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Developing a Scalable IoT-Based Platform for Enhancing Air Quality Monitoring in Public Transport Using Node-RED

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Abstract – *Air quality monitoring is a critical factor in ensuring human safety and well-being. However, existing monitoring systems are often limited to specific locations, resulting in a lack of comprehensive information regarding air quality conditions in various areas. This study proposes the development of an (Internet of Things) IoT-based air quality monitoring platform utilizing Node- RED, implemented in public transportation facilities in Yogyakarta. The system provides real-time data that enhances public awareness and understanding of air quality conditions, particularly in densely populated transportation hubs. The prototype utilizes MQ-7 and MQ-135 sensors to measure key air quality indicators, including carbon monoxide (CO) and carbon dioxide (CO2). Air quality data is collected every minute and can be viewed in real-time through the Node-RED platform, with the data stored in CSV format for further analysis. The system demonstrated consistent performance, with an average transmission time of* 2706 ms*, ensuring near real-time updates across all test locations. The highest average concentrations of CO and CO2 recorded were 28 ppm and 124 ppm, respectively. According to the World Health Organization (WHO) Air Quality Guidelines, carbon monoxide (CO) levels below 50 ppm and carbon dioxide (CO_2) levels below 300 ppm are considered safe. This indicates that the air quality in the monitored locations is generally acceptable.*

Keywords: *Air Quality Monitoring, IoT (Internet of Things), Node-RED, Real-Time, Public Transportation*

I. Introduction

Air quality has become a pressing global issue, especially in urban environments where industrial activities, vehicle emissions, and other anthropogenic factors contribute significantly to pollution. Traffic emissions are a major source of air pollution, and studies have shown that air pollution from traffic emissions doubled between 1999 and 2000 and was projected to increase tenfold by 2020 [1]. Exposure to poor air quality, particularly high concentrations of pollutants like CO and CO2, can have severe impacts on human health. Long-term exposure to air pollutants has the potential to cause serious harm, particularly to the respiratory and cardiovascular systems [2]. Furthermore, rising atmospheric CO2 levels contribute not only to poor air quality but also to significant climate change [3].

Monitoring air quality in real-time is thus critical for public health, enabling timely interventions and raising awareness about environmental conditions. Public transportation facilities, such as bus terminals and stops, are particularly prone to poor air quality due to the high concentration of vehicles and passengers in confined spaces. While much attention has been given to monitoring air quality at a city-wide level, less emphasis has been placed on specific public transit hubs where pollution can accumulate. Real-time monitoring in these areas is crucial for mitigating risks to passengers and staff who are consistently exposed to these environments.

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Traditional air quality monitoring systems are often expensive, geographically limited, and unable to provide real-time data at multiple micro-locations. The advent of the Internet of Things (IoT) has created new opportunities for affordable, scalable, and real-time environmental monitoring solutions [4]. IoT-based systems allow for the integration of low-cost sensors, data transmission, and cloud-based analytics to provide continuous monitoring across diverse environments.

In this study, we present the development and implementation of a scalable IoT-based air quality monitoring platform using the Node-RED framework. Node-RED, a flow-based development tool for visual programming, enables rapid deployment of IoT solutions through seamless integration of sensors, cloud services, and data analytics. The system is applied to public transportation facilities in Yogyakarta, Indonesia, with a focus on key transit hubs, including the Gamping, Malioboro 2, Concat, and Giwangan bus stops. By utilizing MQ-7 and MQ-135 gas sensors, the system measures concentrations of CO and CO2, providing real-time data that can be visualized on dashboards and stored for long-term analysis.

The workflow of the proposed air quality monitoring system is outlined as follows. The literature review is presented in Section II, providing an overview of related work and the current state of air quality monitoring and IoT. The methodology, including system design, hardware components, and implementation details, is described in Section III. Section IV presents the results and discussion, where the system's performance and data collected from the bus stops. Finally, the conclusions drawn from this research are summarized in Section V.

