

Lora Enable Air Quality Monitoring Network for Smart City

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Abstract

This project introduces the LoRa Enable Air Quality Monitoring Network for Smart City, an innovative Internet of Things (IoT) solution that utilizes Long Range (LoRa) communication technology for real-time urban air quality monitoring. The system measures environmental parameters including particulate matter (PM1.0, PM2.5, PM10), volatile organic compounds (VOCs), temperature, and humidity. It integrates low-power sensors and a centralized platform for cost-effective, scalable, and energy-efficient monitoring. The project aims to deploy and validate the system in urban locations, ensuring accurate data collection and long-range communication. Leveraging cloud technology, the collected data will be visualized through dashboards and reports to provide actionable insights. The ultimate goal is to identify pollution hotspots, aid policymakers in urban planning, and enhance public awareness of air quality, demonstrating a sustainable and scalable solution for smart city objectives and a healthier urban environment. The project successfully deployed and validated the system in real-world conditions, demonstrating accurate real-time data acquisition and long-range transmission of environmental parameters, as evidenced by successful data reception on The Things Network (TTN) console and efficient processing via Node-RED. Data visualization through Grafana dashboards confirmed the system's capability to provide actionable insights. The results highlight the system's efficiency, reliability, and scalability, emphasizing its potential to identify pollution hotspots, assist policymakers in urban planning, and improve public awareness of air quality issues, ultimately contributing to a healthier urban environment.

1. Introduction

The escalation of urban development and industrial activity has resulted in a significant decline in ambient air quality, particularly in densely populated areas. Reports by the World Health Organization (2023) indicate that 99% of the global population is exposed to air pollution levels exceeding established health guidelines. This exposure is strongly correlated with increased incidences of respiratory and cardiovascular diseases, as well as long-term neurological conditions (UNEP, 2023). As urban centers strive toward smart city transformation, there is a growing emphasis on integrating technological solutions that enhance environmental sustainability and public health. However, traditional air quality monitoring systems often suffer from limited spatial coverage and high implementation costs, which constrain their ability to provide timely and location-specific pollution data (World Bank, 2023).

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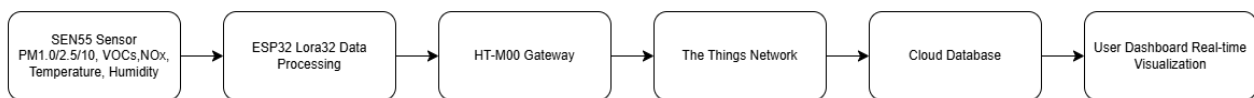
In response to these shortcomings, this study proposes a low-cost, energy-efficient air quality monitoring network based on LoRa (Long Range) communication and Internet of Things (IoT) architecture. The system utilizes the Sensirion SEN55 sensor, integrated with an ESP32 LoRa32 microcontroller, to continuously monitor key environmental indicators such as particulate matter (PM1.0, PM2.5, PM10), temperature, humidity, VOCs, and NOx. The collected data is wirelessly transmitted to a central platform through a LoRaWAN gateway, enabling real-time visualization via cloud-based dashboards. By offering a scalable and autonomous solution, this network has the potential to overcome the constraints of conventional systems, enhance urban air pollution detection capabilities, and contribute to more effective urban planning and health-oriented policy formulation (Semtech, 2023).

2. Methodology

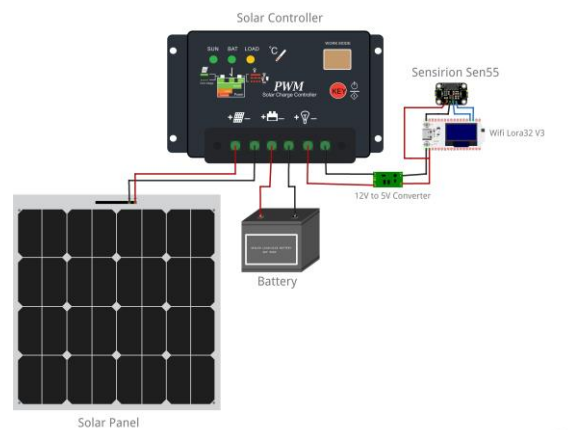
The development of the LoRa-enabled air quality monitoring system was structured around a modular design approach integrating both hardware and software components. The primary sensing unit comprises the Sensirion SEN55 sensor, capable of detecting particulate matter (PM1.0, PM2.5, PM10), temperature, humidity, volatile organic compounds (VOCs), and nitrogen oxides (NOx). These environmental parameters are collected and processed by the ESP32 LoRa32 microcontroller, which is equipped with LoRaWAN communication capabilities. The data is then transmitted via an HT-M00 dual-channel LoRa gateway to The Things Network (TTN), which serves as the cloud infrastructure for data aggregation and transmission.

