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Solar-Powered IoT Gas Monitoring System with Vibration Alerts for Deaf Users

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Abstract

This research focuses on developing a Solar-Powered IoT Gas Monitoring System with Vibration Alerts for Deaf Users to enhance safety in residential and commercial environments. The system utilises solar energy with battery backup to ensure continuous operation during power outages, while the alternating current (AC) supply serves as the primary power source. An automatic power transfer mechanism is implemented to maintain uninterrupted operation of critical components, particularly the gas detection and IoT monitoring modules. The Internet of Things (IoT) technology helps continuously monitor gas levels and sends early notifications to users. In cases of hazardous gas levels, various safety features are triggered, such as an alarm buzzer, an LED alarm, the starting of exhaust fans, and automatic control of a gas solenoid valve to restrict gas leakage. In addition, a vibration-based alert bracelet is incorporated for vibration alarms for deaf and hard-of-hearing individuals. This ensures effective non-auditory alerts for the deaf. Results from experiments confirm that the system can detect gas leakage and hazardous gas levels, as well as activate safety alarms and issue vibration alerts for deaf individuals, in real time. Overall, the developed system demonstrates strong potential as a reliable, inclusive, and sustainable safety solution for modern home and commercial applications.

1. Introduction

The usage of Liquefied Petroleum Gas, abbreviated as LPG, is very common in kitchens, especially in homes and business premises, because of its efficiency, portability, and economic benefits. However, LPG leakage is a major concern, especially given its high flammability, which can lead to rapid accumulation and major incidents such as fire and explosions [1]. In addition, various reported incidents have shown that the problem is worsened by late detection of the leakage and a lack of adequate alarm mechanisms to warn of it [2].

Most available gas leakage detectors operate as individual units that issue local alarm notifications to users but do not support real-time monitoring or notifications [3]. As a result, users may not receive alarm notifications when away from the monitored region, thereby delaying their response to the emergency situation. In other cases, gas leakage detection systems rely on power to perform their detection functions, thereby reducing their reliability during power outages.

With advances in IoT technology, gas monitoring systems can now continuously monitor gas levels, transmit data wirelessly, and issue real-time notifications of hazardous situations via mobile apps. Such a system can reduce response times in hazardous situations by enabling remote monitoring of gas levels at a location and issuing warnings [4]. Another important consideration in gas monitoring systems is reliability, as gas leaks can occur at any time, including during a power outage. Thus, using solar power in combination with a rechargeable battery can provide a solution to this problem.

Another factor to consider in designing the system is inclusiveness, as traditional alarm-based systems have mostly relied on auditory signals, which are ineffective for people who are deaf or have hearing impairments. A system that incorporates a vibration-based alarm would ensure that everyone remains aware of the emergency signal, regardless of hearing ability.

Therefore, the objective of the proposed project is to develop a Solar-Powered IoT Gas Monitoring System with Vibration Alert for Deaf Users. The proposed system is expected to enhance kitchen safety by monitoring gas leaks and automatically ventilating the kitchen. The proposed system includes an ESP32 module, an MQ2 sensor, a solenoid valve, a fan, a buzzer, and a vibration alert system.

2. Methodology

This project used the prototype development methodology, integrating hardware implementation, embedded programming, and experimentation to develop a functional solar-powered IoT-based gas safety system. The project's development strategy began with the design of the system's architecture based on the components required for the LPG leakage detection and safety system. After defining the system's requirements and operating conditions, the hardware components were integrated using a modular subsystem design to improve flexibility and facilitate troubleshooting during development.

The developed prototype was implemented by combining the components of the proposed system: the sensor component, consisting of the sensing unit with the MQ-2 sensor; the control component, consisting of the ESP32 microcontroller; and the response components, consisting of the ventilation fan, solenoid valve, buzzer alarm, and vibration bracelet. System-level tests are conducted to evaluate the overall operational flow of the proposed system, including real-time leakage detection, emergency response activation, and return to normal monitoring mode.

2.1 System Hardware Setup

The proposed hardware system is based on a subsystem design that improves maintainability, reliability, and integration. The proposed hardware system is based on a prototype that is divided into three main subsystems. These subsystems include a solar power supply and energy storage subsystem, an ESP32-based sensing and control subsystem, and a wearable vibration alert bracelet for the deaf and hard-of-hearing individuals.