II. Literature Review

Growing concerns over air quality have driven numerous studies focused on monitoring systems, particularly in urban areas with high traffic density and industrial activities. Air pollution, especially from traffic emissions, has significantly increased over the past few decades. In response to the need for more effective air quality monitoring, IoT-based systems utilizing gas sensors have emerged as practical solutions. This study employs the MQ-7 and MQ-135 sensors to monitor CO and CO2 levels, respectively. The MQ-7 sensor is specifically designed for detecting CO [5], while the MQ-135 sensor can detect a range of gases, including CO2, NH3, and others. Both sensors work by measuring changes in their resistance when exposed to different gases, with this resistance then used to calculate gas concentrations in parts per million (PPM). The following equations are applied to determine the gas concentration in PPM:

$$\mathrm{VRL} = sensorvalue * \frac{v_{in}}{1024} \tag{1}$$

$$r_s = \left(5 * \frac{RL}{VRL}\right) - \mathrm{RL} \tag{2}$$

$$ppm = 10^{\left(-\frac{\log\left(\frac{r_s}{r_o}\right)-a}{b}\right)} \tag{3}$$

TABLE I. DESCRIPTION EQUATIONS (1) (2) AND (3)

Variable	Description
$sensorvalue$	ADC value obtained from the microcontroller (0-1023)
v_{in}	Reference voltage (in Volts) The value on the system is 5 Volts
VRL	Voltage read at the sensor (Volts)
RL	Load resistance set in the circuit (Ohms) The value on the system is 10kΩ
r_s	Sensor resistance in the presence of gas (Ohms)
r_o	Sensor resistance in clean air (Ohms)
a, b	Calibration constants based on the sensor's characteristic curve, either provided by the manufacturer or derived through empirical calibration
ppm	Gas concentration in parts per million (ppm)

II.1. *sensor MQ-7*

The MQ-7 sensor is widely used for detecting CO, a dangerous gas that can accumulate in enclosed spaces such as public transportation facilities or vehicles. The MQ-7 sensor operates by measuring changes in its tin dioxide (SnO2) sensing layer's resistance, which varies depending on the concentration of CO in the air. The sensor outputs an analog signal that is converted into voltage VRL and then into resistance r_s using Equation (2). From there, the concentration of CO is calculated in PPM using the logarithmic relationship described in Equation (3), where the calibration constants a and b are specific to the MQ-7 sensor [6]. The MQ-7's high sensitivity and ability to measure CO levels in the range of 10 ppm to 10,000 ppm make it well-suited for IoT-based air quality monitoring systems [7].

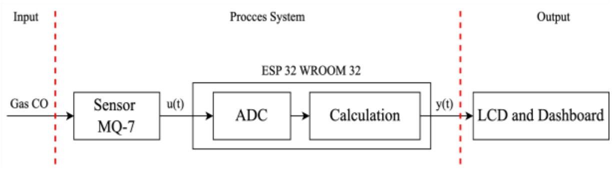

Fig. 1. Measure the PPM CO using the MQ-7 sensor

II.2. *sensor MQ-135*

The MQ-135 sensor is designed to detect a variety of gases, including CO2, ammonia (NH3), nitrogen oxides (NOx), and other harmful pollutants. It operates on the principle of resistance change in the presence of target gases. This sensor is particularly useful for monitoring air quality in public transportation hubs where multiple pollutants may be present due to high passenger density and vehicle emissions [8]. Like the MQ-7, the MQ-135 sensor outputs an analog signal that is converted into voltage, and its resistance is calculated using the same process. The gas concentration in PPM is then derived using Equation (3), but the calibration constants a and b vary depending on the specific gas being measured. In this study, the MQ-135 sensor is primarily used to monitor CO2 levels in transportation facilities, where elevated CO2 levels can indicate poor air quality and inadequate ventilation. The sensor's broad detection range, from low to high gas concentrations, makes it an ideal choice for continuous environmental monitoring in real-time applications [9][10].

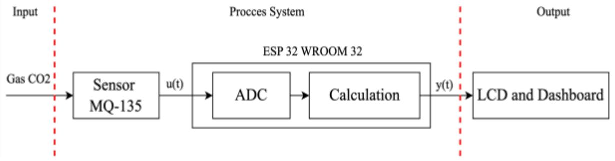

Fig. 2. Measure the PPM CO2 using the MQ-135 sensor

II.3. *Node-RED*

Node-RED is an open-source, flow-based development tool that simplifies the integration and visualization of IoT data. This platform has become popular for IoT-based environmental monitoring applications due to its ability to process and display real-time sensor data with minimal coding and maintenance [11][4]. Node-RED can support multiple communication protocols, such as MQTT and HTTP, to connect sensor devices to cloud storage and analysis platforms [12]. In the context of air quality monitoring, Node-RED has been used to create dashboards that visualize pollutant concentrations in real-time, enabling users to monitor air quality trends and receive notifications when pollutant levels exceed safe thresholds [13]. In this study, Node-RED is utilized to collect and display real-time data from the MQ-7 and MQ-135 sensors, providing a user-friendly interface for visualizing CO and CO2 concentrations at public transportation hubs. The system also logs sensor data for long-term analysis, ensuring that historical trends can be studied to improve public health and safety measures.

