Raspberry Pi Pico based Gas Detection and Environmental Monitoring

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Abstract

Environmental pollution and the release of hazardous gases have become growing concerns in both industrial and domestic areas. Prolonged exposure to harmful gases such as carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4) can lead to serious health complications and even life-threatening conditions. To address these challenges, this paper proposes a cost-effective, scalable, and real-time gas detection and environmental monitoring system built around the Raspberry Pi Pico microcontroller. The system incorporates a suite of calibrated gas sensors, including MQ-series sensors, to accurately detect and measure the concentration levels of target gases. The Raspberry Pi Pico, with its low power consumption and real-time processing capability, serves as the central control unit, acquiring analog sensor data, converting it via ADCs, and transmitting the information to a cloud-based IoT platform using Wi-Fi. The IoT integration enables continuous remote monitoring and data logging, offering real-time alerts and visual dashboards through mobile or web interfaces. This facilitates proactive safety measures, timely maintenance, and environmental compliance. The system is designed with flexibility and portability in mind, making it suitable for deployment across diverse environments, including industrial zones, residential buildings, parking garages, and outdoor pollution monitoring stations.

Keywords: *Raspberry Pi Pico, Gas Detection, Environmental Monitoring, IoT-based Sensing, Hazardous Gas Sensors, Real-time Data Logging*

I. Introduction

Gas detection and environmental monitoring are critical components in ensuring the safety and sustainability of both industrial operations and public living environments. From manufacturing plants and chemical processing units to residential buildings and urban centers, the presence of hazardous gases poses a significant risk to human well-being and ecological balance. Toxic gases such as carbon monoxide (CO), methane (CH_4), and carbon dioxide (CO_2) are often odorless and colorless, making them particularly dangerous if not continuously monitored. Exposure to such gases can lead to a wide range of adverse health effects including respiratory distress, neurological damage, and in severe cases, death.

Traditionally, gas detection systems have relied on proprietary technologies that are often costly, complex to install, and require regular maintenance and calibration. These limitations have restricted widespread deployment, especially in low-resource or decentralized environments. As environmental concerns continue to grow due to rapid urbanization, industrialization, and climate change, there is an increasing need for affordable, reliable, and scalable monitoring solutions that can be implemented in diverse settings.

The advent of the Internet of Things (IoT) has revolutionized the way environmental data is captured and utilized. IoT-enabled gas detection systems allow for real-time data acquisition, cloud integration, remote access, and timely notifications, thereby enabling preventive and corrective actions before a situation becomes critical. These systems not only help ensure compliance with environmental regulations but also support sustainable development by promoting safer living and working conditions.

In this context, the Raspberry Pi Pico, a compact and cost-effective microcontroller based on the RP2040 dual-core ARM Cortex-M0+ processor, emerges as a promising platform for building such solutions. Unlike traditional microcontrollers, the Pico offers enhanced performance, multiple GPIOs, analog-digital conversion capabilities, and

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compatibility with MicroPython and C/C++, allowing for rapid development and easy integration of multiple gas sensors and communication modules. This paper explores the development of a real-time gas detection and environmental monitoring system using the Raspberry Pi Pico. The system is equipped with a variety of gas sensors to detect and measure the concentration of toxic gases such as CO, CH_4, and CO_2. Data collected from these sensors is processed and transmitted through IoT protocols to a cloud-based dashboard, providing users with intuitive visualizations, real-time alerts, and historical analysis capabilities. The low-cost design, ease of deployment, and scalability of the system make it suitable for a wide range of applications including industrial plants, residential complexes, public transportation systems, and urban monitoring zones.

By leveraging modern embedded systems and IoT technologies, the proposed solution aims to bridge the gap between affordability and functionality in environmental monitoring. It not only contributes to improving safety standards but also supports a proactive approach to environmental management and public health preservation.