A solar-powered system was incorporated to ensure autonomous and sustainable operation in outdoor environments. The circuit design includes a solar panel, battery pack, and a DC-DC buck converter to provide a stable 5V output to the microcontroller and sensor module. The system workflow begins with sensor initialization, followed by data acquisition, LoRa-based transmission, and cloud-side processing. To manage the data pipeline, Node-RED was utilized as a middleware for parsing incoming data from TTN and logging it into a MySQL database hosted via XAMPP. For end-user accessibility, the environmental data is visualized using Grafana, enabling intuitive interpretation through real-time graphs, dashboards, and tabular displays.

Figure 1(a) illustrates the overall block diagram of the system architecture. It outlines the flow of data from the SEN55 sensor to the ESP32 board, followed by LoRa-based transmission to the gateway. The gateway then relays the data to The Things Network (TTN), a cloud-based LoRaWAN infrastructure, where it can be accessed for further processing and visualization. To enable continuous and independent operation, the system is powered by a solar energy unit, consisting of a photovoltaic panel, a rechargeable battery, and a DC-DC converter. The circuit schematic, shown in Figure 1(b), details the wiring and component connections. The sensor communicates with the ESP32 via the I²C protocol (using GPIO21 and GPIO22), while power is stabilized using a regulated 5V output. Node-RED acts as middleware to decode and parse incoming data from TTN, storing it in a local MySQL database via XAMPP, while Grafana provides real-time dashboards for monitoring air quality indicators.



(a)



(b)

Fig. 1 Project description (a) System Block Diagram; (b) Project Circuit Schematic

2.1 Project Flowchart

Figure 2 details the data collection and transmission procedure with a Sensirion SEN55 sensor and LoRaWAN technology. The procedure starts with the initialization of the sensor and system components. Upon initialization, the Sensirion SEN55 sensor gathers environmental data, including temperature, humidity, and particle matter. The raw data is transmitted to an ESP32 microcontroller equipped with LoRa capabilities, where it is processed and prepared for transmission. The ESP32 transfers the processed data to an HT-M00 LoRa gateway, which relays the data to The Things Network (TTN). TTN is utilized for managing data uploads to the cloud. A decision point ascertains the success of the data upload. Upon success, the data is stored in the cloud, and a timer commences for a one-minute interval before the cycle is repeated.