III. Methodology and Implementation

This section outlines the approach used in designing, implementing, and testing a real-time air quality monitoring system. The system detects CO and CO2 levels using MQ-7 and MQ-135 sensors. The sensor data is processed by an ESP32 WROOM 32 microcontroller, which transmits the information to a cloud platform for visualization and storage via the MQTT protocol. The system was tested at various bus stops in the Trans Jogja network to evaluate its performance in urban environments.

III.1. *system design*

The air quality monitoring system is designed around two key components: the sensor module and the IoT-based data visualization platform. The system utilizes MQ-7 and MQ-135 sensors to measure CO and CO2 concentrations, respectively. The ESP32 WROOM 32 microcontroller reads the sensor values and processes the analog signals using its built-in ADC (Analog-to-Digital Converter). The processed data is then transmitted to a cloud platform via MQTT for real-time monitoring. The data is displayed locally on an LCD 20x4, and remotely on a Node-RED dashboard for continuous monitoring and analysis.

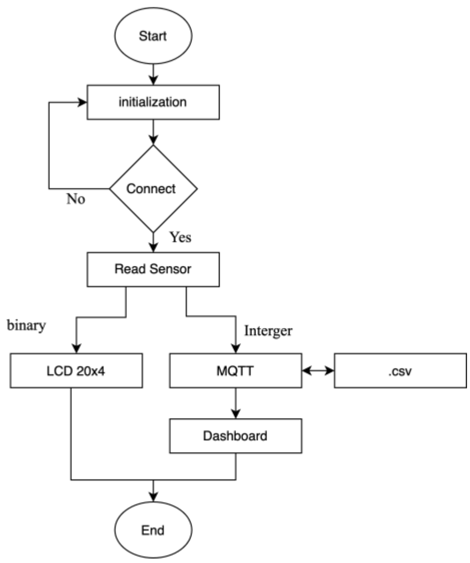

Fig. 3. System Flowchart

III.2. *hardware design*

The hardware of the air quality monitoring system consists of the MQ-7 and MQ-135 sensors connected to the ESP32 WROOM 32 microcontroller, which serves as the central processing unit. The sensors output analog signals based on the concentration of CO and CO2 in the environment, and these signals are converted to digital data using the ESP32's ADC. The converted data is then processed and displayed on an LCD screen for on-site visualization, while simultaneously being transmitted to the cloud via Wi-Fi for remote monitoring. The system's power requirements are met by the microcontroller’s 5V regulated output, ensuring stable operation across various environments. The system's design allows for flexibility, scalability, and easy integration with additional sensors, making it suitable for larger IoT deployments.

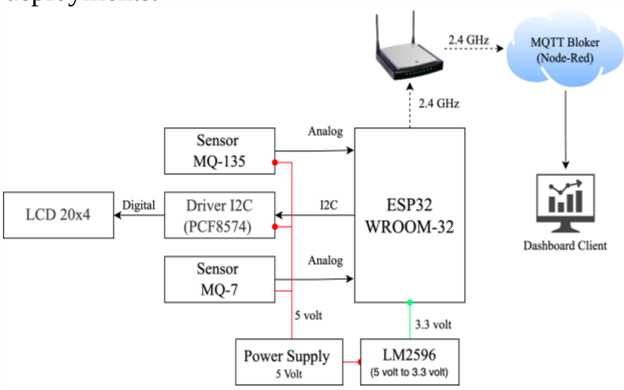

Fig. 4. Hardware Design Diagram

III.3. *Prototype Testing Locations*

To evaluate the system's performance in real-world conditions, the prototype was deployed at four different Trans Jogja bus stops, each representing various urban traffic environments.

