. The gas leakage detection and message warning system would be mounted in kitchens and rooms as a permanent unit. The message warning system contains a GSM SIM800L module to send the notification to the house owner. We interface the GSM SIM800L and MQ-4 sensors with a node MCU. Finally, a buzzer can sound if there is a gas leak, and the buck converter power the solenoid valve and exhaust fan. Our prototype also has a flame sensor that detects fire. When the fire detector detects a fire in the chamber, the sucker can through a fire extinguisher ball with the help of a servo motor.

In Section 2.1, we discuss some IoT systems briefly. In this section, we closely monitor a few more IoT systems that motivate us to implement this project. In Table 1, we compare our IoT system with some prominent IoT systems. The main contributions of the project are as follows,

1. Design and implement an efficient gas leakage detection system
2. Implement countermeasures to minimize the effect of gas leakage/explosion
3. Design and implement a fire detection system
4. Implement countermeasures to minimize the effect of fire incidents
5. Implement an efficient alerting (e.g. buzzer), notification (GSM module), and controlling (Blynk app) platform
6. Implement a safe, cost-efficient, low-power consumed, and portable intelligent IoT prototype

Table 1. Comparison of some promising existing systems with our system

Existing systems	Comparison with our system
Booneua et al. (2022) [30]	The authors in [30] develop a hydroponics system using IoT to improve crop treatment by controlling growth factors such as humidity, weather and water temperature, $_{P}$H, etc. The hydroponics system uses an up-to-date notification system for the framers. We also use a sophisticated system for notification in our IoT system, but our use case is completely different which is very crucial to human life and the environment.
Esquicha-Tejada & Copa-Pineda (2022) [31]	In [31], the researchers design low-cost and energy-efficient home automation using IoT. However, they do not consider gas leakage and fire protection for their automated home which exposes severe security concerns. Again, our system also saves costs by providing low-cost and efficient hardware.
Baharum et al. (2021) [32]	The investigators of the project in [32], implement a mobile-based IoT application for the smart light system for monitoring and controlling. Article [32] focuses only on the light system to save energy which reduces the cost. On the other hand, our low-cost IoT system is designed for more important and multifarious tasks.
Gaur et al. (2022) [33]	The researchers in [33], describe a fire protection system by measuring the temperature of the surrounding wall. The system can decide the fire stages by measuring the temperature difference between the inside and outside of the wall surfaces. However, the system’s response time is not good enough comparing our system. The system also does not include gas leakage detection activities.

3 Requirements and system overview

In this section, an overview of IoT systems and devices is provided briefly. Additional descriptions can be found in [21]. Section 3.1 introduces several IoT components that build the whole prototype. Section 3.2 gives an overview of the complete system.

3.1 Components

The main building blocks of the prototype are node MCU (Micro-controller Unit), GSM module, relay module, buck converter, solenoid valve, servo motor, flame sensor, MQ-4 gas sensor, cooling fan, solder sucker, and LCD. All devices can be classified into three categories, namely, i) Sensors ii) Actuators and iii) Other electronic components. The details of these components are provided in the following.

1. **Sensors:** The main sensors used in the board are the gas sensor (MQ-4), and flame sensor. The detail of the MQ-4 sensor is specified in Section 4.4.
2. **Actuators:** The main actuators used in the prototype are a solenoid valve, cooling fan, servo motor, solder sucker, GSM SIM module, buzzer, LCD, and LED. Figure 1 shows a few actuators along with a short description.
3. **Other electronic components:** Other electronic components used in the prototype are NodeMCU, relay, buck convertor, 12 V adaptor, etc. Figure 2 shows some components along with a short description.

Description	Pictures
Solenoid Valve A solenoid valve would be set up on the gas cylinder. This solenoid valve has two valves, one of which is connected to a gas cylinder and the other to the mainline. Users can regulate the flow of gas through this solenoid valve. If a gas leak occurs, the user turns off the valve and can avoid a gas accident.	
Servo Motor A servo motor is a small motor that has an output shaft. This shaft may be moved to various angle positions by passing a coded signal to the servo motor. As long as the encoded signal is present on the input, the servo motor maintains the shaft's angular alignment.	

