Evaluation of Lo-Ra base Air Pollution Monitoring System

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Abstract

Air pollution is a silent but severe danger to human health and environmental sustainability. Traditional gas monitoring systems often fail to meet the need of scalability, cost-efficiency, and real-time data transmission in remote environments. This paper presents a human-centred, LoRa-based air pollution quality monitoring system capable of detecting multiple hazardous gases including CO, CO_2, and NO_x in real-time. The system utilizes affordable gas sensors (MQ2, MQ7, MQ135) integrated with STM32 and Arduino microcontrollers for data acquisition and visualization via both LCD and web-based interfaces. Field tests demonstrate the system's effective range of 900 meters, suitability for both indoor and outdoor deployment, and significant potential for enhancing environmental awareness and safety.

INTRODUCTION

In today's rapidly industrializing world, monitoring air quality and detecting harmful for ensuring environmental safety and human health. The proposed project focuses on the development of a using LoRa (Long Range) communication technology. This system integrates multiple gas sensors — MQ2 for detecting smoke and flammable gases, MQ7 for carbon monoxide (CO), and MQ135 for various air pollutants such as ammonia, benzene, and carbon dioxide. The sensing unit is built using an STM microcontroller, which reads data from the sensors nodes and transmits it using a LoRa transmitter module. On the receiving end, an Arduino Nano with a 16x2 I2C LCD and a LoRa receiver displays the gas concentration levels in real time. The implementation of LoRa allows the system to operate effectively over long distances, making it highly suitable for applications in remote industries, factories, agricultural fields, and residential areas. This project provides a cost-effective and scalable solution for real-time air quality monitoring, contributing to better environmental awareness and safety.

LITERATURE SURVEY

The concept of gas detection and monitoring systems has been explored in various fields, particularly in industrial safety, environmental monitoring, and smart homes. Numerous studies and commercial products have been developed to detect hazardous gases and ensure safety in different settings. Traditional gas detection systems, such as fixed gas monitors, rely heavily on wired infrastructure and limited communication methods. For example, a study by Amin et al. (2016) highlighted the use of gas sensors connected to control units via wired connections for industrial monitoring, but these systems were found to be cost-intensive, difficult to scale, and not adaptable to remote areas.

Wireless gas detection systems have seen significant advancements with the adoption of technologies like Wi-Fi, Bluetooth, and GSM. Sharma and Yadav (2018) proposed a wireless gas detection system using GSM for industrial applications, which offered the advantage of remote monitoring via mobile phones. However, this system faced challenges with power consumption and network dependence, which limited its usability in remote environments. Additionally, GSM- based systems require reliable cellular coverage, which may not be available in rural or industrial areas.

Another study by Soni et al. (2019) focused on LoRa-based communication for long-range, low-power applications, highlighting its potential for wireless monitoring systems. LoRa offers several advantages over wireless systems like Wi-Fi and Bluetooth, including extended range (up to several kilometers), lower power consumption, and the ability to transmit data over a long distances without relying on cellular networks. The use of LoRa technology for gas monitoring systems has been explored in several projects, such as Rodrigues et al. (2020), which successfully demonstrated the use of LoRa for environmental monitoring of various gases in rural settings.

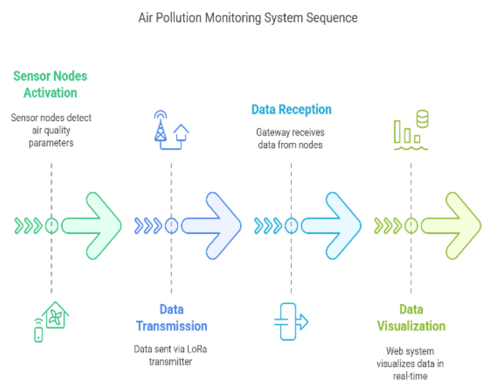
The incorporation of multi-gas sensors in wireless systems has also be a significant focus in recent research. Systems utilizing sensors like MQ2, MQ7, and MQ135 for detecting smoke, carbon monoxide, and air pollutants have be developed for both industrial and environmental safety. A study by Chong et al. (2017) proposed a gas monitoring system using the MQ series sensors with wireless communication to detect air quality in urban areas, demonstrating the feasibility of multi-gas detection systems. However, the challenges in providing real-time data, scalability, and energy efficiency remain.