2.1.1 Solar Power System Setup

Fig. 1 shows the setup of the solar power system. The solar power subsystem is intended to provide a continuous energy supply to the monitoring system, especially when power from the primary electrical power source is unavailable. The solar power subsystem is composed of a photovoltaic panel and a solar charge regulator. The solar charge regulator controls the solar panel's charging and stores the energy in a rechargeable battery. The energy from the batteries is then utilised by the system load through a regulator. The regulator is responsible for ensuring a steady voltage supply from the batteries to power the ESP32 module.

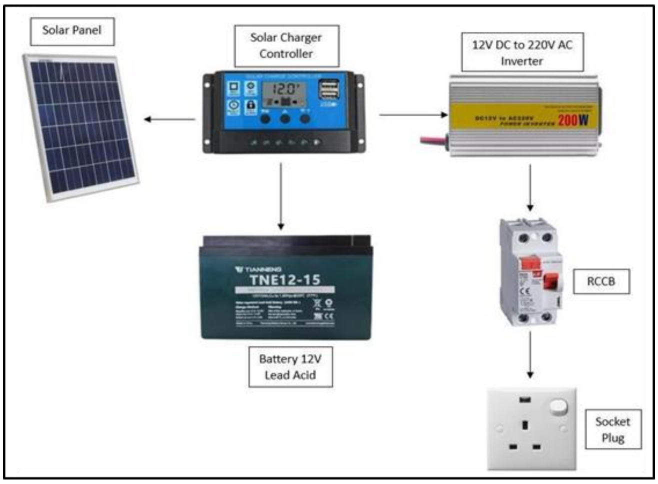


Fig. 1 *Solar power system setup*

2.1.2 Main ESP32 Sensing and Control Setup

The main subsystem serves as the system's sensor, decision-making, and actuation module. The ESP32 module serves as the system's core module. Fig. 2 shows the main ESP32 setup. The ESP32 module features embedded Wi-Fi and is widely used in the development of IoT-based monitoring systems [4]. The MQ-2 sensor is used as the system's sensor module. The LPG level is sensed by the MQ-2 sensor. The LPG level is continuously monitored and compared with the set threshold level. When an abnormal LPG level is detected, the system's safety response is initiated. The system's exhaust fan and buzzer serve as the safety response module. The solenoid valve serves as the system's shutdown module.