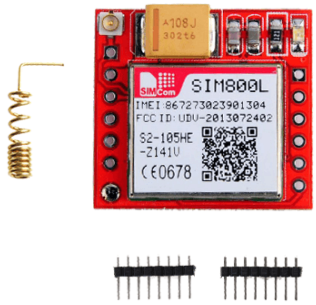
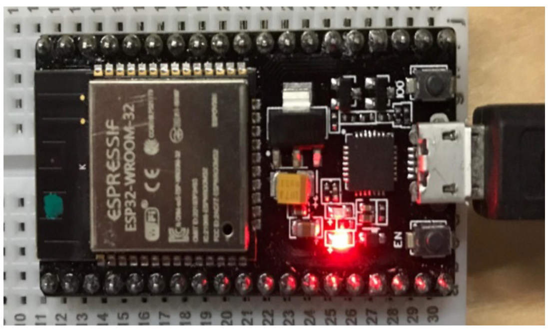
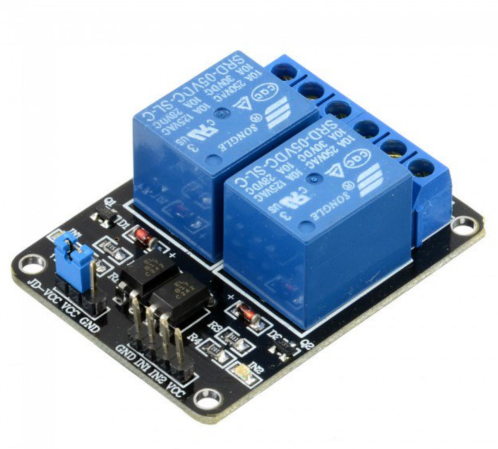
Solder Sucker A desoldering pump often referred to as a solder sucker, is a manual device used to remove solder from a printed circuit board. There are two styles: plunger and bulb. Ours one is a plunger sucker. In our project, it is used to through the fire extinguisher ball to the fire.	
SIM800L GSM Our project framework is built around human-computer interactions. The GSM SIM module is used to deliver SMS notifications in the event of a gas leak and fire alarm. In this system, serial communication is used. NodMCU commands the GSM module to send an SMS to the user.	

Fig. 1. Actuators used in the board

Description	Pictures
NodeMCU NodeMCU is an open-source Internet of Things platform designed for low-cost deployments. It is composed of hardware, namely the Espressif Systems, i.e. ESP8266 System, and firmware, which is written in the Lua scripting language. The NodeMCU is comparable to the Arduino microcontroller and ESP8266 module. It uses USB for serial communication and it can communicate through Wi-Fi.	

Relay Module

A power relay module is an electromagnetically driven electrical switch. The electromagnet is operated by a microcontroller through a separate low-power signal. When activated, the magnet pulls to either open or close an electrical circuit. In our project, we use a 2 channel 5 V relay module that is connected to the NodeMCU and allows us to control the solenoid valve.



Buck Converter

The LM2596 is a widely used step-down switching regulator integrated circuit. It can accept input voltage from 4.5 to 40 volts and transform it to variable voltage sourcing with a continuous current of up to 3 amps. It is widely used to power/control heavy loads due to its high current capability.

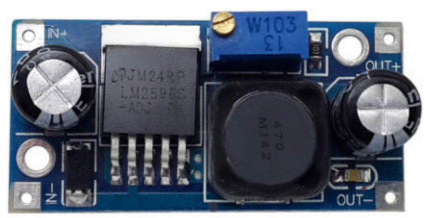


Fig. 2. Other electronic components used in the board

3.2 System overview

The overview of the system is described in this section. Figure 3 shows a high-level view of the complete system. The system's functions can be divided into mainly two classes: i) Gas leakage detection and countermeasures ii) Fire detection and countermeasures.

