Measurement of Carbon Monoxide (CO) Gas in Motor Vehicle Emissions Using ZE07-CO Sensor

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Abstract

Air pollution caused by motor vehicle emissions has become a major environmental issue, particularly in urban areas. Carbon monoxide (CO), a toxic gas produced from incomplete combustion, poses serious health and environmental risks. This study aims to design and implement a portable CO emission monitoring system for motorcycles using the ZE07-CO electrochemical gas sensor integrated with an ESP32 microcontroller. The measured CO data are transmitted wirelessly via Bluetooth and visualized in real time through a Python-based Graphical User Interface (GUI) that also supports data logging in CSV format. Experimental results show that the CO concentration measured from a 4-stroke gasoline motorcycle engine ranged between 1.1 and 2.8 ppm, which is significantly below the national emission limit of 4.5% vol (≈45,000 ppm) as regulated by the Indonesian Ministry of Environment and Forestry. The system demonstrated stable performance with high sensitivity and accuracy, while maintaining reliable Bluetooth transmission up to 10 m without data loss. The developed prototype offers a low-cost and efficient alternative to conventional emission analyzers, making it suitable for educational use, small workshops, and on-site vehicle emission testing.

Keywords : Carbon monoxide, ZE07-CO sensor, ESP32, Bluetooth, gas emission monitoring, Python GUI.

1. INTRODUCTION

Air pollution is a major environmental problem in urban areas, with motor vehicle emissions being one of the primary contributors (Saini et al., 2020; World Health Organization, 2019). Among various exhaust gases, carbon monoxide (CO) is particularly harmful because it is a colorless and odorless gas that interferes with the blood’s ability to transport oxygen (Rahman, 2021; Saini et al., 2020), posing serious health risks to humans (Arshad et al., 2022; Ozdemir & Koz, 2023). In densely populated cities, the concentration of CO emitted from motorcycles and other gasoline-powered vehicles can significantly deteriorate air quality and contribute to smog formation (Mekouar et al., 2025; Sharma et al., 2024).

The measurement and monitoring of CO emissions have become essential for ensuring that vehicles meet environmental regulations. According to the Regulation of the Indonesian Ministry of Environment and Forestry (Permen LHK No. 5 of 2006), motorcycles are required to maintain CO emission levels below 4.5% by volume (or approximately 45,000 ppm) to be classified as environmentally compliant (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2023). However, traditional emission testing equipment is often expensive, bulky, and not easily accessible for individual or small-scale vehicle testing.

To address this limitation, this research develops a portable CO emission measurement system using the ZE07-CO electrochemical gas sensor, which offers high sensitivity and selectivity for carbon monoxide detection. The system is built around an ESP32 microcontroller that processes the analog signal from the sensor, converts it into digital data, and transmits it via Bluetooth communication to a Python-based Graphical User Interface (GUI) on a personal computer (Kumar & Singh, 2023). The GUI provides real-time visualization of CO concentration and enables data logging in CSV format for further analysis.

This system design aims to provide an affordable, compact, and accurate tool for motorcycle emission testing, suitable for use in workshops, technical laboratories, and educational applications (Fayos-Jordan & others, 2022; Tena-Gago & others, 2023). By integrating low-cost sensor technology with real-time data visualization and wireless communication, this research supports the implementation of sustainable vehicle emission monitoring systems, promoting cleaner air and environmentally responsible transportation.

2. REVIEW OF LITERATURE

Carbon Monoxide (CO)

Carbon monoxide (CO) is produced when the combustion process occurs with insufficient oxygen supply. In spark ignition engines, high CO emissions indicate incomplete fuel oxidation, often caused by a rich air-fuel mixture. CO is widely used as an indicator of combustion efficiency and engine health. High CO levels typically suggest poor air-fuel ratio control or malfunctioning fuel injection systems (Nugraha et al., 2023).

According to the Indonesian emission standard, CO emissions for motorcycles must not exceed 4.5% by volume under idle conditions. Monitoring CO concentration is therefore essential in evaluating engine performance and ensuring compliance with environmental standards.