LoRaWAN-Based IoT System Implementation for Long-Range (2022) Researchers developed a LoRaWAN-based measuring $PM_{2.5}$, CO_2, CO, SO_2, NO_2. The system transmitted data via The Things Network (TTN) to the ThingSpeak IoT server, providing real-time access through a web dashboard and mobile application. Validation against Aeroqual devices confirmed its reliability.

Low-Cost Solution for Air Quality Monitoring: Unmanned Aerial System and Data Transmission via LoRa Protocol (2024) The study introduces an integrated platform combining unmanned aerial systems (UAS) with LoRa communication for air quality monitoring. adapted with sensors for CO, O_3, and NO_2, the system offers a portable and cost-effective alternative to traditional networks, with real-time data visualization through a web application.

The paper presents a distributed embedded system utilizing LoRa technology for real-time data monitoring of pollutants like $PM_{2.5}$, PM_{10}, CO, NO_x, O_3, NH_3, along with meteorological parameters. The system employs sensors, known for their sensitivity and making it suitable for large-scale deployments

METHODOLOGY



Sensor Nodes Activation: Tiny sensors placed in the environment start working and begin checking the air for pollution and other quality indicators.

Data Transmission: These sensors send the collected air data wirelessly using a special signal (LoRa) to a central receiver.

Data Reception: A gateway device receives this air quality information from the sensors.

Data Visualization: The collected information is displayed on a website or dashboard so people can see real-time updates about the air quality around them.

COMPONENTS

HARDWARE COMPONENTS

ARDUINO NANO: The Arduino Nano is a compact and versatile microcontroller board ATmega328P chip. It various electronic projects due to its small size, affordability, and ease of use.

ESP8266: The ESP8266 is a low-cost, highly integrated microcontroller with built-in Wi-Fi capabilities. It is widely used in IoT (Internet of Things) projects for providing wireless connectivity to devices, allowing them to communicate across a network or the internet.

LORA: The LoRa (Long Range) transceiver module is a crucial component for enabling long-range, low-power wireless communication in IoT projects. Using LoRa modulation, it allows for data transmission a several kilometers, even in remote locations where other wireless technologies like Wi-Fi or Bluetooth may not reach.

MQ135 SENSOR: The MQ135 gas sensor is used to detect a wide array of gases, including ammonia (NH3), benzene (C6H6), alcohol, carbon dioxide (CO2), and other harmful gases. It is primarily used for general air quality monitoring, as it is sensitive to a variety of indoor air pollutants.

MQ7 SENSOR: The MQ7 gas sensor is designed to specifically detect carbonmonoxide (CO), a colorless and odorless gas that can be toxic at high concentrations. This sensor is essential in environments where CO may accumulate, such as in homes with gas heaters or industrial areas where combustion processes occur.

MQ2 SENSOR: The MQ2 gas sensor is used to detect a wide range of gases, including methane (CH4), liquefied petroleum gas (LPG), carbon monoxide (CO), smoke, and other volatile organic compounds (VOCs). This sensor works by measuring changes in the resistance of its sensing element when exposed to these gases.

LCD: The 16x2 LCD with I2C is a popular display module used in embedded systems and microcontroller-based projects. It features a 16-character by 2-line display, where each line can hold up to 16 characters.

BATTERY: Common battery options include Li-ion (Lithium-Ion) or Li-Po (Lithium-Polymer) rechargeable batteries, which are compact, have high energy density, and offer longer operation times. These are especially useful when the device is expected to function continuously over extended periods without frequent recharging.

SOFTWARE COMPONENTS

Arduino IDE:

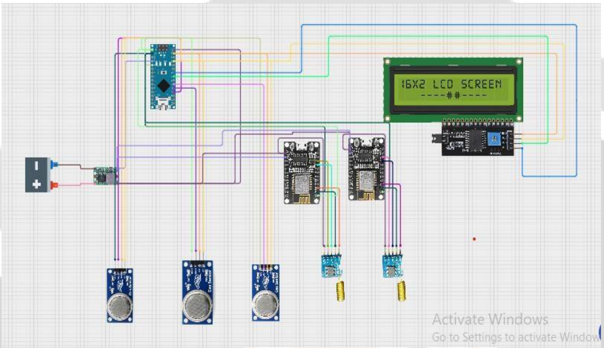
Description: The Arduino IDE is an open-source platform for writing and uploading code to Arduino boards. It supports various microcontrollers such as Arduino Nano, ESP8266, and STM32, which are central to your project.
Usage: You will use this IDE to write the firmware for your microcontrollers, including data acquisition from sensors, control of alarms, and communication via LoRa.