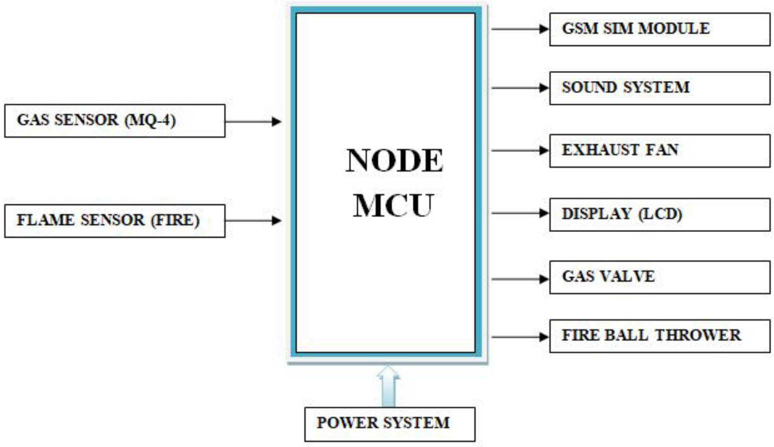


Fig. 3. A high-level view of the system

1. *Gas leakage detection and countermeasures:* At first, when the MQ-4 gas sensor detects that gas density is higher above the threshold in the room/chamber, then it sends a signal to node MCU. After that, node MCU is taking action by sending the signal to the gas valve, exhaust fan, GSM SIM module, sound system (buzzer), and display (LCD). The gas valve shut off the gas supply and the exhaust fan throws the leaked gas outside of the chamber. The GSM SIM module sends a message to the house owner. The buzzer produces sounds. The density of the gas in the room would be displayed on the LCD.
2. *Fire detection and countermeasures:* When the flame sensor (fire detector) detects fire in the chamber, then it sends a signal to node MCU. Node MCU is taking action by sending a signal to the GSM SIM module, and servo motor. GSM SIM module sends a message to the house owner that his/her house is on fire. The servo motor pressures the solder sucker button and then the fire extinguisher ball is thrown out to the fire.

4 System design and implementation

4.1 Design of PSU and DU of solenoid valve

In this section, we discuss the power supply unit (PSU) and drive unit (DU) of the solenoid valve.

Power Supply Unit (PSU). The PSU converts the 220V AC (Alternating Current) available mains to the required DC (Direct Current) which is used to run the circuit. The PSU powers all components of the board, e.g., solenoid valve, exhaust fan, and relay module. Figure 4 shows the circuit of the power supply unit.

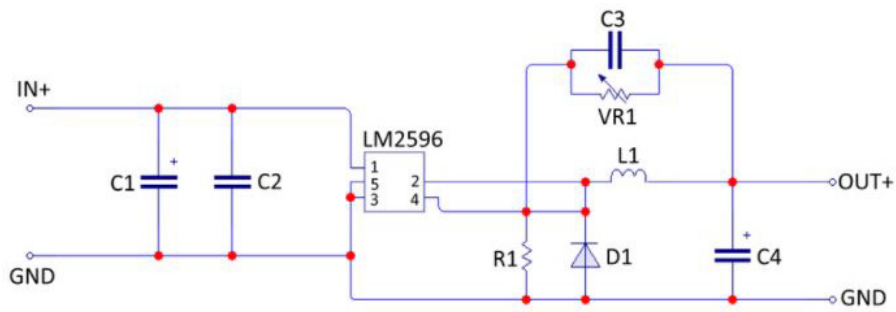


Fig. 4. Power Supply Unit (PSU)

Drive Unit (DU) of solenoid valve. The solenoid valve driving unit regulates the solenoid valve's opening and shutting. It regulates the flow of gas from the source to the point of usage. The solenoid valve drive receives the control unit's signal and does the necessary operation. The circuit schematic for the solenoid valve driving unit is shown in Figure 5.

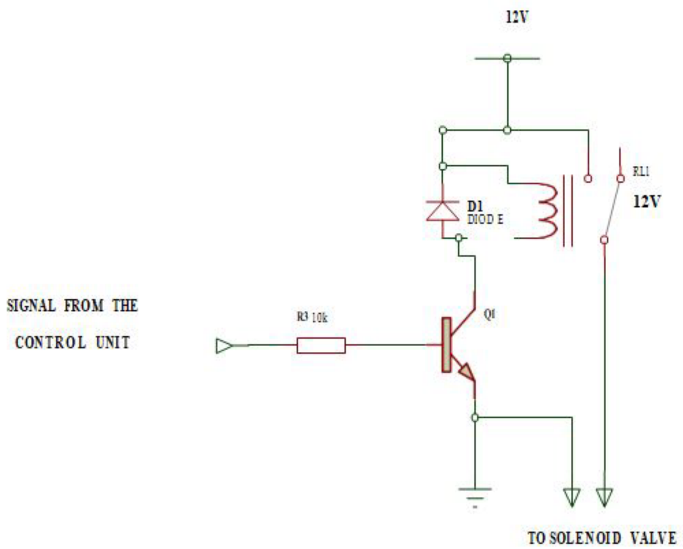


Fig. 5. Drive unit of solenoid valve

4.2 Design of control unit

In this prototype, the susceptibility is so high that the sensor recognizes the LPG, i-butane, propane, and other gaseous particles easily. The sensor is very susceptible and its response time is very low. Figure 6 shows the control unit and corresponding circuit. In this design, node MCU controls the whole system. The power supply in the buck converter is always on and the exhaust fan, solenoid valve, relay module, and GSM

SIM module are directly powered by the buck converter. The exhaust fan, solenoid valve, etc. receive signals from the node MCU and work accordingly.