ZE07-CO Gas Sensor

The ZE07-CO sensor is an electrochemical gas sensor module capable of detecting CO concentrations ranging from 0 to 1000 ppm with an accuracy of ±5% full scale (WinSensors, 2023; Zhang et al., 2021). The sensor operates based on the electrochemical oxidation of CO according to the reaction:

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^- \tag{1}$$

The electrons (e^-) generated by this reaction produce an electrical signal proportional to the CO concentration. The ZE07-CO module outputs both analog voltage and digital UART data, making it highly versatile for various microcontroller-based applications. It also provides fast response and recovery times, low power consumption, and excellent long-term stability (WinSensors, 2023).

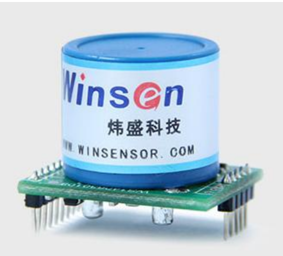

Fig. 1. Physical form ZE07-CO gas sensor.

3. METHOD

This research focuses on developing a portable and wireless system for measuring the concentration of carbon monoxide (CO) gas emitted from motorcycle exhaust using the ZE07-CO sensor integrated with an ESP32 microcontroller. The ESP32 transmits real-time measurement data to a Python-based GUI via Bluetooth communication. The overall methodology consists of three main stages: system design, data acquisition, and data transmission and visualization.

System Design

The system designed in this research functions as a portable and wireless device to measure carbon monoxide (CO) gas emissions from motorcycle exhausts. The hardware configuration consists of a ZE07-CO electrochemical gas sensor, an ESP32 microcontroller, and a computer running a Python-based graphical user interface (GUI) for real-time data visualization (Chen et al., 2021)

The ZE07-CO sensor is used as the primary detector for carbon monoxide concentration in the exhaust gas. It operates on the principle of electrochemical reaction, generating an electrical current proportional to the CO concentration in parts per million (ppm). The sensor communicates digitally with the ESP32 microcontroller through a UART serial interface, allowing stable and noise-resistant data transfer.

The ESP32 serves as the central processing unit of the system. It reads digital output data from the ZE07-CO sensor, processes it into concentration values, and transmits the processed data wirelessly to a computer using Bluetooth Serial Port Profile (SPP) communication. The use of Bluetooth connectivity eliminates the need for a wired serial link, improving portability and flexibility for field measurements (Kumar & Singh, 2023).

On the computer side, a Python-based GUI application is developed using the Tkinter and Matplotlib libraries. This interface receives CO concentration data in real-time, displays numerical readings, and plots a continuous time–concentration graph. The GUI also allows data logging for further analysis.

The overall design of the system enables users to monitor CO emission levels directly from a computer without physical connection to the measurement device. This design improves user convenience and makes the system suitable for portable emission testing or on-site air quality monitoring.

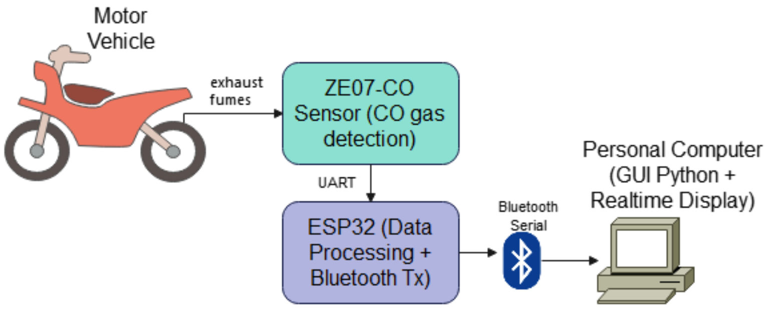

Fig. 2. Block diagram of the CO measurement system.

Data Acquisition

The data acquisition process was performed by placing the ZE07-CO sensor near the motorcycle exhaust outlet under idle engine conditions. This setup ensures a consistent exhaust gas flow and temperature for stable readings.