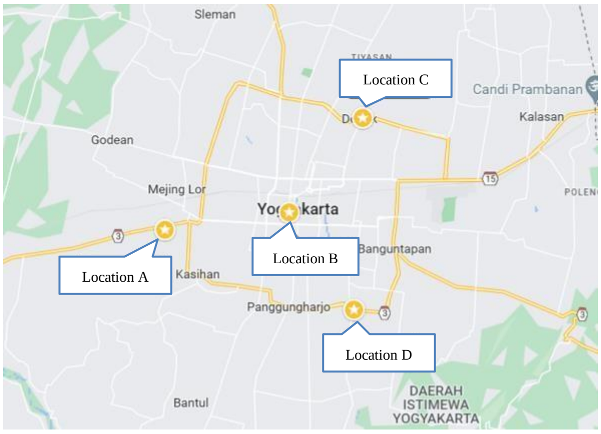

Fig. 5. Location Map of Testing Sites

These locations were: Halte Bus Trans Jogja Gamping (Location A), Halte Bus Trans Jogja Malioboro 2 (Location B), Halte Bus Trans Jogja Concat (Location C), and Halte Bus Trans Jogja Terminal Giwangan (Location D). The testing at each site was conducted for 1 hour, during which the system continuously monitored CO and CO2 levels. This multi-location testing allowed for a comprehensive assessment of the system’s effectiveness across different environmental conditions and pollution levels, ensuring its robustness and adaptability (Figure 3).

III.4. *Data Processing and Visualization*

The sensor data, after being processed by the ESP32 microcontroller, was converted into PPM (parts per million) values for CO and CO2 using the calibration equations discussed earlier. The processed data was then transmitted via MQTT to the Node-RED platform, which provided real-time visualization and monitoring capabilities. The Node-RED dashboard allowed users to view current CO and CO2 levels graphically, as well as set threshold alerts to notify operators if pollution levels exceeded safe limits. Additionally, the system stored data in CSV format for future analysis, enabling users to study historical air quality trends and assess long-term environmental conditions (Figure 4).

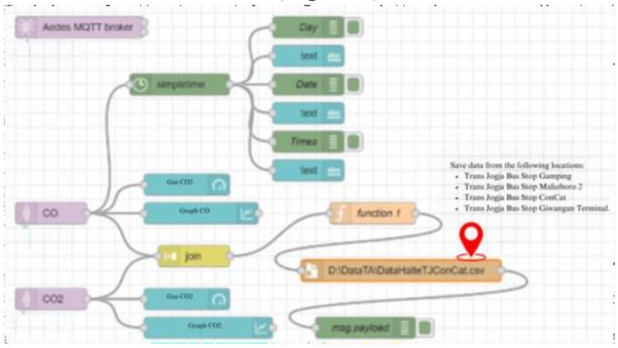

Fig. 6. Design Node-RED for Dashboard User Interface

Fig. 7. Node-RED Dashboard User Interface

IV. Results and Discussion

This section presents the results from the air quality monitoring system, which was deployed at four different Trans Jogja bus stops. It includes a discussion of the system’s performance in measuring and transmitting CO and CO2 levels in real-time, along with an analysis of the data collected during the 1-hour testing period.

IV.1. *Sensor Readings and Accuracy CO*

Figure 8 shows the CO concentration measured over a 52-minute period at the four test locations. The data reveals that CO levels remained relatively stable at most bus stops, with slight fluctuations observed at specific locations. The CO levels at Halte Gamping consistently hovered around 16 ppm, indicating a lower concentration of CO, which is likely due to lower traffic density. Halte Malioboro 2 exhibited minor fluctuations, with levels ranging between 21-24 ppm, reflecting the higher traffic levels and denser population. At Halte Concat, the levels varied from 18 to 26 ppm, while Halte Terminal Giwangan, which started with a steady CO concentration of 22 ppm, experienced a significant increase toward the end of the observation period, peaking at 30 ppm. This suggests that Terminal Giwangan may experience more CO accumulation due to factors such as increased vehicle traffic and confined space.

