

Research Article

IoT-Driven System Architecture for Continuous Hydrogen Leak Surveillance in Safety-Critical Environments

Ajit J Sevara¹, Pari RBamania², Eti A Kantawala³, Hiren M Bhatt⁴

^{1,2,3}Student, Department of Information Technology, Atmiya University, Rajkot, Gujarat, India

⁴Assistant Professor, Department of Computer Engineering, Atmiya University, Rajkot, Gujarat, India

DOI: <https://doi.org/10.24321/3051.4282.202501>

I N F O

Corresponding Author:

Eti A Kantawala, Department of Information Technology, Atmiya University, Rajkot, Gujarat, India

E-mail Id:

etikantawala23@gmail.com

Orcid Id:

<https://orcid.org/0009-0005-7883-2231>

How to cite this article:

Sevara A J, Bamania P R, Kantawala E A, Bhatt H M. IoT-Driven System Architecture for Continuous Hydrogen Leak Surveillance in Safety-Critical Environments. *J Adv Res Oper Syst Dev Evol* 2025; 1(2): 1-4.

Date of Submission: 2025-08-15

Date of Acceptance: 2025-08-28

A B S T R A C T

The study describes the design, implementation, and evaluation of a low-cost, real-time hydrogen (H₂) gas monitoring and alerting system. The system takes advantage of the Internet of Things (IoT) to provide localized and remote safety notifications. The hardware core is an ESP32 microcontroller, and it is supplemented with an MQ-8 chemiresistive gas sensor and a 1.3-inch OLED screen. Local alerts make use of audible (alarm) and visual (LED) alarms, while remote monitoring uses a WebSocket-based web server to push real-time concentration data to any web client connected to the system. The paper describes the hardware interfacing, including the necessary signal conditioning to interface the sensor, the firmware architecture to acquire and process the data, and the full-stack development of the real-time communications channel. A performance analysis and evaluation show that the system is responsive to H₂ gas and is effective in measuring and displaying gas concentration data, confirming the device is a solution to providing safety in environments where hydrogen gas is a potential hazard.

Keywords: ESP32, WebSocket, Real-Time Monitoring, Gas Detection, Safety System, Embedded Systems

Introduction

Hydrogen has been identified as a highly advantageous, clean energy carrier, useful in transportation methods, industrial processing, and power generation. With high energy density and no-carbon emissions, hydrogen is an attractive alternative to fossil fuels. Hydrogen is also highly flammable, has a wide explosive range while in air, and has extremely low ignition energy. It is dangerous. Hydrogen is undetectable to humans because it is colourless, odorless, and tasteless. Therefore, hydrogen leaks cannot be detected by the human senses and reliable, continuous monitoring

should be in place where hydrogen is produced, stored, or used.

Traditional gas detection approaches often rely on separate alarms and passive ventilation. While the alarms themselves are certainly operational, and in some instances, provide very minimal tracking, traditional practices lack modern centralised monitoring, remote accessibility, and real-time logging, all of which are critical to safety infrastructure today. As a result, response times, as well as communication of recurring leak patterns are often lost.

The combination of Internet of Things (IoT) technologies offers us a new way for gas detection systems. When sensors are combined with wireless technologies and real-time processing, these systems allow it to send a message to the user immediately after a sensor is triggered or an event occurs and visualise the leak remotely while also being aware of the event in real time.

This study describes the design and evaluation of a real-time hydrogen leak detection system utilising an ESP32 microcontroller and MQ-8 sensor.

Literature Review

Hydrogen gas detection is an area of considerable investigation as a result of its extreme flammability and its emergence in clean energy applications. A number of sensing technologies have been researched, including thermal conductivity sensors, electrochemical cells, catalytic bead and metal oxide semiconductor (MOS) sensors.¹ MQ-series sensors, especially the MQ-8, have become widely used due to their low cost and good sensitivity to hydrogen gas concentrations, specifically in the 100-10,000 ppm range.²

Traditional gas detection systems tend to be standalone hardware with limited functionality: local audio-visual alarms or analog meters, without the ability to log data, send remote alerts, or be part of broader safety management systems.^{3,4}

Recent developments in the area of embedded technologies have created smart detection platforms using embedded microcontrollers including Arduino, Raspberry Pi, and ESP32. The boards offer computing power, analog-to-digital conversion, and on-board capabilities for communication technologies (Wi-Fi/Bluetooth). The ESP32-based system has been shown to be used to detect gas leaks and monitor the environment.⁵⁻⁷ The systems are used in real-time, provide wireless access and are low power.

Arduino-based gas detection systems have been evaluated for low-cost monitoring applications. However, these led to designs that don't include support for web communication in real-time or interactive dashboards,⁸⁻¹⁰ and therefore, they are not as appropriate compared to ESP32-based proposals for safety-critical applications.