Platform IO:

Description: Platform IO is an integrated development environment (IDE) for embedded systems. It is a alternative to the Arduino IDE, supporting a wider range of hardware and offering advanced features like library management, debugging, and cross-platform builds.
Usage: Platform IO can be used for building a more complex firmware if you need greater flexibility and advanced debugging tools.

SYSTEM ARCHITECTURE

The **System Architecture** of your gas detection and monitoring system can be described as a layered structure that handles various tasks such as gas detection, data transmission, user interface management, and alerting. Below is a detailed breakdown of the architecture.



The system architecture of the follows a **distributed sensor network model** consisting of multiple sensing nodes and a central gateway. Each **sensor node** integrates a set of gas sensors (MQ-2, MQ-7, and MQ-135) with an **Arduino UNO R3 microcontroller** and a **LoRa transceiver module (RFM95W)** for wireless communication. The gas sensors detect specific pollutants—carbon monoxide (CO), nitrogen oxides (NO), and carbon dioxide (CO_2)—and send analog data to the microcontroller, which processes the information and formats it for transmission. The processed data is then transmitted via LoRa to a **LoRa gateway**, which serves as the central collection point for the entire network. The gateway receives and stores the data in a local repository (in text format) for analysis. A **web-based user interface** is linked to the gateway, allowing real-time access to pollution data through internet-connected devices. The system architecture is designed to be **scalable, low-power, and cost-effective**, making it suitable for both indoor and outdoor deployment across diverse geographic areas without relying on traditional cellular or Wi-Fi networks.

Step-by-Step Process Flow

The process flow outlines the sequence of events from the detection of gases by sensors to the transmission of data and triggering of alerts. Below is the detailed step-by-step process flow of your system:

Sensor Initialization and Calibration

Step 1: Power On

- The system is powered on either by battery or external power.
- The microcontroller (Arduino Nano or ESP8266/ESP32) initializes the sensors (MQ2, MQ7, MQ135) connected to the system.

Step 2: Sensor Calibration

- The sensors are calibrated to ensure that they provide accurate readings.
- This calculate process involves setting the baseline readings for each gas sensor to account for environmental variations (e.g., temperature, humidity).

Continuous Gas Detection

Step 3: Sensor Data Acquisition

- The gas sensors continuously monitor the environment for specific gases (e.g., methane, carbon monoxide, ammonia).
- The sensors detect changes in gas concentration in real-time and produce an analog signal.

Step 4: Analog to Digital Conversion

- The microcontroller reads the analog signals from the gas sensors.
- The analog data is converted to a digital signal for forward processing using the microcontroller's ADC (Analog-to-

Digital Converter).

Data Processing and Decision Making

Step 5: Data Processing

- The microcontroller processes the digital sensor data to extract gas concentrations in terms of parts per million (PPM).
- The data is then compared to for each gas sensor.
- If none of the gas levels exceed safe thresholds, the system continues monitoring.

Step 6: Data Logging (Optional)

- If the system is connected to a cloud platform (e.g., ThingSpeak or Firebase), the data is uploaded for long-term storage.
- The device can also store data locally for future reference.

Communication and Data Transmission

Step 7: Long-Range Communication (LoRa or Wi-Fi)

If any gas concentration exceeds the threshold:

- LoRa Communication: The system transmits the gas detection data over long- range LoRa communication (using SX1276/RFM95 LoRa modules) to a central receiver or gateway.

Air Quality Sensor Readings

Sensor	Value
MQ2	170
MQ7	109
MQ135	61

- Wi-Fi Communication: Alternatively, the system can transmit data to a remote server or cloud platform via Wi-Fi (using ESP8266/ESP32) for real-time monitoring.