II. Related Works

The Internet of Things (IoT) has revolutionized gas detection by enabling real-time monitoring and alerts. Santiputri and Tio (2018) developed an IoT-based gas leak identification system that monitors gas concentrations, fire hazards, and human presence within a structure. IoT-based solutions often incorporate Wi-Fi-enabled microcontrollers like ESP8266 to send alerts via messaging platforms such as Telegram. Leak detection in industrial pipelines is another critical area. Liu et al. (2011) proposed a Supervisory Control and Data Acquisition (SCADA) model to analyze leakage points in gas pipeline systems. The model captures temperature, pressure, and flow dynamics at 30-second intervals, aiding in real-time anomaly detection. Manohar Raju and Sushma Rani (2014) developed an Android based gas detection robot that transmits gas leak data via Bluetooth. Rajaramya et al. (2014) proposed an ARM7-based automated LPG refill booking and leak detection system. Dorje et al. (2021) demonstrated an IoT-enabled system using a Node Microcontroller Unit (NodeMCU) for gas detection. Numerous research efforts have been made in the domain of gas detection and environmental monitoring, particularly with the rise of low-cost embedded systems and IoT technologies. Traditional gas detection systems often utilize industrial-grade detectors, which, although highly accurate, tend to be expensive, bulky, and less adaptable to portable or widespread deployment. Recent developments in microcontroller-based sensor systems have paved the way for more accessible and scalable solutions.

Several studies have demonstrated the use of low-cost gas sensors such as the MQ-series (e.g., MQ-2, MQ-4, MQ-7) for detecting gases like carbon monoxide, methane, and liquefied petroleum gas (LPG). For example, Kumar et al. (2020) developed a pollution monitoring system using MQ-135 and Arduino Uno, enabling local air quality assessment in urban areas. Although effective, the system lacked real-time remote access and scalability. IoT-enabled monitoring systems have gained traction due to their ability to transmit environmental data to cloud platforms for visualization and analysis. Patel and Sharma (2021) proposed an IoT-based air quality monitoring system using NodeMCU and various gas sensors. The project offered real-time updates via a web dashboard but relied on more power-hungry microcontrollers, making continuous deployment in energy-constrained settings less feasible.

The Raspberry Pi series (mainly Raspberry Pi 3/4) has been widely used in environmental projects due to its processing power and Linux-based flexibility. However, these boards are not optimized for low-power or embedded sensor interfacing applications. In contrast, the Raspberry Pi Pico, introduced in 2021, offers an efficient microcontroller-based alternative. It provides direct GPIO access, analog input capabilities, and supports MicroPython, making it ideal for real-time sensor integration at a significantly lower cost.

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Recent works have also explored integrating environmental monitoring systems into broader smart city frameworks. For instance, Singh et al. (2022) demonstrated a multi-sensor IoT network for monitoring temperature, humidity, and gas levels across city zones. While comprehensive, such systems require complex infrastructure and backend management, often limiting deployment in low-resource settings.

Despite the growing interest, relatively few projects have focused on using Raspberry Pi Pico as the core platform for environmental gas monitoring. The potential of the RP2040 microcontroller remains underutilized in this domain, especially in combining affordability, real-time processing, and IoT connectivity for field-ready solutions.

III. System Design

The proposed system is designed to detect and monitor harmful gases in real-time using a modular, cost-effective embedded platform. The key design objective is to create a reliable, scalable, and energy-efficient solution that can be deployed across various environments.