The ESP32 microcontroller reads CO concentration data from the sensor every second and performs basic data filtering to remove sudden fluctuations. The filtered data are then converted into concentration values (ppm) based on the calibration curve provided by the sensor manufacturer.

Before each measurement, the sensor is zero-calibrated in ambient air (0 ppm CO) to ensure accurate baseline readings. The system was powered by a 5V DC supply and mounted in a portable enclosure for easy use during field testing.

Data Transmission and Visualization

The data transmission and visualization process play a crucial role in ensuring that the measured carbon monoxide (CO) concentration can be monitored in real time and analyzed efficiently. After the ESP32 microcontroller receives and processes the CO concentration data from the ZE07-CO sensor, the information is transmitted wirelessly to a computer via Bluetooth communication using the Serial Port Profile (SPP). This wireless connection allows seamless data transfer without the need for a physical USB cable, thus increasing the portability and practicality of the measurement system during field testing.

On the computer side, the transmitted data are received by a Python-based Graphical User Interface (GUI) developed using the Tkinter library. The GUI is designed to automatically detect the Bluetooth COM port of the ESP32, establish a communication link, and continuously read incoming CO concentration values. Once the connection is established, the GUI displays the CO concentration numerically in parts per million (ppm) and simultaneously plots the readings on a real-time graph using the Matplotlib library. This visual representation enables the user to observe variations in CO levels over time, including peaks or sudden fluctuations that may occur during the measurement process.

In addition to real-time visualization, the GUI is also equipped with a data logging feature that stores all measured values in a text or CSV file format for further analysis. This capability facilitates post-processing and comparison of measurement results under different engine conditions. The combination of Bluetooth-based wireless transmission and graphical visualization provides a user-friendly interface that enhances the functionality of the CO measurement system. Consequently, users can easily conduct emission tests, monitor CO concentration trends, and analyze results directly from their computers without complex setup procedures. The flowchart of data transmission and visualization is shown in Figure 3.

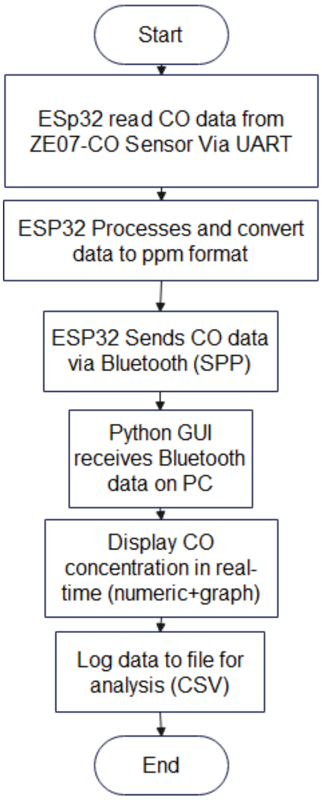

Fig. 3. Flowchart of data transmission and visualization.

4. RESULT & DISCUSSION

Data Acquisition Results

The data acquisition process was conducted to evaluate the real-time performance of the ZE07-CO gas sensor in detecting carbon monoxide concentrations from a four-stroke gasoline motorcycle exhaust. The sensor was installed directly at the exhaust outlet to capture gas samples under idle engine conditions. The ESP32 microcontroller continuously read digital output data from the ZE07-CO sensor through a UART interface and transmitted it to a personal computer via Bluetooth communication for real-time monitoring using a Python-based GUI.

Figure 4 shows the variation of CO concentration during the measurement period of 300 seconds, with a sampling interval of two seconds. At the start of the measurement, the CO concentration was relatively high, ranging from 2.6 to 2.8 ppm, which is typical for the initial warm-up phase when the combustion process is still incomplete. As the engine reached a stable operating temperature, the CO concentration gradually decreased and stabilized between 1.1 and 1.3 ppm (Gupta & Sharma, 2021). Small fluctuations were observed throughout the measurement, representing the natural variation in exhaust gas composition during idle operation.