The buzzer, LCD, MQ-4 sensor, flame sensor, and servo motor are directly connected with node MCU and are also powered via node MCU. Node MCU is directly powered by the buck converter. MQ-4 sensor, the flame sensor sends signals to node MCU, then node MCU completes actions by sending signals to other relevant components. The buzzer, LCD, servo motor, and GSM module are getting signals from the node MCU and function accordingly.

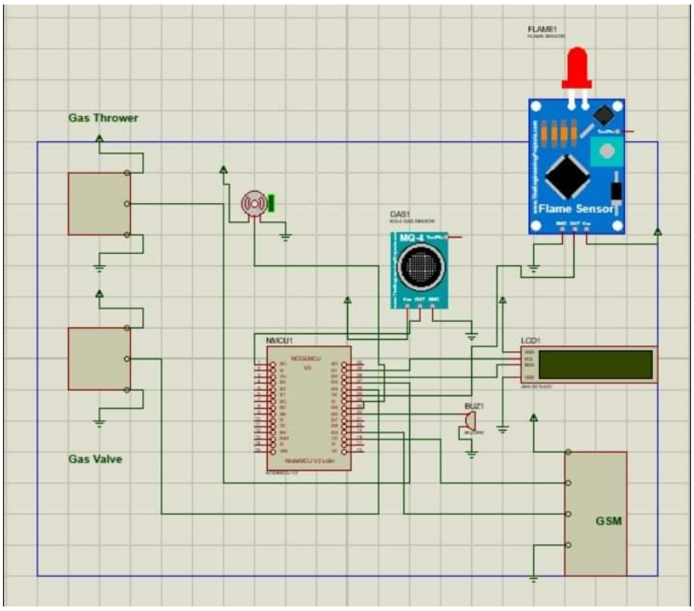


Fig. 6. Design of control unit

4.3 Flowchart of the control algorithm

As stated earlier, this project mainly consists of two portions: Gas leakage detection activities, and fire detection activities. Every portion has sub-activities and contains several IoT devices. Figure 7. Shows the flowchart for the system operation which is fully automated.