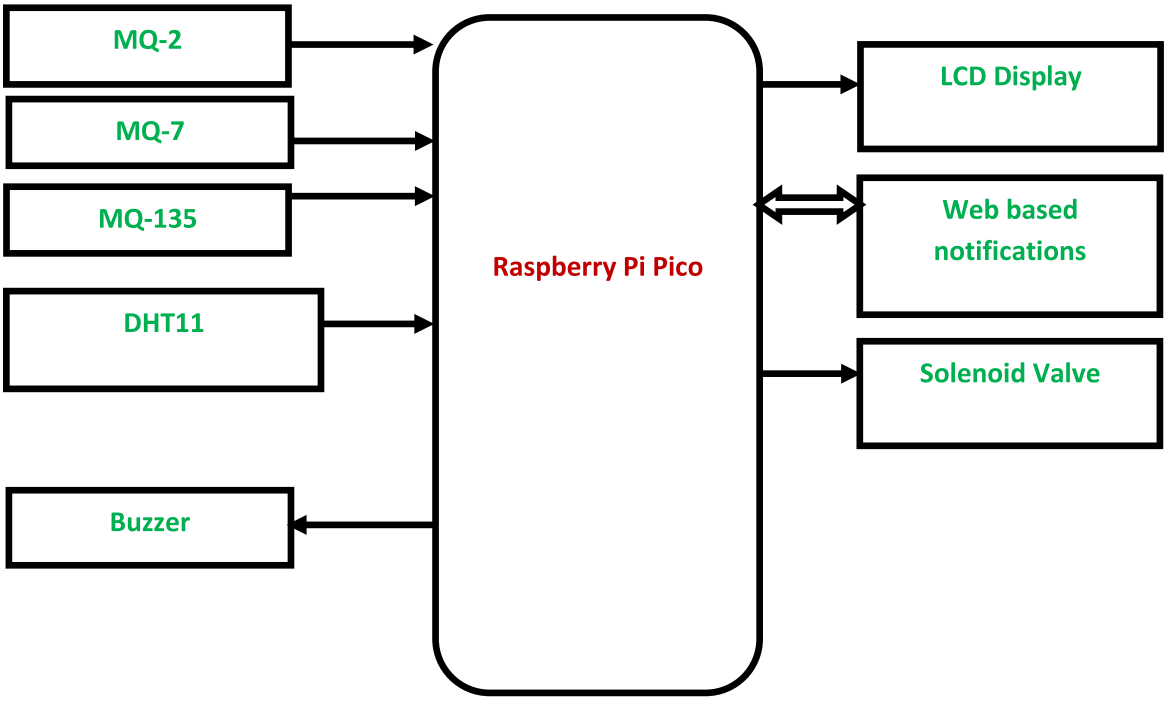

Figure 1: Block Diagram of proposed system

The block diagram of the proposed gas detection and environmental monitoring system outlines the interaction between various hardware and software components required for real-time environmental sensing and data communication. The key components and their functionalities are as Gas Sensors (MQ-7, MQ-4, MQ-135). These are analog gas sensors capable of detecting harmful gases such as Carbon Monoxide (CO), Methane (CH_4), and general air pollutants (CO_2, NH_3, alcohol vapors, etc.). Each sensor produces an analog voltage signal proportional to the concentration of the target gas in the environment. The Raspberry Pi Pico includes built-in ADC channels which convert the analog voltage signals from the gas sensors into digital values. These digital values represent gas concentration levels and are used for further processing. Raspberry Pi Pico (RP2040 Microcontroller) serves as the central control unit of the system. It performs the following functions such as reads sensor data via its ADCs, Executes programmed logic to process the data, Compares real-time readings against defined safety thresholds, Communicates with external modules

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for data transmission and alert generation. The platform receives gas sensor data from the system and displays it through a user-friendly dashboard. Users can visualize gas concentration trends over time; receive alerts when gas levels exceed critical thresholds and access data remotely via smartphone or web browser, when gas levels exceed predefined limits, the system triggers immediate local alerts.

IV. Mathematical Model

To accurately quantify gas concentrations from sensor outputs and analyze environmental parameters, the system relies on mathematical models that convert raw sensor data into meaningful metrics. These models help in calibration, thresholding, and real-time decision-making. The following are the key models used:

4.1. Sensor Calibration Model

Each gas sensor (e.g., MQ-7, MQ-4, MQ-135) outputs an analog voltage that varies with gas concentration. This voltage is first converted to a digital value using the Raspberry Pi Pico's ADC. The relationship between the sensor output and gas concentration can be approximated using a logarithmic model based on the sensor's data.

$$\frac{R_s}{R_0} = A \cdot \left(\frac{P}{P_0}\right)^{-B}$$

Where:

- R_s: Sensor resistance at a given gas concentration
- R_0: Sensor resistance in clean air
- P: Measured gas concentration (ppm)
- P_0: Reference gas concentration (ppm)
- A, B: Constants derived from sensor calibration curves

To find R_s, use:

$$R_s = \frac{(V_{cc} - V_{out}) \cdot R_L}{V_{out}}$$

Where:

- V_{cc}: Supply voltage
- V_{out}: Output voltage from the sensor
- R_L: Load resistance connected to the sensor

4.2. Analog-to-Digital Conversion (ADC)

The Raspberry Pi Pico has a 12-bit ADC, which converts analog voltages to digital values from 0 to 4095. The actual voltage from the sensor can be calculated as:

$$V_{out} = \frac{ADC_{value}}{4095} \cdot V_{ref}$$

Where:

- ADC_{value}: Raw digital value from ADC
- V_{ref}: Reference voltage (typically 3.3V)

4.3. Threshold-Based Alert Logic

To identify hazardous levels, a simple threshold model is used:

$$\text{Alert} = \begin{cases} 1, & \text{if } P \geq P_{\text{critical}} \\ 0, & \text{if } P < P_{\text{critical}} \end{cases}$$

Where:

- P: Measured gas concentration
- P_{critical}: Predefined safety threshold (ppm)
- Alert = 1 triggers buzzer/LED and IoT notification

4.4. Data Smoothing Model

Sensor data can be noisy; thus, a simple moving average (SMA) filter is applied:

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$$SMA_t = \frac{1}{n}\sum_{i=0}^{n-1} x_{t-i}$$

Where:

- SMA_t: Smoothed value at time t
- x_{t-i}: Previous raw readings
- n: Window size

4.5. Data Transmission Time Model

If needed, the system's data upload interval T_{upload} can be modeled as:

$$T_{upload} = T_{sample} + T_{process} + T_{send}$$

Where:

- T_{sample}: Time to read and convert sensor values
- $T_{process}$: Time for calculations and formatting
- T_{send}: Time taken to send data to the cloud

These mathematical models ensure accurate measurement, filtering, and timely alerts, making the system intelligent, responsive, and suitable for real-time environmental monitoring.

V. Results

The project titled "Gas Detection and Environmental Monitoring Using Raspberry Pi Pico" presents a compact and efficient system for real-time monitoring of environmental conditions. Utilizing the Raspberry Pi Pico microcontroller, the system integrates a DHT11 sensor to measure temperature and humidity, alongside MQ series gas sensors—MQ-2 for smoke and LPG, MQ-135 for air quality pollutants like ammonia and benzene, and MQ-7 for carbon monoxide detection. These sensors continuously feed data to the microcontroller, which processes the readings and displays them on an LCD screen. A buzzer is included to alert users when harmful gas levels exceed safe thresholds, ensuring timely warnings. Powered via email, this setup is ideal for low-cost indoor air quality monitoring, offering potential applications in smart homes, health monitoring, and industrial safety systems.