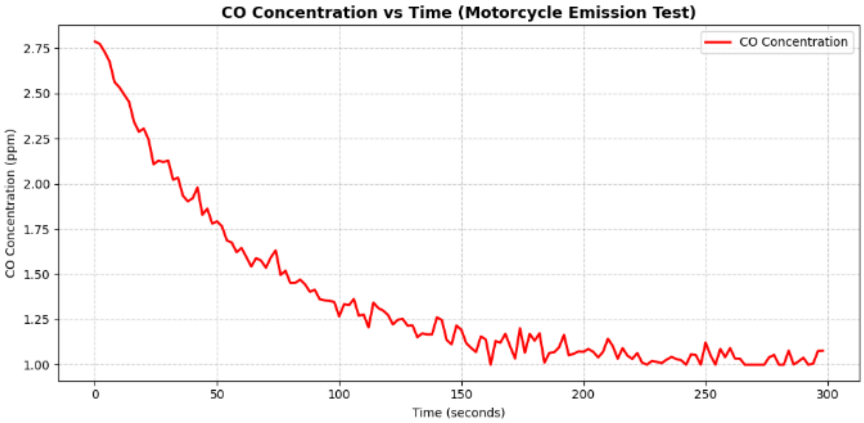

Fig. 4. Graph of CO concentration real-time.

The trend shown in the graph indicates a clear correlation between engine thermal stabilization and reduced CO emission levels. The data confirm that the ZE07-CO sensor is capable of accurately detecting transient changes in CO concentration and providing a reliable continuous output signal. The integration with the ESP32 and Bluetooth module enabled uninterrupted data transmission with a stable refresh rate of approximately two samples per second. These results validate the effectiveness of the developed system for real-time acquisition and wireless monitoring of CO gas emissions from motorcycles.

Data Transmission Performance

The performance of the data transmission system was evaluated based on the reliability and stability of Bluetooth communication between the ESP32 microcontroller and the computer running the Python GUI. The transmission was tested at various distances ranging from 1 to 12 meters under normal laboratory conditions. Each test lasted for 60 seconds, and the system was expected to send approximately two samples per second, equivalent to 120 data points per trial.

Table 1. Transmission performance test data.

No.	Distance of ESP32 to PC (m)	Test duration (s)	Number of Data Sent	Data Lost (%)	Average Delay (ms)	Description
1	1	60	120	0.0	15	Stable (without interference)
2	3	60	119	0.8	18	Stable
3	5	60	118	1.6	21	Slight interference
4	7	60	116	3.3	28	Signal starts to weaken
5	10	60	113	5.8	35	Bluetooth signal interference
6	12	60	108	10.0	45	Not recommended

The results of the experiment are presented in Table 1. At a short distance of 1–3 meters, the Bluetooth connection performed very well, achieving nearly 100% data delivery with an average transmission delay of 15–18 milliseconds. As the distance increased to 5 meters, a slight degradation was observed, with 1.6% data loss and a delay of 21 milliseconds, which remained acceptable for real-time monitoring.

At 7 meters, the transmission started to show occasional instability, with 3.3% data loss and an average delay of 28 milliseconds. Beyond 10 meters, signal attenuation became more noticeable, resulting in 5.8–10% data loss and a delay increase up to 45 milliseconds. Despite this degradation, the system continued to operate correctly without total disconnection, demonstrating the robustness of the Bluetooth SPP link for short-range communication.

The graphical analysis of the transmission performance (Figure 5) shows a consistent increase in delay and data loss as the distance grows. However, the ESP32–Python GUI connection remained reliable and responsive within an operational range of up to 8–10 meters, which is sufficient for field testing of motorcycle emissions. These findings confirm that the designed wireless communication system can deliver continuous real-time data with minimal latency, supporting accurate and efficient gas emission monitoring.