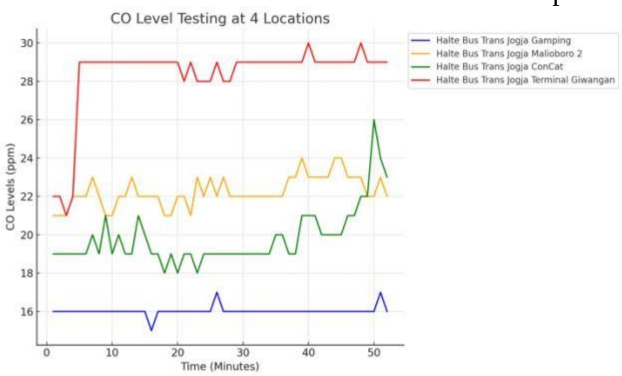

Fig. 8. CO Level Testing at 4 Locations

IV.2. *Sensor Readings and Accuracy CO2*

The CO2 concentration data, shown in Figure 9, presents the levels measured at the four bus stops over the 60-minute observation period. The CO2 levels at Halte Gamping remained relatively steady, fluctuating between 90 and 115 ppm, suggesting stable air quality in this suburban location. Similarly, Halte Malioboro 2 displayed minor variations between 100 and 134 ppm, consistent with the moderately higher population and vehicle density. However, at Halte Concat, the CO2 levels exhibited greater volatility, with fluctuations ranging from 100 to 185 ppm, particularly during the middle and later stages of the test. The highest CO2 levels were observed at Halte Terminal Giwangan, with concentrations consistently rising throughout the testing period and peaking at 170 ppm. This trend indicates that Terminal Giwangan may suffer from poor ventilation or excessive vehicle emissions, leading to higher CO2 accumulation.

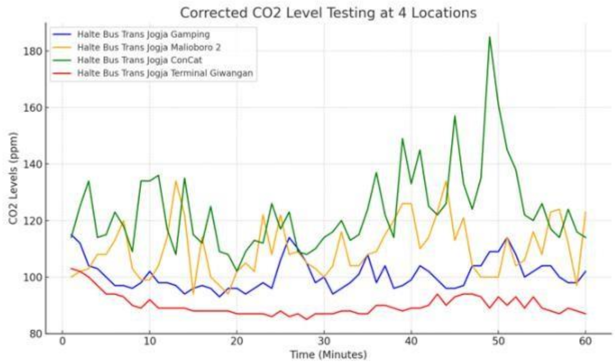

Fig. 9. CO2 Level Testing at 4 Locations

IV.3. *Sensor Readings and Accuracy CO2*

The Table 2 presents the transmission times recorded at each location during the 1-hour testing period. The table shows the average time (in milliseconds) taken for the sensor data to be sent from the ESP32 microcontroller to the Node-RED dashboard via the MQTT protocol.

TABLE II. COMPARATIVE ANALYSIS OF MINIMUM AND MAXIMUM TRANSMISSION ACROSS LOCATIONS

Location	**Minimum Transmission Time (ms)**	**Maximum Transmission Time (ms)**
Gamping	2540	2800
Malioboro 2	2600	2900
Concat	2560	2820
Giwangan	2580	2850

As shown in Table 2, the transmission time across all locations ranged from 2540 ms to 2900 ms, with the average transmission time being approximately 2706 ms . The system demonstrated consistent performance across all locations, with slight variations likely due to differences in network latency or environmental conditions. In addition to real-time monitoring, the system stored historical data, which can be analyzed to detect long-term trends in air quality. The ability to set threshold alerts for CO and CO2 levels on the Node-RED dashboard allowed for immediate notification if pollutant concentrations approached unsafe levels.

V. Conclusion

In this study, a real-time air quality monitoring system was developed and successfully tested at four

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Trans Jogja bus stops using MQ-7 and MQ-135 sensors integrated with an ESP32 WROOM 32 microcontroller. The system monitored carbon CO and CO2 levels and transmitted the data via MQTT to a Node-RED dashboard for real-time visualization and historical the data stored in CSV format for further analysis. The results showed the system's high accuracy and effectiveness in tracking air quality, with Halte Malioboro 2 and Halte Giwangan recording higher CO and with Halte Malioboro 2 and Halte Concat recording higher CO2 levels, likely due to increased vehicle traffic and limited ventilation. The system demonstrated consistent performance, with an average transmission time of 2706 ms, ensuring near real-time updates across all test locations. This monitoring system offers valuable functionality by providing real-time data and threshold alerts, making it an effective tool for managing air quality in public transportation hubs. However, there is room for improvement, particularly in refining the MQ-135 sensor calibration to enhance CO2 detection accuracy and expanding the system to monitor additional pollutants such as NOx and PM10. Overall, the system presents a scalable, reliable solution that can significantly contribute to urban air quality management, public health safety, and future smart city infrastructure initiatives.

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