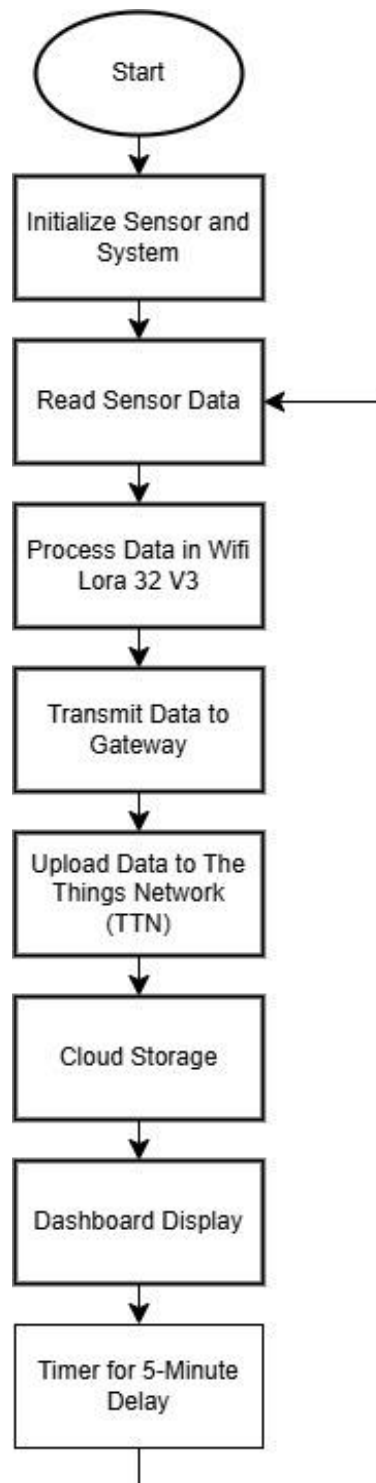


Fig. 2 System Flowchart

3. Results

The real-time data acquisition capability of the system was validated through successful uplink transmissions to The Things Network (TTN). Data packets containing sensor readings for PM concentrations, VOC levels, temperature, humidity, and NOx were received and confirmed in the TTN console interface. The Node-RED flow then parsed these packets and inserted the values into a structured database, as verified through continuous log entries and functional operation of the XAMPP MySQL server. These processes confirmed the system's ability to perform reliable long-range communication with minimal data loss or latency.

Data visualization through Grafana dashboards demonstrated the system's effectiveness in providing clear, real-time insights. Graphical panels displayed trends in air quality parameters, and tabular queries confirmed the completeness and accuracy of data collection. For instance, time-series plots showed expected fluctuations in particulate matter over 20-minute intervals, and sensor stability was evident through consistent readings across multiple environmental conditions. Overall, the results indicate that the system offers high-resolution environmental monitoring, minimal power consumption, and robust data integrity, making it well-suited for scalable deployment in smart city scenarios.

The functionality of the LoRa-based air quality monitoring system was evaluated through a series of tests involving real-time data collection, transmission, and visualization. The system successfully transmitted environmental data to The Things Network (TTN), and the received values were parsed using Node-RED before being stored in a MySQL database hosted locally via XAMPP. The TTN console (Figure 3) displayed a consistent stream of uplink packets, confirming that the ESP32 LoRa32 microcontroller could reliably send air quality data to the cloud.

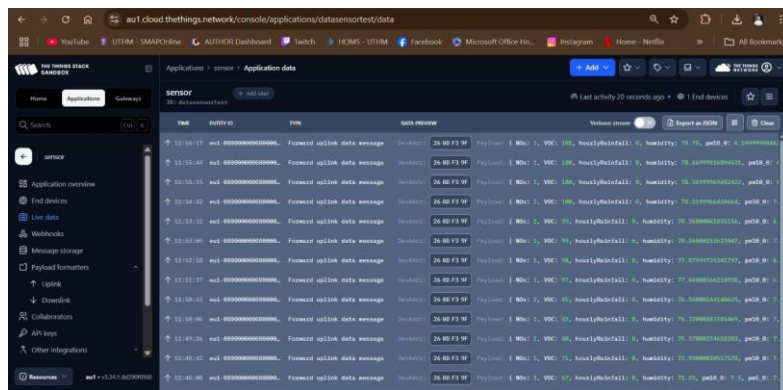


Fig. 3 Uplink Data Received on The Things Network Console

Subsequently, the decoded data was passed into Node-RED, where each parameter such as PM2.5, temperature, and VOC—was individually extracted and routed to the database. As shown in Figure 4, Node-RED enabled visualization of the live data payload and allowed for confirmation of successful parsing and storage.