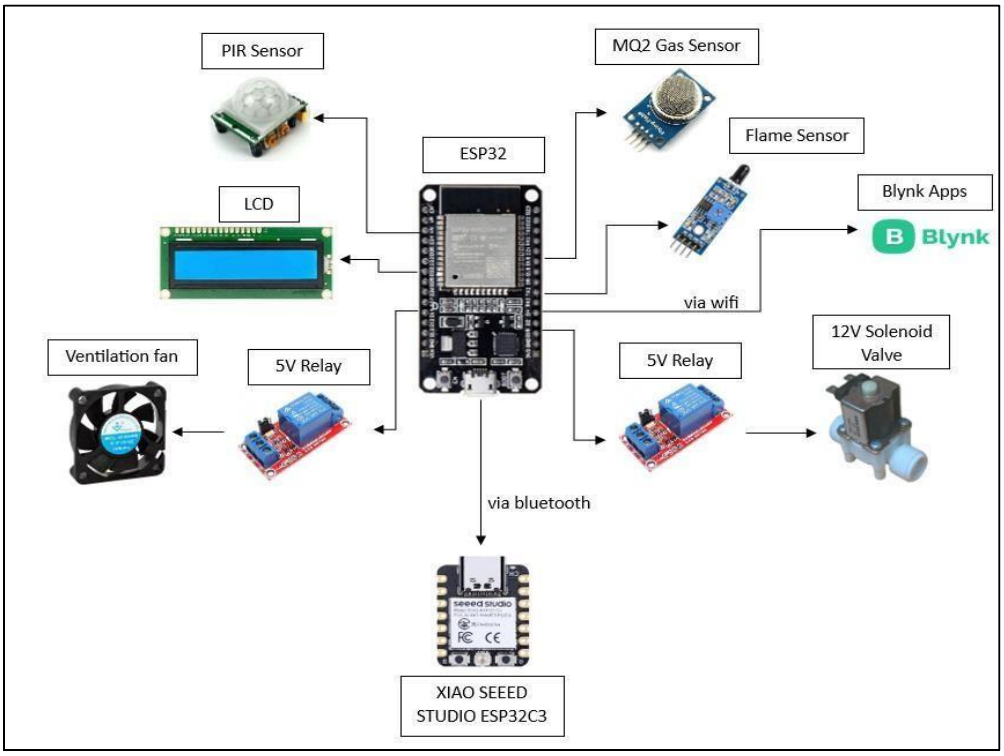


Fig. 2 *Main ESP32 setup*

2.1.3 Deaf Alert Bracelet Setup

Fig. 3 shows the deaf bracelet setup. To ensure greater inclusivity, a vibrating bracelet is also incorporated to alert deaf and hard-of-hearing people. It receives alert signals from the main controller and vibrates during a leakage situation. It is also more effective to use a vibrating alert than an audio-based alert system, ensuring safety information is always accessible to people regardless of their hearing ability [5]. It is also incorporated independently to enhance usability and ensure effective alerting to people outside the buzzer alarm's range.

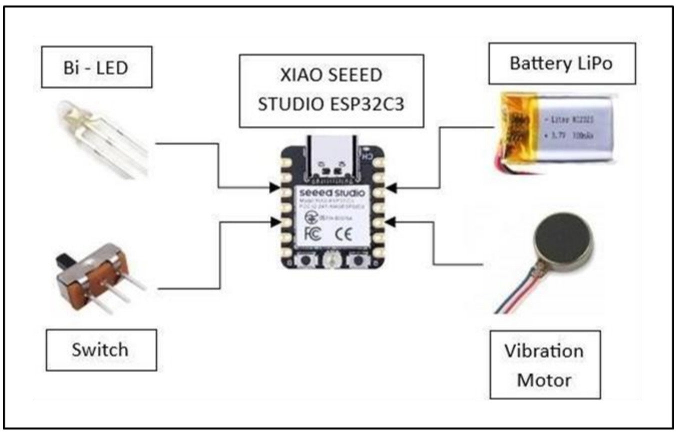


Fig. 3: *Hardware setup for the deaf bracelet*

2.2 System Hardware Setup

The ESP32 controller can be used to construct the control logic of this system by sensing and making decisions depending on a threshold level. When a gas leak occurs during normal operation, the system's state is determined by comparing a real-time reading from the MQ-2 sensor to a predetermined leakage threshold. This system instantly enters a state of emergency to mitigate potential threats by utilising a fan to lower gas concentrations in a room and a valve to stop gas flow in the room as soon as a reading from this sensor exceeds a predetermined gas concentration threshold. At this stage of the system's operation, a buzzer alarm and a vibration alert bracelet generate a warning message that alerts both general users and users who are deaf or have hearing impairments to a potentially dangerous condition in the room. A flowchart of this project's operations is shown in Fig. 4.