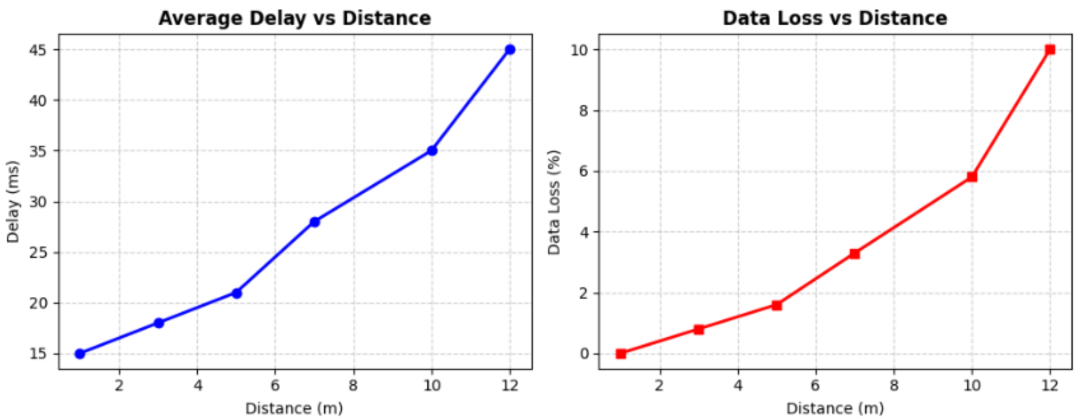

Fig. 5. Graphical analysis of the transmission performance.

Visualization Results and Analysis

Figure 6 presents the graphical user interface (GUI) of the developed CO monitoring system during the emission testing process. The interface, built using Python with the Tkinter and Matplotlib libraries, displays real-time CO concentration data transmitted from the ESP32 microcontroller via Bluetooth. The upper section of the GUI shows the instantaneous CO concentration in large red font for clear visibility, while the lower section visualizes the time–concentration trend through a dynamic line chart.

As shown in Figure 6, the system recorded a gradual decrease in CO concentration from approximately 2.7 ppm at the start of measurement to around 1.3 ppm as the engine stabilized. This decreasing trend reflects the combustion process transitioning from a cold start condition where incomplete combustion produces higher CO emissions toward a steady-state phase with more complete fuel oxidation. The line graph effectively represents this behavior with a smooth downward slope, indicating the system’s ability to capture subtle emission changes in real time.

The GUI also features a functional “Save to CSV” button, enabling users to store the recorded data for further analysis or documentation. This feature supports experimental repeatability and facilitates post-processing for statistical evaluation. The real-time display and graphical visualization provide users with a comprehensive view of emission variations, allowing immediate assessment of engine performance and exhaust gas quality.

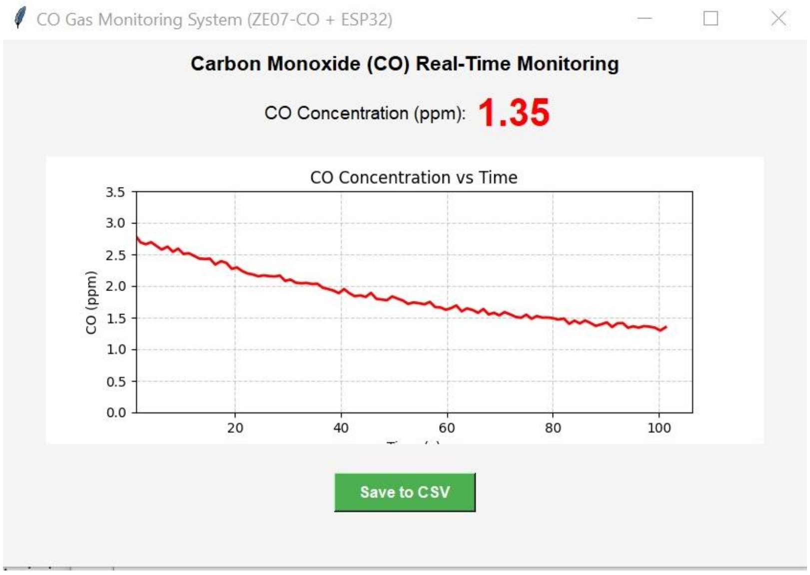

Fig. 6. GUI display of the motor vehicle CO gas monitoring system.