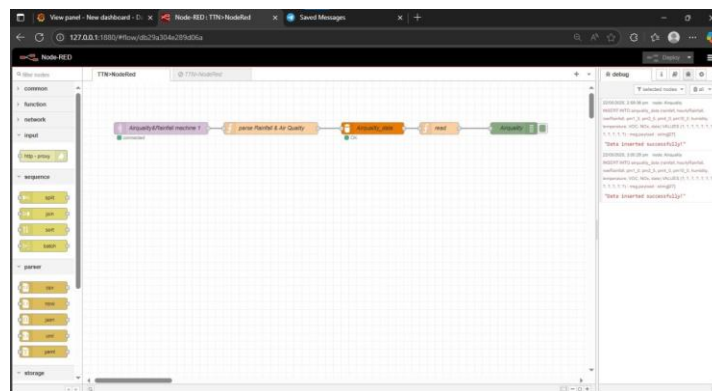


Fig. 4 Node-RED Dashboard Displaying Parsed Sensor Data

Once stored in the MySQL database, the data was visualized using Grafana dashboards, enabling real-time and historical monitoring. Figure 5 presents an example of the dashboard layout with gauges and tabular views for different pollutants. The system also includes real-time plotting of air quality parameters, as shown in Figure 6, where fluctuations in PM levels and gas concentrations are clearly displayed over time intervals.



Fig. 5 Grafana Dashboard Showing PM, VOC, Temperature, and Humidity Readings



Fig. 6 Time-Series Graphs of Air Quality Parameters in Grafana

The graphical outputs validated that the system was capable of continuously collecting accurate environmental data and presenting it in an accessible format. Furthermore, Figures 7 and 8 provide additional validation by showing detailed graphs for VOC and NOx levels, confirming the SEN55 sensor’s ability to detect subtle environmental changes. These results illustrate the feasibility of deploying such systems in urban areas to improve air quality monitoring and decision-making.

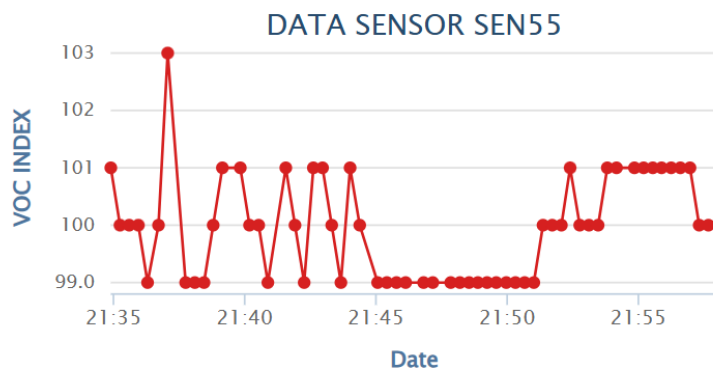


Fig. 7 VOC Concentration Trends Over Time

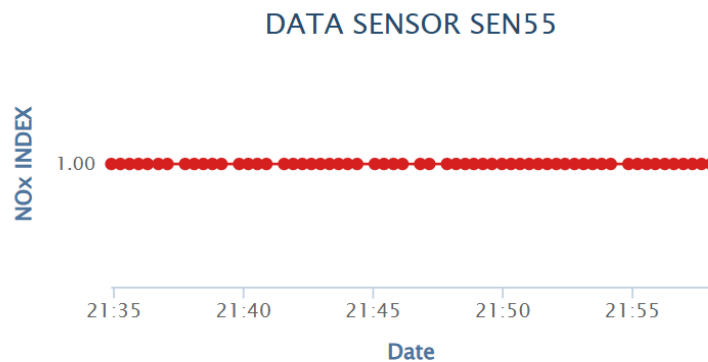


Fig. 6 *NOx Level Monitoring*

4. Conclusion

The LoRa-Enabled Air Quality Monitoring Network for Smart City represents a significant advancement in environmental monitoring, offering an innovative, cost-effective, and scalable solution for real-time air quality assessment in urban environments. This system effectively integrates advanced LoRa communication with sophisticated environmental sensors, overcoming the limitations of traditional monitoring systems by reducing costs, extending geographic reach, and improving energy efficiency through its low-power capabilities and the use of renewable energy. By providing actionable, real-time air quality data, the project enables proactive urban environmental management, empowering stakeholders to identify pollution hotspots and implement targeted mitigation strategies to enhance public health and urban sustainability. Future efforts will focus on expanding network coverage, incorporating machine learning for predictive modeling, enhancing user engagement through improved interfaces, and exploring interoperability with other smart city infrastructures to ensure its continued relevance in smart urban development.

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