Step 8: Cloud Data Upload (Optional)

- If connected to a cloud platform like ThingSpeak or Firebase, the gas levels, timestamp, and sensor IDs are uploaded to the cloud.
- Users can remotely monitor and track the gas levels via a web dashboard or mobile app. User Interaction and Control

Step 9: Remote Monitoring

- Users can access the data remotely through a web dashboard (via ThingSpeak or a custom server) or the Blynk mobile app.
- The dashboard shows real-time sensor data, including gas concentrations and status.

Step 10: Data Visualization

- The system visualizes the historical sensor data on the cloud platform, showing trends, gas levels over time, and frequency of alerts. This helps in analyzing and identifying patterns related to environmental changes.

RESULTS

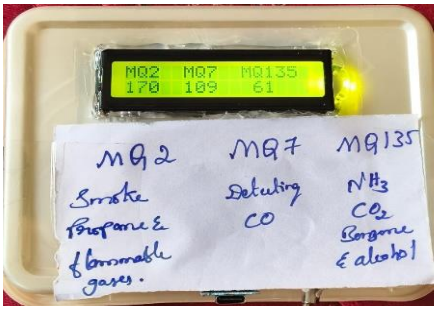
The evaluated by collecting real-time gas concentration data in parts per million (ppm) across different indoor and outdoor surroundings. results:

Hall and Library

Hall: Node 1 was placed inside a library to measure indoor air quality pollution where as a node 2 was placed in a closed hall with students while node 3 was placed in a hall of the same size but it is empty hall. The gateway was placed inside the library to receive sensor data from the three nodes. The gateway was placed inside the library to receive sensor data from the three nodes. The results shown that during the presence of three students in the hall, the carbon dioxide ratio with a increase in the ratio of carbon monoxide and nitrogen oxides. This was classified as a low pollution level and is classified as good.

1. ***Open Hall:***

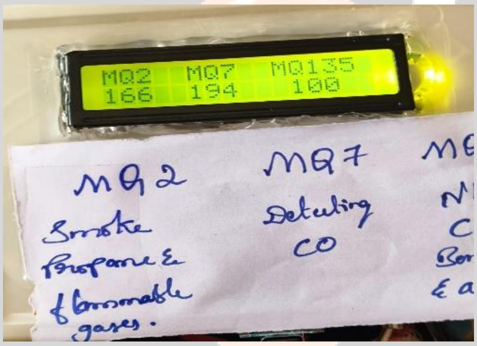
- ***CO (MQ-7):*** *~100–150 ppm.*
- ***CO_2 (MQ-135):*** *~50–120 ppm.*
- ***NO (MQ-2):*** *~150–250 ppm.*
- *Significantly lower levels observed in absence of human activity*



a. LCD Display
b. Display in Web application

2. Closed Hall:

- ***CO (MQ-7):*** *~150–200 ppm.*
- ***CO_2 (MQ-135):*** *~60–120 ppm.*
- ***NO (MQ-2):*** *~150–350 ppm.*



a. LCD Display

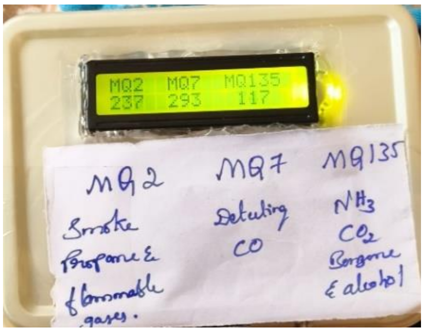
Air Quality Sensor Readings

Sensor	Value
MQ2	166
MQ7	194
MQ135	100

b. Display in Web application

Library Hall:

- CO (MQ-7): ~200–300 ppm.
- CO_2 (MQ-135): ~90–150 ppm.
- NO (MQ-2): ~180–350 ppm.



a. LCD Display

- Levels rose with more people present, likely due to exhalation and poor ventilation.