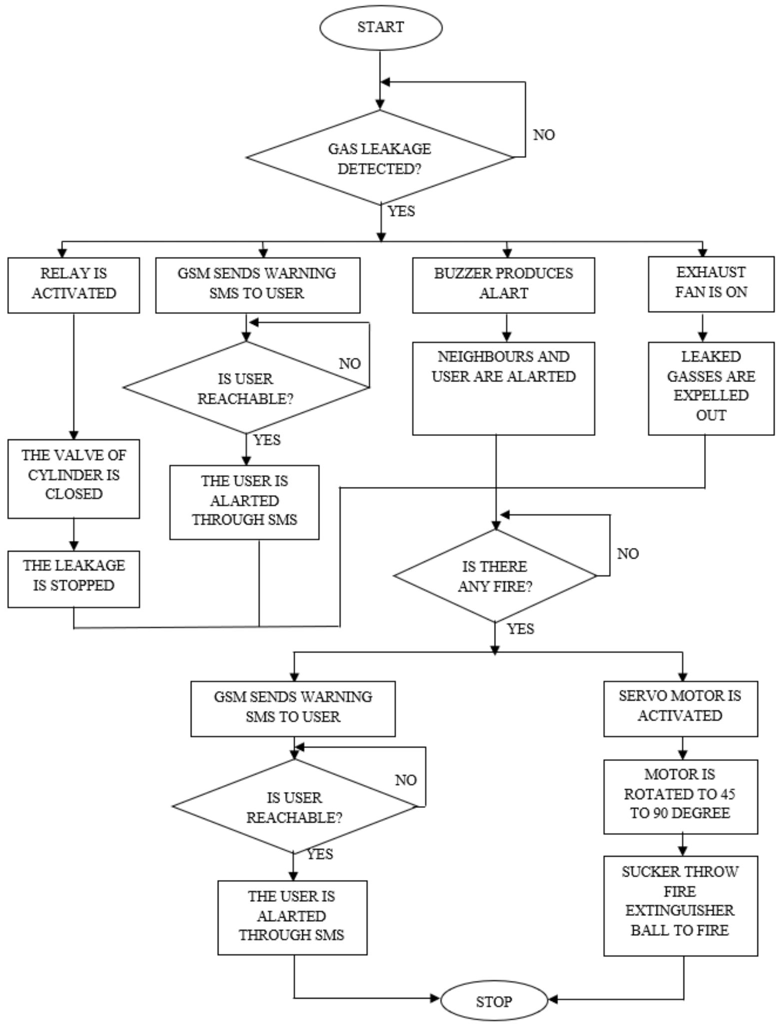


Fig. 7. Flowchart for system operation

4.4 Mathematical model

The MQ-4 gas sensor is used in the system to detect the presence of natural gas, LPG, and LNG (Liquefied Natural Gas). Digital and Analog outputs are available on the module. It detects LPG at concentrations ranging from 200 to 10,000 particles per million. The MQ-4 has low sensitivity to alcohol and smoke. Figure 8 shows an MQ-4 sensor and its specifications. The gas sensing layer of the MQ-4 is made of tin oxide (SnO_2). When the combustible gases exist in the environment, the sensor's conductivity increases, and the resistance of the sensor changes with the concentration of combustible gases. The resistance of the sensor is measured by the following equation (1).

$$R_S = (V_C/V_{RL} - 1) \times R_L \tag{1}$$

where, R_S is the sensor resistance, V_C is the supply voltage to the load cell, V_{RL} is the voltage across load resistance, and R_L is the load resistance.

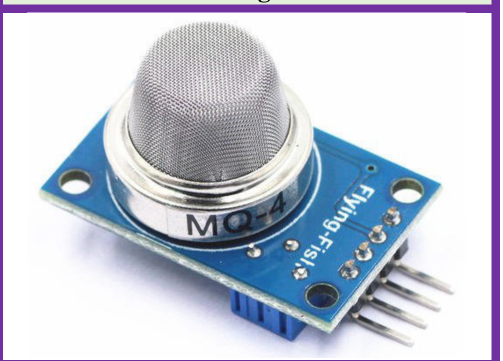
Specifications/Characteristics	Image
• Power supply (V_C), +5V • Load resistance (R_L), 20 KΩ • Gas sensing layer, SnO_2 • High sensitivity to CH_4, natural gas, LNG • Detecting concentration, 200-10000 ppm • Standard detecting temperature, 20°C±2°C	

Fig. 8. Image and specifications of the MQ-4 sensor

4.5 System programming

We program actuators, the GSM SIM module, and other devices through an Arduino application [22]. We have coded using the C++ programming language. A snapshot of coding for the actuators is shown in Figure 9. In this portion, the node MCU, i.e., ESP8266 is programmed to activate the gas valve and servo motor. ESP8266 Wi-Fi sends the command to LCD to display gas density readings. It is noted that the buzzer and exhaust fan do not require to be exclusively programmed. The node MCU would respond and activate devices (gas valve, exhaust fan) as soon as the gas sensor detects gas leakage. Similarly, when the fire sensor detects a fire, the node MCU activated the servo motor.