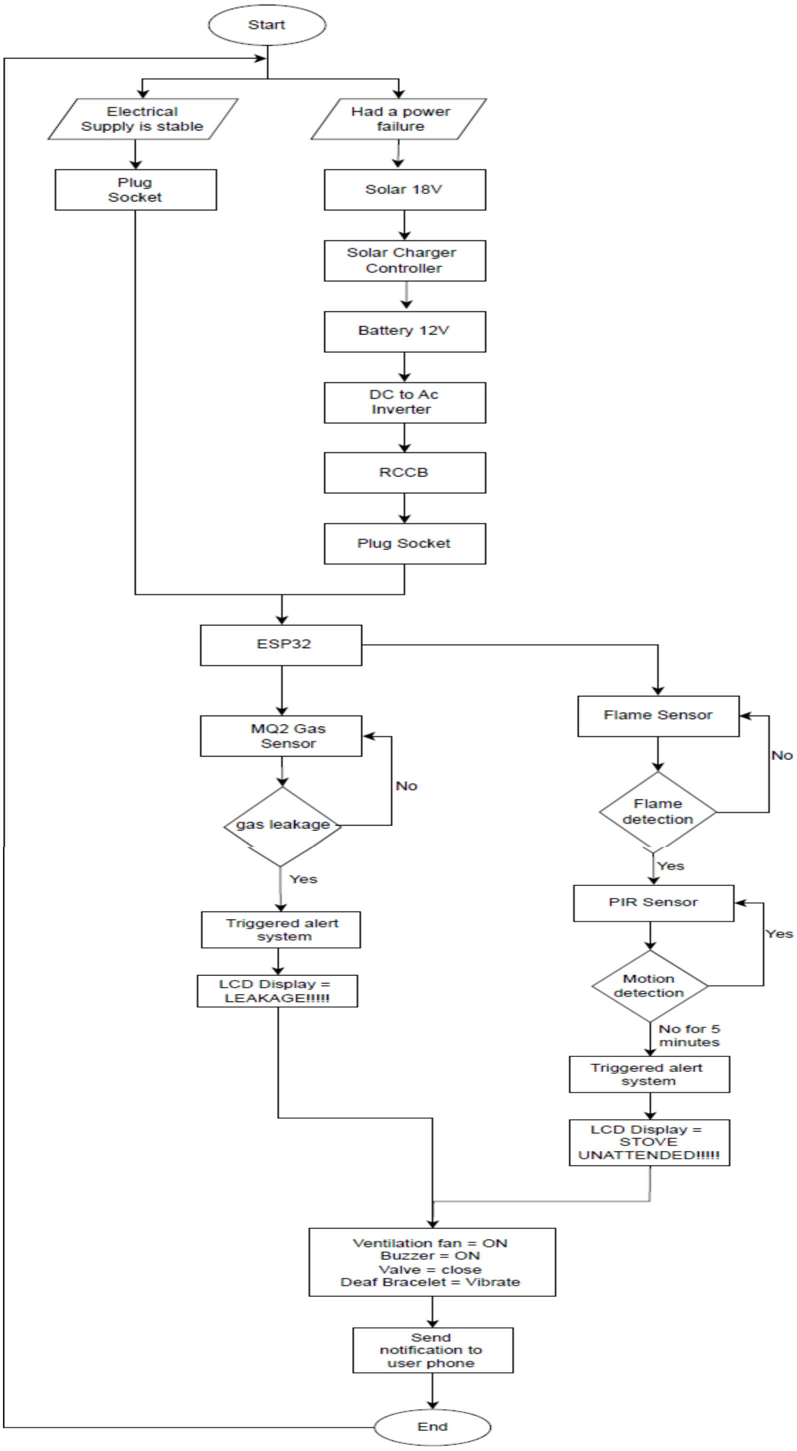


Fig. 4 *Flowchart of the project operation*

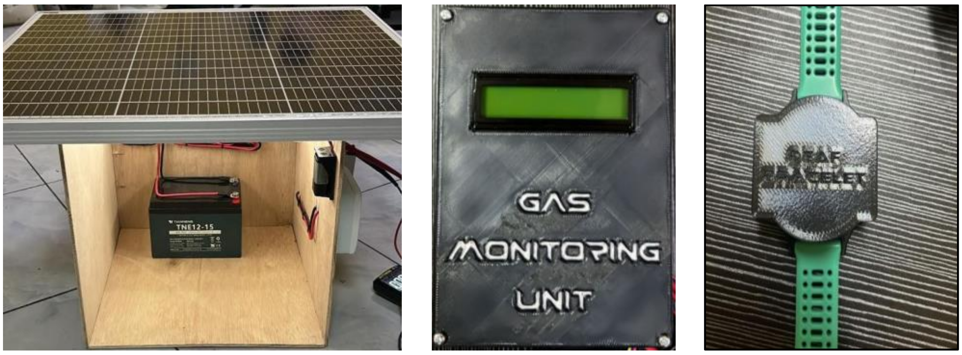
3. Result and Discussion

This section presents the results and discussion of the Solar-Powered IoT Gas Monitoring System with Vibration Alerts for Deaf Users developed in this work.