In addition, the use of IoT technology in gas sensing systems has increased the ability to collect data in real-time, remote access, and operational cost and implementation benefits from cloud-based processing analytics. Many systems have adopted common communication protocols such as MQTT

and WebSocket with increasingly real-time connecting between sensor nodes to the user interface.⁶ Despite the advances in detecting gas leaks in general, relatively few studies have explored hydrogen specific sensing using low-cost, real time IoT architectures that are accessible and applicable in safety- critical environments.

This study will build upon these studies by developing a hydrogen detection system utilising ESP32 and MQ-8 technologies, WebSocket real-time communication, and browser-based visualisations focusing on accessibility, affordability, and reliability.

Methodology

System Overview

The hydrogen leak detection system will be configured to allow continuous monitoring of hydrogen concentration and will provide local and remote alerts. The example of operational hydrogen leak detection entails an MQ-8 gas sensor combined with an ESP32 microcontroller. The semiconductor gas sensor will be wired to the ESP32 microcontroller. The ESP32 will read the analog voltage output from the sensor, compare it with the user-defined threshold, and signal the local notification via on-device lights and reload the user's web-based dashboard (Table 1).

Components Used

Electronics and Control

The MQ-8 hydrogen sensor generates an analog voltage output which is wired to one of the ESP32's ADC pins.⁶ The OLED display is wired to the ESP32 via the I²C protocol and provides a live display of the sensor readings. The red and green LEDs are connected to GPIO pins which toggle states depending on the sensor reading in relation to a user-defined threshold. The ESP32 was programmed using the Arduino IDE and features a WebSocket server for real-time data transmission and threshold setup on a browser-based interface. The threshold can be adjusted while the device is running, without needing to reboot the device (Figure 1).

Web Interface

The user interface is a minimal HTML/JavaScript page served from the ESP32's flash memory. It shows hydrogen concentration and allows threshold values to be input by the user. This value is sent back to the ESP32 via WebSocket and applied instantaneously.

Table I.Components Lists

Parameters	Test Conditions	Result
Sensor response time	Gas applied from butane source	1-2 seconds for detectable change
Sensor warm-up time	After power-on	~30 seconds before stable readings
Visual alert latency	Change in sensor value triggers LED	< 200 milliseconds
WebSocket data latency	ESP32 to browser dashboard (local Wi-Fi)	~90 milliseconds
Threshold reconfiguration	Adjusted via browser WebSocket input	< 100 milliseconds
Interface browser compatibility	Google Chrome, Mozilla Firefox	No performance issues observed

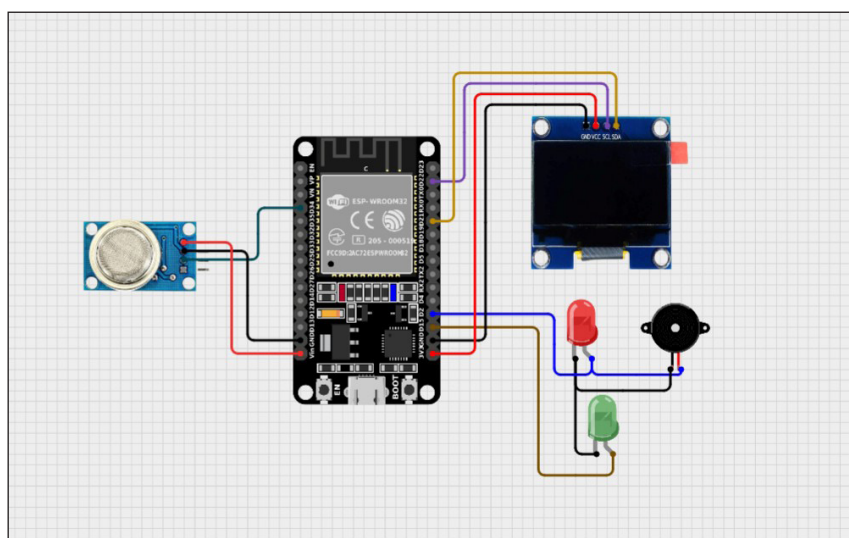


Figure 1.Circuit diagram of an IoT-based gas detection system

Result And Discussion

The evaluation of the hydrogen leak detection system occurred under controlled laboratory conditions to evaluate the system's responsiveness, data transmission in real-time, and alerting functionality based on concentration threshold.

Sensor Responsiveness

The MQ-8: Sensor indicated the presence of hydrogen gas released from a butane lighter (without flame) within 2–3 seconds of exposure at very close distances. The MQ-8: sensor stabilised rapidly upon power being applied (generally within 30 seconds) and displayed no extensive drift during the testing process.

LEd Alert Mechanism

The red and green LEDs activated properly to changes in gas concentration. When the user-defined threshold for immediate actions was exceeded, the green LED turned off and the red LED turned on, providing real-time visual feedback. The LED positive response time in changing state was less than 200 milliseconds, providing for timely alerts.