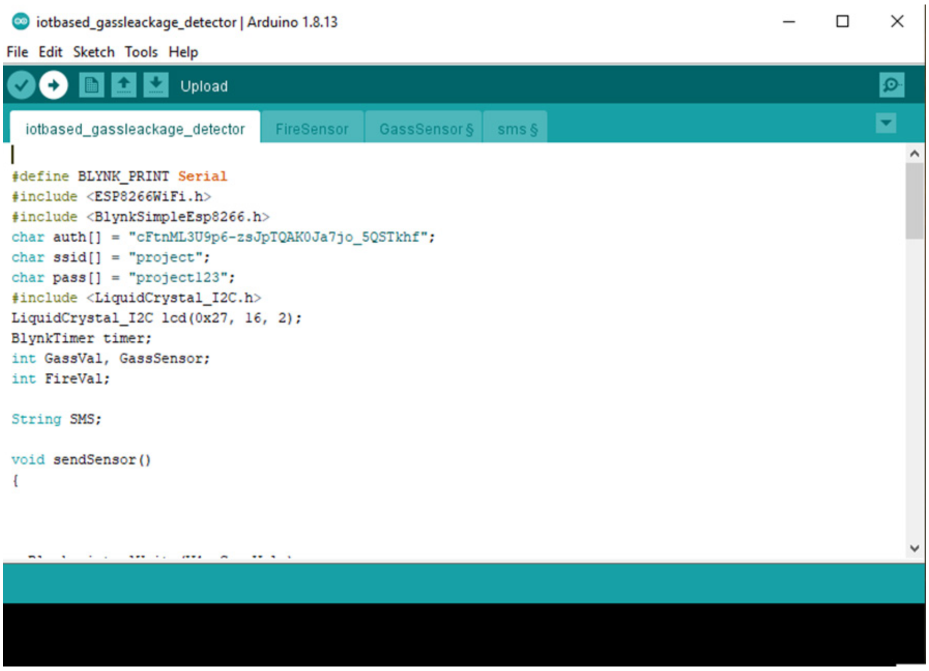


Fig. 9. Snapshot of coding for the actuators

The snapshot of coding for the GSM SIM module is shown in Figure 10. In this portion, the node MCU, i.e., ESP8266 is programmed to activate the SIM module to send the message to a specific phone number (e.g., house owner). When the flame sensor detects fire in the house/chamber, the SIM module sends an SMS to the user. The user is alerted with a text message along with the location of the incidents.

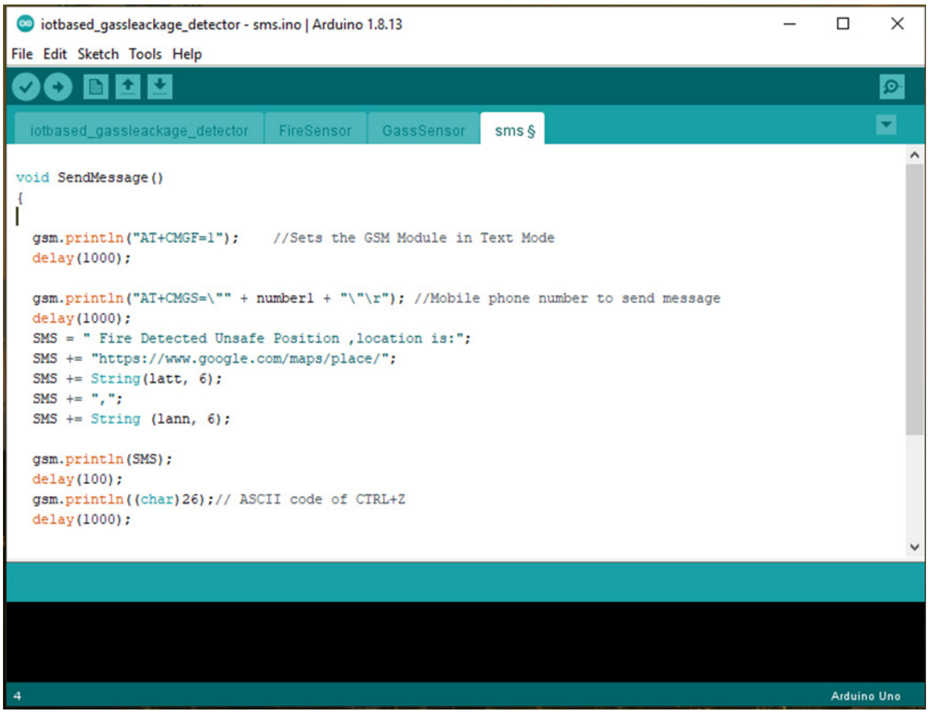


Fig. 10. Snapshot of coding for the GSM SIM module

5 Test, result, and survey

5.1 Test and result

In this sub-section, the test and the result of the experiment are explained. We test it in a kitchen of a house. When gas leaking occurs beyond the threshold, the system sensor detects it and sends an alert SMS to the user, triggers the alarm and offers protection circuitry (exhaust fan), and regulates the cylinder knob using the relay and valve. The experiment of the proposed prototype is shown in Figure 11.