3.1 Prototype of Hardware Design

The hardware system has three main modules in the prototype design: the solar power system, the ESP32-based sensor system, and the deaf people's vibration alert bracelet. The solar power system consists of a photovoltaic panel, a solar charge controller, and an energy storage system in the form of a rechargeable battery pack. The solar panel serves as the primary power source, while the rechargeable battery pack provides a constant supply of power during power interruptions in the electrical supply system.

The module is based on an ESP32 microcontroller connected to an MQ-2 gas sensor to continuously monitor LPG concentration. If the gas concentration exceeds a threshold, the ESP32 module is programmed to trigger an emergency mitigation process that includes activating the exhaust fan, shutting off the gas supply via a solenoid valve, and generating an audible alarm via a buzzer. At the same time, the wearable device, the vibration alert bracelet, is also activated to transmit the emergency information to the wearer, making the information accessible to the hearing-impaired individuals beyond the frequency limit of the buzzer. Fig. 5 shows the prototype of the hardware design.



(a) **(b)** **(c)**

Fig. 5 *The prototype of hardware design (a) Solar power system; (b) Main ESP32 Setup; (c) Deaf Bracelet*

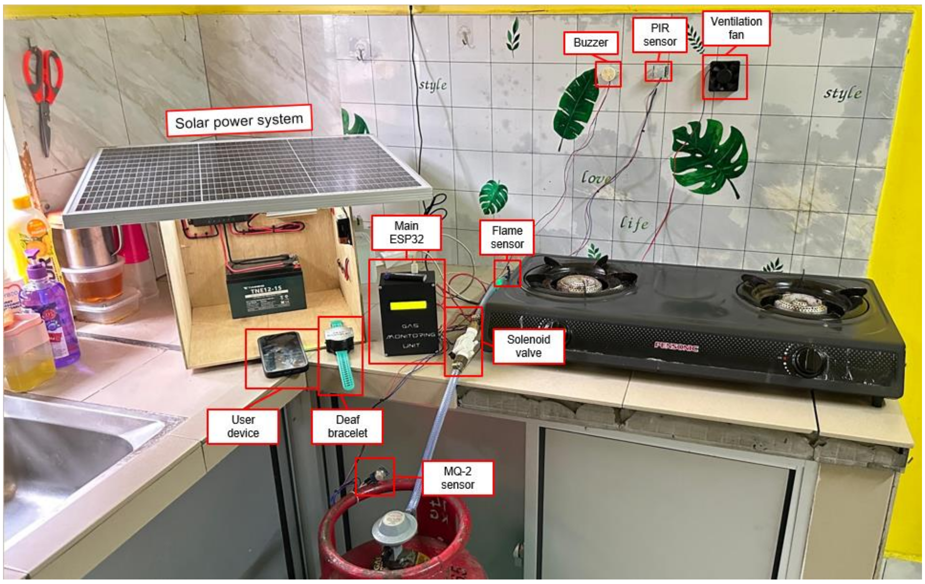


Fig. 6 *Overall system setup*

3.2 Overall System Setup

The proposed system was fully functionally tested in the domestic kitchen environment to ensure the feasibility of the suggested system in the actual environment of application, as shown in Fig. 6. The solar power system, ESP control system, MQ-2 gas sensor, solenoid valve, ventilation fan, buzzer alarm, vibration alert bracelet, and Internet of Things were fully functionally tested in the actual environment of application. The solar power system was fully functionally tested in the actual operating environment. The proposed system was fully functionally tested in the actual application environment. Overall, the results demonstrate that the proposed system operates reliably as an integrated safety solution and is suitable for practical household implementation.