a. Display in Web application

Air Quality Sensor Readings

Sensor	Value
MQ2	237
MQ7	293
MQ135	117

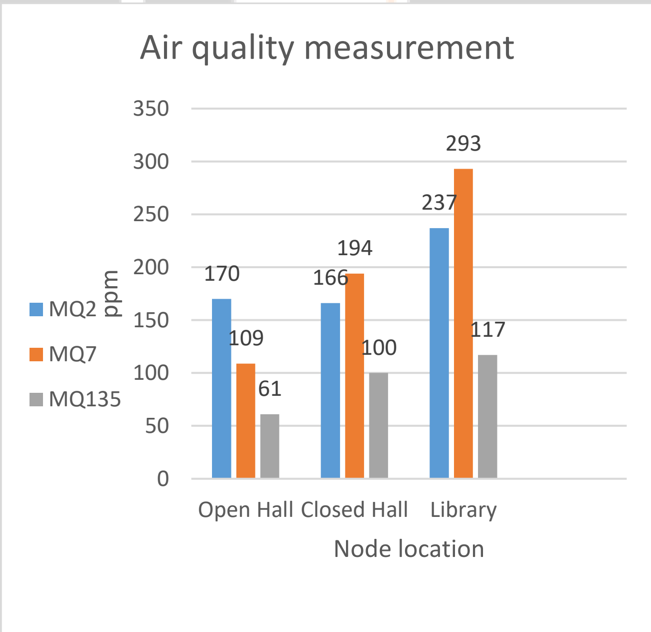


Fig: Air Quality in Hall and Library

CO2 was detected in the closed due to student respiration, while the ratios of CO and nitrogen oxides were not equal to those in the air fig shows the proportions of pollution quality measured by nodes. the air fig shows the proportions of air quality measured by nodes.

FUTURE ENHANCEMENT

In the future, the gas detection and monitoring system can be enhanced by integrating advanced sensors capable of detecting a wider range of hazardous gases with higher accuracy and faster response times. The system can also incorporate AI and machine learning algorithms to predict hazardous situations based on historical data trends, improving preventive actions. Cloud connectivity can be further expanded to include detailed data analytics dashboards and real-time GPS tracking for mobile deployment in vehicles or drones. Another major enhancement would be the development of a mobile application for remote monitoring, notifications, and system configuration, offering better user convenience. Additionally, incorporating solar charging support for the battery module can make the system more sustainable and ideal for deployment in remote or off-grid areas. Finally, observation with industry safety standards and certifications can ensure commercial and industrial applications.

Proposed Future Enhancements:

1. Integration of more advanced gas sensors for detecting a broader range of hazardous and dangerous gases with improved accuracy.
2. Implementation of AI/ML algorithms for predictive analysis and early warning alerts based on historical data trends.
3. Development of a user-friendly mobile application for real-time monitoring, remote control, and instant alert notifications.
4. Addition of GPS modules for location-based tracking of gas levels, especially in mobile or large- area deployments.
5. Incorporation of solar charging capability to support long-term, energy-efficient operation in remote locations.
6. Enhancement of the systems cloud infrastructure for real-time analytics, visualization dashboards, and secure data storage.
7. Introduction of automatic ventilation or mitigation mechanisms triggered by dangerous gas level detection.
8. Making the system modular and scalable to support multiple sensor nodes and centralized monitoring through a gateway.
9. Improving battery management and incorporating power-saving modes for extended battery life.
10. Ensuring compliancy with industry standards and certifications to make the system suitable for industrial or commercial deployment.

CONCLUSION

This project demonstrate how technology simple yet powerful way to monitor the air we breathe. By combining affordable sensors with long-range LoRa communication, the system provides real-time updates on pollution levels both indoors and outdoors. It’s easy to set up, doesn’t rely on expensive mobile networks, and gives people access to live air quality data through a web interface. Whether it's a busy city street or a quiet university campus, the system adapts well and helps highlight how our environment changes depending on human activity. low-cost, energy-efficient air monitoring a practical tool for creating healthier living spaces and spreading awareness about pollution in our everyday lives.

Future studies can focus on enhancing the coverage of LoRa technology. In the future, the gas detection and monitoring system can be enhanced by integrating advanced sensors capable of detecting a wider range of hazardous gases with higher accuracy and faster response times. The system can also incorporate AI and machine learning algorithms to predict hazardous situations based on historical data trends, improving preventive actions. Cloud connectivity can be further expanded to include detailed data analytics dashboards and real-time GPS tracking for mobile deployment in vehicles or drones. Another major enhancement would be the development of a mobile application for remote monitoring, notifications, and system configuration, offering better user convenience. Additionally, incorporating solar charging support for the battery module can make the system more sustainable and ideal for deployment in remote or off-grid areas. Finally, and certifications can ensure commercial and industrial applications.

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