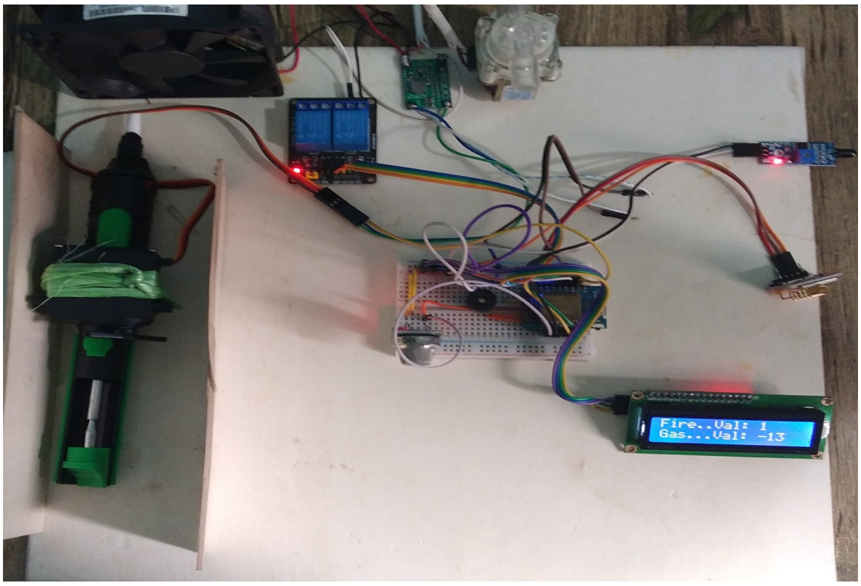


Fig. 11. Test of the whole system

Specifically, if PPM (Parts-Per-Million) > 620, the exhaust fan starts to run, and the solenoid valve waits for 15 seconds from that moment. After 15 seconds, if still PPM > 620, then the solenoid valve would shut off the gas supply. If catches fire after the leakage, the temperature goes up. If the temperature is greater than or equal to 50° C (centigrade), the servo motor is activated to pressure the sucker's button for throwing the fire extinguisher ball. At the same time, the buzzer sounds until the temperature falls below 50° C. We test our system in different conditions to verify its reliability, performance, and coherence. Table 2 describes the performance and reliability of the proposed IoT system.

Table 2. Performance and reliability of the proposed IoT system

Criteria	Performance and Reliability	Description
Response time	Early Detection	Detecting gas and fire in the early stage. When detects gas, the system sends an SMS to the owner and shuts off the gas line as well as starts the exhaust fan. Similarly, when detects the fire, sends an SMS to the owner, triggers the alarm, and throws the fire extinguisher ball
Sensitivity	200-10000 PPM	The detection range of MQ-4 is 200-10000 PPM (Parts-Per-Million)
Monitoring	24 hours	The System can operate automatically anytime day/night
Environment	Any weather	The system shows good performance in different environmental conditions such as cloudy, sunny, and rainy
Cost	Low-cost	The IoT components are low-cost and efficient
Energy	Consume little energy	The proposed system consumes little energy and hence increases the longevity
Notification	Low-cost and efficient	Buzzer sounds and the GSM module sends an SMS

5.2 Survey and users' feedback

We survey to receive users' feedback about our system. We are also interested to know the perception of people about smart IoT-based home solutions. We have randomly chosen 103 people from different places in the county who are living in the city, suburbs, and rural villages. The questionnaire for the survey is included in Appendix A of the article. The questionnaire contains five queries and all 103 people have provided their answers. Table 3 summarizes the reflection of the people who participated in the survey.

Table 3. Survey results

Subjects	Results/Remarks
1. Types of resources used for cooking	Gas: 44%, Electricity: 9%, Wood: 36%, Others: 11%
2. Usefulness of smart IoT-based system	Yes: 92%, No: 8%
3. Interested to buy a system	Yes: 68%, No: 32%
4. User rating of the proposed prototype? (1 = bad to 5 = Excellent)	Average rating: 4.3
5. Income group (sample size 103)	Rich: 14, Middle Class: 73, Poor: 16

It is observed from the table most of the people of the country use gas (LPG/Pipe Line) for cooking. Specifically, city dwellers rely on gas and villagers primarily depend on combustible wood. Most people (around 92%) admit the necessity of an intelligent IoT-based system. Still, some people (8%) are dubious about the IoT system and they are mostly illiterate. Around 68% of people are ready to take advantage of a smart system. Again, 32% are not ready to buy the system because they are mostly poor, illiterate, or skeptical about the technology. The average user rating of our proposed IoT system is also very promising which is around 4.3 on a scale ranging from 1 to 5. The bar chart in Figure 12 shows how the people have rated the prototype.