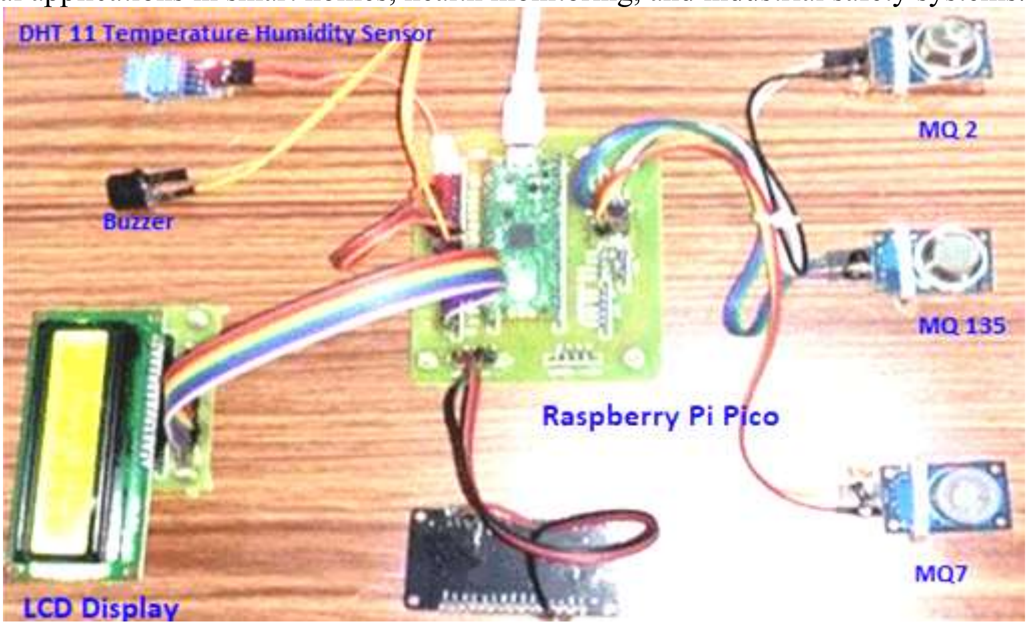

Figure 2: Experimental results

VI. Conclusion

This paper demonstrates the successful development of a low-cost, real-time gas detection and environmental monitoring system using the Raspberry Pi Pico microcontroller. By integrating multiple gas sensors (MQ-7, MQ-4, MQ-135) and utilizing the Pico's built-in

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ADC and IoT communication capabilities, the system effectively detects harmful gases such as carbon monoxide (CO), methane (CH_4), and carbon dioxide (CO_2). The processed data is transmitted to a cloud platform for real-time visualization, alerting, and historical analysis. The use of the Raspberry Pi Pico provides a compact, energy-efficient, and programmable platform ideal for embedded environmental monitoring applications. Mathematical models for calibration, signal processing, and decision-making enhance the system's accuracy and reliability. The design is modular and scalable, making it suitable for deployment in various environments such as homes, industries, public infrastructure, and agricultural settings. Overall, the proposed system offers a practical and affordable solution for enhancing public safety, supporting environmental compliance, and enabling proactive measures against air pollution and hazardous gas exposure. Future enhancements may include the integration of machine learning algorithms for gas classification, mobile app connectivity, and support for additional environmental parameters such as temperature, humidity, and particulate matter.

References

1. Ch. Manohar Raju & N. Sushma Rani, *An Android-Based Automatic Gas Detection and Indication Robot*, Int. J. of Computer Engineering and Applications, 2014.
2. Metta Santiputri & Muhammad Tio, *IoT-Based Gas Leak Detection Device*, Int. Conf. on Applied Engineering (ICAE), Japan, 2018.
3. Pal-Stefan Murvay & Ioan Silea, *A Survey on Gas Leak Detection and Localization Techniques*, Journal of Loss Prevention in the Process Industries, 2012.
4. V. G. Rajaramya et al., *ARM7-Based Automated High-Performance System for LPG Refill Booking & Leakage Detection*, IJERST, 2014.
5. Zhao Yang et al., *Leakage Detection and Analysis of Leakage Points in Gas Pipeline Systems*, Open Journal of Safety Science and Technology, 2011.
6. Vasudev Yadav et al., *Microcontroller-Based LPG Gas Leakage Detection Using IoT and GSM Module*, Int. J. of Sci. Res. & Mgmt. Studies, 2016.
7. Tarun Joseph et al., *Portable Gas Detection Device with Warning System*, Global Conf. for Advancement in Technology (GCAT), 2019.
8. Dorje Prabhakar et al., *Gas Leakage Detection Using NodeMCU*, Int. Conf. on Advanced Computing and Communication Systems, 2021.
9. J. Vijaya Lakshmi et al., *Implementation of Ammonia Gas Leakage Detection Using IoT*, Third Int. Conf. on I-SMAC, 2019.

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