Web Interface Performance

The ESP32 was shown to transmit sensor readings to a browser-based dashboard using WebSocket protocol. The average data delay while connected to a local Wi-Fi network was 90 ms.⁸ The dashboard was able to constantly refresh without fuss, and was suited for users to simply update the threshold without even a page refresh.

Threshold Control and User Interaction

The dynamic threshold setting allowed users to enter a new threshold value on the web interface, and the system implemented the new threshold right away (without the need to reboot or refresh the page). This means testing would remain convenient regardless of a concentration range.

These results demonstrate that the system can operate correctly for real-time hydrogen leak detection, with the advantage of providing low-latency wireless monitoring and wireless alerts, as well as selectable thresholds giving the users ultimate control. This architecture may also find suitable deployment in safety-relevant environments, including laboratories, hydrogen fuel stations, and industrial storage facilities (Table 2).

Table 2.Result

Parameters	Test Conditions	Result
Sensor response time	Gas applied from butane source	1-2 seconds for detectable change
Sensor warm-up time	After power-on	~30 seconds before stable readings
Visual alert latency	Change in sensor value triggers LED	< 200 milliseconds
WebSocket data latency	ESP32 to browser dashboard (local Wi-Fi)	~90 milliseconds
Threshold reconfiguration	Adjusted via browser WebSocket input	< 100 milliseconds
Interface browser compatibility	Google Chrome, Mozilla Firefox	No performance issues observed

Conclusion

This work has presented a functional and efficient Internet of Things (IoT)-based hydrogen leak detection system developed utilising an ESP32 microcontroller and MQ-8 gas sensor. All aspects of the system showed the capability to yield real-time monitoring of hydrogen and gas alert data engaged visual alerts with LED and buzzer alarms, and allow reference to a WebSocket-enabled web dashboard to configure the threshold alerts remotely. The experimental results of the system showed reliable sensor response, low-latency low-cost communication methods, and effective alert triggering for the detection of hydrogen leaks. This means the system can be placed into service in safety-sensitive environments, laboratories, and industrial settings. The system architecture was a starting point, and as with any IoT solution, adaptability and improvement are possible, allowing for improvements into significantly more sophisticated systems like cloud integration, push notifications, and predictive analytics to move to proactive safety management practice.

Declaration of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Acknowledgement

The authors would like to extend their sincere thanks to Atmiya University, Rajkot, India. for providing the necessary research facilities that included laboratory resources, technical supports etc.,and they would like to acknowledge Mr. Hiren M. Bhatt, Assistant Professor, Department of Information Technology, who provided invaluable support during the course of this project.

References

1. Sunny AI, Zhao A, Li L, Sakiliba SK. Low-cost IoT-based sensor system: A case study on harsh environmental monitoring. *Sensors*. 2020 Dec 31;21(1):214.
2. Luo Y, Zhang C, Zheng B, Geng X, Debliquy M. Hydrogen sensors based on noble metal doped metal-oxide

semiconductor: A review. *International Journal of Hydrogen Energy*. 2017 Aug 3;42(31):20386-97.

3. Islam MM, Nooruddin S, Karray F, Muhammad G. Internet of things: Device capabilities, architectures, protocols, and smart applications in healthcare domain. *IEEE Internet of Things Journal*. 2022 Dec 13;10(4):3611-41.
4. Vijayalakshmi M, Ramesh KB, PG S. Iot-Enabled Lpg Leakage Monitoring with Arduino Uno, Esp32, and Real-Time Mobile Alerts Via Flutter. *Esp32, and Real-Time Mobile Alerts Via Flutter* (November 15, 2024). 2024 Nov 15.
5. Agarwal S, Kumar S, Agrawal H, Moinuddin MG, Kumar M, Sharma SK, Awasthi K. An efficient hydrogen gas sensor based on hierarchical Ag/ZnO hollow microstructures. *Sensors and Actuators B: Chemical*. 2021 Nov 1;346:130510.
6. Carrillo-Amado YR, Califa-Urquiza MA, Ramón-Valencia JA. Calibration and standardization of air quality measurements using MQ sensors. *Respuestas*. 2020 Jan 1;25(1):70-7.
7. Hercog D, Lerher T, Truntič M, Težak O. Design and implementation of ESP32-based IoT devices. *Sensors*. 2023 Jul 27;23(15):6739.
8. Zhang H, Zhang R, Sun J. Developing real-time IoT-based public safety alert and emergency response systems. *Scientific Reports*. 2025 Aug 8;15(1):29056.
9. Saxena P, Shukla P. A review on recent developments and advances in environmental gas sensors to monitor toxic gas pollutants. *Environmental Progress & Sustainable Energy*. 2023 Sep;42(5):e14126.
10. Holovatyy A, Teslyuk V, Lobur M, Pobereyko S, Sokolovsky Y. Development of arduino-based embedded system for detection of toxic gases in air. In 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT) 2018 Sep 11 (Vol. 1, pp. 139-142). IEEE.