3.3 Result Data for MQ-2 Gas Sensor

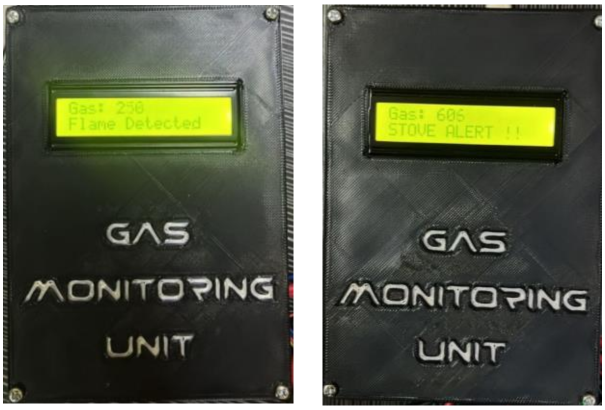
As shown in the experiment results for the MQ-2 gas sensor, the proposed system can effectively detect LPG gas leakage and take appropriate safety measures when the predetermined threshold is exceeded. In the experiment conducted on the proposed system, when the measured value of the gas concentration was more than 700 ppm, the environment was considered to be in the leakage condition, where the buzzer alarm, ventilation fan, deaf alert bracelet, solenoid valve switch-off, alert signals sent to the users through the Blynk mobile application and email, and the LCD display of the warning message were activated. Otherwise, when the measured value of the gas concentration was less than 700 ppm, the environment was considered to be in a safe condition, where the alert signals were turned off, the solenoid valve was turned on, and the LCD display was showing the safe condition of the environment as “AIR SAFE”. Fig. 7 shows the LCD display when leakage happens and when it is safe.

(a) **(b)**

Fig. 7 *LCD display when: (a) leakage happens and (b) air is safe*

3.4 Result Data for flame sensor and PIR sensor

In this test, the system's ability to recognise dangerous stove settings was evaluated using the IR Flame Sensor and the PIR Motion Sensor. The system recognised a flame as a hazardous state and triggered its safety responses, including shutting down the solenoid valve, turning on the ventilation fan, sounding the buzzer alarm, and vibrating the deaf alert bracelet if the motion sensor failed to detect human presence within 5 minutes. In this instance, the system recognised the dangerous condition by displaying the warning "STOVE ALERT" on the LCD. When a motion was detected near the stove while a flame was present in the system, the system recognised this as a safe state and did not display the emergency messages on the screen; instead, it only showed the message "FLAME DETECTED." The system returned to the safe state and displayed the message "AIR SAFE" on the screen when it detected no flame. Fig. 8 shows the LCD display when flame is detected and when the stove is unattended.

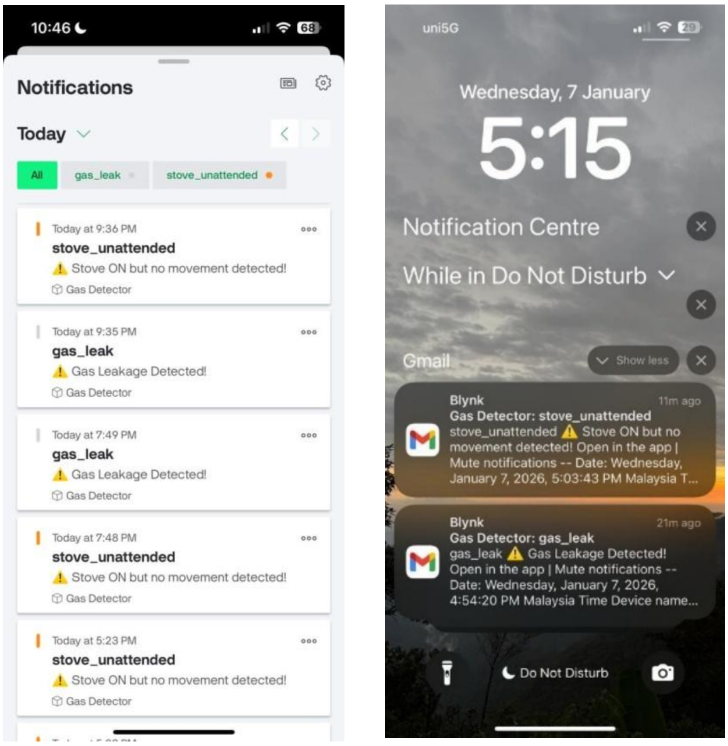


(a) **(b)**

Fig. 8 *LCD display when: (a) flame detected and (b) stove unattended*

3.5 Result Data for Blynk Apps

The proposed system's remote monitoring system through the Blynk app was tested. The system was found to be efficient at sending the user real-time alarm notifications via the user's email account and the Blynk app in hazardous situations, such as an LPG leak, fire alarm activation, or a stove left on in the kitchen. The user can respond to the hazardous situation in real time, even if they are not in close proximity to the kitchen environment, through notifications that indicate the identified system status. Once the user sees the notification in the Blynk app, they can confirm receipt, indicating the system successfully sent the alarm notification to the user in real time. No warning notifications were generated once the environment stabilised. Fig. 9 shows the email notification on the smartphone's notification panel.