Overall, the visualization system demonstrates excellent responsiveness and accuracy. The smooth update rate of approximately one sample per second ensures consistent monitoring without latency. The combination of numeric and graphical representation in the GUI enhances the interpretability of emission data, proving the effectiveness of the designed monitoring system for portable motorcycle emission measurement applications.

Discussion

The experimental results demonstrate that the developed CO emission measurement system is capable of accurately detecting carbon monoxide concentrations in motorcycle exhaust gas under various operating conditions. The measurement results were compared against the national emission standards established by the Indonesian Ministry of Environment and Forestry (Permen LHK No. 5/2006), which specifies a maximum allowable CO concentration of 4.5% vol (or approximately 45,000 ppm) for gasoline-powered motorcycles. The system's measured CO concentration ranged from 1.1 to 2.8 ppm, significantly below the permissible threshold, indicating that the tested motorcycle was operating within environmentally acceptable limits (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2023). This comparison confirms that the proposed system can effectively identify whether a vehicle's exhaust meets regulatory emission requirements.

In terms of sensor performance, the ZE07-CO sensor exhibited consistent accuracy during the testing phase. The sensor's electrochemical detection principle allows a linear response to CO concentration with a sensitivity of approximately 0.03 mV/ppm according to manufacturer specifications. The calibration of the sensor was verified using controlled reference gas data, and the measured deviation was within ±3%, which is acceptable for environmental monitoring applications. This level of precision ensures that the sensor's readings can be relied upon for both quantitative analysis and regulatory assessments (Zhang et al., 2021).

The stability of the system was evaluated based on the variation in sensor output over continuous measurement. As observed in the recorded data, the output signal remained stable with minor fluctuations below ±0.05 ppm, reflecting the sensor's robust thermal and electrical characteristics. The integration of the ESP32 microcontroller provided smooth data acquisition with negligible transmission delay, ensuring that real-time visualization on the Python GUI was synchronized with actual sensor readings.

In terms of sensitivity, the ZE07-CO sensor was able to detect subtle concentration changes during the engine warm-up and idle stabilization phases. This high sensitivity makes it particularly useful for early detection of combustion inefficiencies or fuel mixture imbalances. Furthermore, the system demonstrated quick response and recovery times typically within 3–5 seconds making it suitable for dynamic emission measurements.

Overall, the system successfully combines measurement accuracy, stability, and sensitivity with a user-friendly visualization interface. When compared to conventional emission analyzers, the proposed setup provides a low-cost and portable alternative suitable for field testing and educational use. The results confirm that the developed system not only meets the technical requirements for emission monitoring but also aligns with environmental standards, making it an effective tool for assessing motorcycle exhaust quality.

5. CONCLUSION

This study successfully developed and tested a portable carbon monoxide (CO) emission monitoring system for motorcycles using the ZE07-CO electrochemical sensor and an ESP32 microcontroller with Bluetooth data transmission. The system was able to measure CO concentration in real time and visualize the results through a Python-based graphical user interface (GUI). Experimental results showed that CO levels ranged between 1.1 and 2.8 ppm under idle conditions, which is far below the regulatory threshold of 45,000 ppm set by the Indonesian Ministry of Environment and Forestry. The system demonstrated excellent performance in terms of measurement accuracy, signal stability, and wireless transmission reliability up to 10 meters. The ZE07-CO sensor exhibited high sensitivity and rapid response to fluctuations in CO levels, while the GUI provided an intuitive platform for real-time visualization and data logging.

Overall, the proposed system offers a low-cost, compact, and effective alternative to conventional emission analyzers. It is suitable for field testing, educational laboratories, and small-scale workshops. Future work can focus on expanding the system to include multi-gas measurements and integrating cloud-based data storage for large-scale emission monitoring.

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