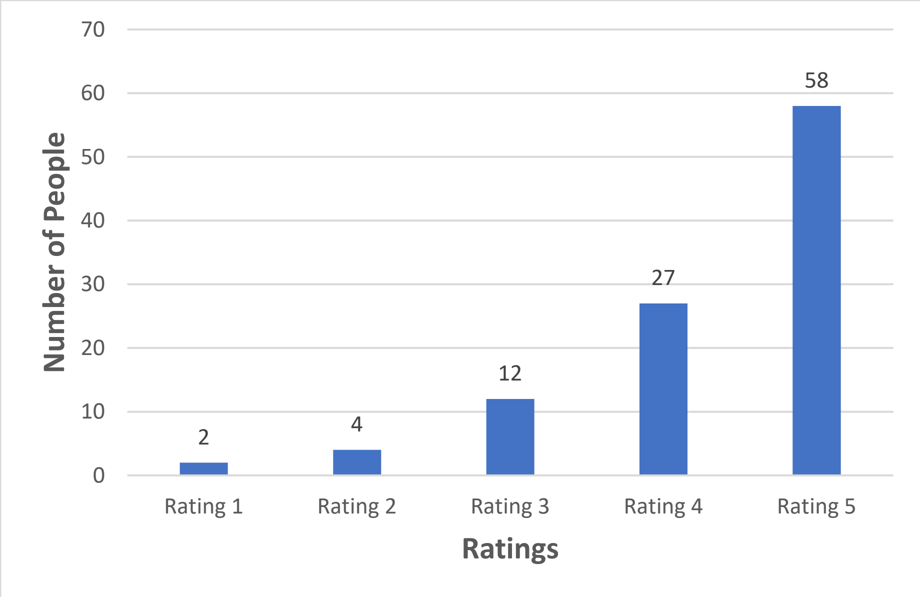


Fig. 12. Rating of the participants

6 Further development

We have developed an intelligent and simple prototype for gas and fire detection using the IoT. We have also offered protection circuitry and several counter activities to mitigate the effect if any mishappening occurs. In the future, we can make a fireproof cover for the protection of the prototype from accidental damage. The cover saves and secures numerous components and internal parts from unintentional impacts. Thus, the protection cover also improves the quality of the device's output. Our system is practically implementable and a real system can include more functionalities and activities to increase its efficiency and accuracy. In the following paragraph, we suggest some improvements.

The monitoring system can be further enhanced by utilizing Bluetooth or Wi-Fi [23], [24] in addition to GSM to send alert messages to users. Thus, the system can alert users who are residing within certain ranges of the system without having cellular connectivity and internet connections. It is noted that the range of Bluetooth is around 10 meters and that of Wi-Fi is around 100 meters [25]-[27]. For industrial purposes, robots and small firefighter cars can be introduced for detecting multiple gas concentrations as well as extinguishing fires [28], [29]. In addition to the gas sensor, a pressure sensor can also be used to detect the pressure of gas in the cylinder pipe. When low pressure is detected, it indicates a leak occurs inside the pipe and displays the alert SMS.

7 Conclusion

Ours is a technologically advanced age. People are becoming more dependent on embedded systems. As time passes, this reliance grows exponentially. While LPG gas has become more widely available, some leakage incidents can pose serious risks to people. As such, we have created an IoT prototype that would help us minimize its effects. Accordingly, we have designed and implemented a complete intelligent automatic gas leakage detection and fire protection system. We have designed a framework that builds around human-computer interactions. In the future, the automation system would look like our system. The system ensures our safety and saves our life. In this project, we have successfully built a low-cost automatic gas leak detection and fire extinguishing prototype.

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10 Appendix A

Survey on:
IoT-Based Intelligent Gas Leakage Detection and Fire Protection System
Q.1. What types of resources do you use for cooking?
Ans: i) Pipe Line Gas ii) LPG iii) Electricity iv) Wood v) Others
Q.2. Does an intelligent IoT system for kitchens/rooms helpful?
Ans: i) Yes ii) No iii) Moderate
Q.3. Do you want to buy these sorts of automated IoT systems?
Ans: i) Yes ii) No
Q.4. How do you rate our IoT prototype (1 = bad, 5 = Excellent)?
Ans: i) 1 ii) 2 iii) 3 iv) 4 v) 5
Q.5. How much is your annual income?
Ans: i) Below 4194 $ ii) 4194 -13979 $ iii) Above 13979 $