(a) (b)

Fig. 9 *Notification shows at: (a) Blynk apps and (b) email notification*

3.6 Result Data for Deaf Bracelet

The effectiveness of the Deaf Alert Bracelet in providing non-auditory safety alerts in dangerous circumstances was also tested. The bracelet generated the vibration alarm output as soon as the state entered the emergency state for safety responses in scenarios such as leak detection, fire detection, and unattended stove use. This suggested that hearing-impaired people could benefit from the bracelet even without buzzer alerts or Internet of Things messages alerting them to potentially dangerous circumstances in their surroundings. The alert would also end immediately if the state is safe again.

3.7 Overall Result Data for the system

The system responses in different operating situations are shown in Table 1. The solenoid valve is open, all alert devices are off, the LCD display shows "AIR SAFE," and the system does not send a notification in safe mode (MQ-2 ≤ 700 ppm). The system initiates an emergency response by turning off the solenoid valve, turning on the fan, buzzer, and vibration bracelet devices, displaying "LEAKAGE!!!" on the LCD, and sending Blynk and email notifications in the case of a gas leak (MQ-2 > 700 ppm). When motion is sensed in the system, the display on the LCD reads “FLAME DETECTED.” The flame detection system functions normally, but when a flame is present without motion, the LCD display reads “STOVE ALERT!!”

Table 1 *Overall result data for the system*

System Condition	MQ-2 Gas Sensor	IR Flame Sensor	PIR Motion Sensor	Gas Solenoid Valve	Buzzer	Ventilation Fan	Deaf Alert Bracelet	LCD Display	Blynk & Email Notification
Safe Condition	Below threshold (≤ 700 ppm)	No flame	Motion / No motion	ON (Open)	OFF	OFF	OFF	AIR SAFE	No notification
Gas Leakage Detected	Above threshold (> 700 ppm)	–	–	OFF (Closed)	ON	ON	ON (Vibration)	LEAKAGE!!!	Alert sent
Flame Detected with Motion	Normal	Flame detected	Motion detected	ON (Open)	OFF	OFF	OFF	FLAME DETECTED	No notification
Flame Detected with No Motion (≥ 5 s)	Normal	Flame detected	No motion (≥ 5 s)	OFF (Closed)	ON	ON	ON (Vibration)	STOVE ALERT !!	Alert sent
System Returned to Normal	Below threshold	Flame off	Motion detected	ON (Open)	OFF	OFF	OFF	AIR SAFE	No notification

4. Conclusion

In this research, the proposed Solar-Powered IoT Gas Monitoring System with Vibration Alerts for Deaf Users was developed to monitor the presence of leaks of liquefied petroleum gas (LPG) while promoting kitchen safety through the implementation of an inclusive model of warning support targeting the deaf and hard-of-hearing community. Consequently, the experiment has confirmed the proposed system's capability to effectively monitor LPG leaks by utilising the MQ-2 sensor, which is set to trigger an alert at 700 parts per million. Consequently, the proposed system is capable of initiating emergency mitigation measures while sending real-time alerts via the Blynk platform, which is empowered to send email alerts to the relevant stakeholders. Moreover, the proposed system is also empowered to utilise the flame sensor and PIR motion sensor to monitor unattended conditions of the stove, sending relevant alerts to the relevant stakeholders. Consequently, the experiment has confirmed the proposed system's ability to effectively monitor LPG leaks and promote kitchen safety.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper. All studies and simulations were carried out on an academic basis at Universiti Tun Hussein Onn Malaysia.

Author Contribution

The authors attest to the following: planning and designing the study, analysing and interpreting the data, and writing the paper.

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