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Design and Development of an Air Quality Monitoring System with PM10, PM2.5, CO, Temperature, and Humidity Detection Based on Long Range (LoRa)

Baso Maruddani, Aodah Diamah, Grace Susan Marien
Electrical Electronics Engineering Program, Faculty of Engineering
Universitas Negeri Jakarta, Indonesia
basomaruddani@unj.ac.id, adiamah@unj.ac.id, gracesusanmarien103@gmail.com

Abstract—Air pollution can adversely affect human health, creating a need for a monitoring system that can provide information on ambient air quality in open environments. This study aimed to design, develop, and test a Long Range (LoRa)-based air quality monitoring system capable of measuring PM2.5, PM10, estimated carbon monoxide (CO), temperature, and humidity, while also presenting air-quality categories according to the Indonesian Air Pollution Standard Index (ISPU). The research employed a Research and Development (R&D) approach using the V-Model. An Arduino Uno R3 was used as the transmitter controller and an ESP32 as the receiver controller. The measurement subsystem consisted of a ZH03B particulate-matter sensor, an MQ135 gas sensor, and a DHT22 temperature and humidity sensor, while an E32-900T20D module provided wireless communication. After calibration, the average measurement errors were 5.01% for PM2.5, 4.35% for PM10, 19.4% for estimated CO, 0.42% for temperature, and 0.98% for humidity. LoRa communication successfully transmitted data up to 1.4 km in a rooftop-to-rooftop scenario under Non-Line of Sight (NLoS) conditions. The calculated ISPU values ranged from 56 to 68, placing all observations in the Moderate category. The system was able to display measurements on a 20×4 LCD and the Blynk application and to transmit data through LoRa in real time.

Index Terms—Air quality, Blynk, ISPU, LoRa, monitoring, PM2.5, PM10.

I. INTRODUCTION

Healthy living environments depend on acceptable air quality. Ambient air contains oxygen as well as other substances, including carbon monoxide (CO), biological contaminants, and particulate matter. When pollutants exceed normal concentrations, they may adversely affect human health. Previous work has reported the use of microcontroller- and mobile-application-based systems for air-quality monitoring, while wireless sensor networks have also been applied to air-quality classification [1], [2].

An air-quality monitoring system therefore needs to measure relevant particulate and gaseous pollutants together with environmental conditions and provide information that can be accessed efficiently. In Indonesia, the Indonesian Air Pollution Standard Index (ISPU) is used to represent ambient air quality officially [3]. The present study develops a monitoring system that combines particulate-matter measurement, estimated CO measurement, temperature and humidity measurement, long-range wireless transmission, local LCD display, and online visualization through Blynk.

The main objective was to design, build, and test an open-environment monitoring prototype using a ZH03B sensor for PM2.5 and PM10, an MQ135 sensor for estimated CO, a DHT22 sensor for temperature and humidity, Arduino Uno R3 and ESP32 controllers, and E32-900T20D LoRa communication. The system was developed using the V-Model so that verification and validation could be performed from individual modules to the integrated system.

II. SYSTEM DESIGN AND METHODOLOGY

A. Air Quality Parameters

Particulate matter (PM) is classified according to particle diameter. PM10 refers to particles smaller than 10 µm, while PM2.5 refers to fine particles smaller than 2.5 µm. Smaller particles can penetrate more deeply into the respiratory system [4], [5]. Carbon monoxide is a pollutant produced by incomplete combustion and is toxic even though it is colorless, odorless, and tasteless [6]. In this study, CO is treated as an estimated concentration because the MQ135 is sensitive to several gases and is not a CO-specific sensor.

The ISPU classification used in the source study ranges from Good (1–50), Moderate (51–100), Unhealthy (101–200), Very Unhealthy (201–300), to Hazardous (301 and above). For CO, the source study used the following concentration breakpoints: Good, 0–4.4 ppm; Moderate, 4.5–9.4 ppm; Unhealthy, 9.5–15.4 ppm; Very Unhealthy, 15.5–30.4 ppm; and Hazardous, 30.5–50.4 ppm [7].

B. Hardware and Monitoring Architecture

The developed system is divided into transmitter and receiver units. The transmitter uses an Arduino Uno R3 to read the ZH03B, MQ135, and DHT22 sensors and to send the processed measurements through the LoRa module. The receiver uses an ESP32 to receive the LoRa data, display the values on a 20×4 LCD, and forward the data to the Blynk platform through an Internet connection. This architecture allows the measurement point to communicate over a long distance without requiring Internet access at the transmitter location.

The ZH03B detects particulate matter using laser-scattering principles and provides PM2.5 and PM10 measurements [8], [9]. The MQ135 changes its sensing-element resistance when exposed to pollutant gases and provides an analog signal; after calibration, the signal is used to estimate CO [10]. The DHT22 provides digital temperature and humidity measurements [11], [12]. The E32-900T20D is used for long-range wireless communication; the source study reports an operating frequency range of 862–931 MHz for the selected module [13], [14]. Blynk is used as the online user interface for real-time monitoring [15], [16].

TABLE I. MAIN SYSTEM COMPONENTS AND FUNCTIONS

TABLE I. MAIN SYSTEM COMPONENTS	FUNCTION
Arduino Uno R3	Transmitter controller and sensor data processing
ZH03B	PM2.5 and PM10 measurement
MQ135	Estimated CO measurement
DHT22	Temperature and humidity measurement
E32-900T20D LoRa	Wireless long-range data transmission
ESP32 DevKitC V1	Receiver controller and online interface gateway
20×4 LCD	Local measurement display
Blynk	Online real-time monitoring interface

C. Development Method

The research used a Research and Development (R&D) method with the V-Model as the system-development framework. The V-Model was selected because the development process requires verification and validation of sensor, communication, display, and integrated-system functions. The implemented stages were: (1) requirement analysis, (2) specification, (3) architectural design, (4) detail design, (5) coding, (6) unit testing, (7) integration testing, (8) system testing, and (9) acceptance testing.

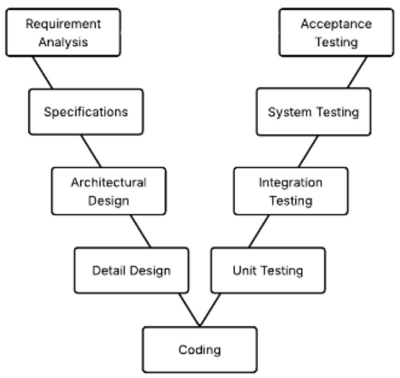

Fig. 1. V-Model development framework used in the study.

D. Calibration and Testing

Before system testing, the sensors were calibrated using an Air Quality Detector as the reference instrument to reduce measurement deviation. Linear regression was used for PM2.5, PM10, estimated CO, and temperature, while an offset correction was applied to humidity. The corrected values were then used for subsequent performance analysis.

TABLE II. CALIBRATION METHODS FOR SENSOR PARAMETERS

TABLE II. CALIBRATION METHODS	CALIBRATION METHOD
PM2.5	Linear regression
PM10	Linear regression
Estimated CO	Linear regression
Temperature	Linear regression
Humidity	Offset correction

Unit testing was performed on the sensor, LoRa, and LCD modules separately. Integration testing evaluated the connection among the modules and the consistency of data transfer. System testing evaluated sensor acquisition, LoRa transmission, LCD presentation, and Blynk visualization as a complete system. Acceptance testing evaluated whether the developed prototype met the research objectives.

III. RESULTS AND DISCUSSION

A. ZH03B Performance

The ZH03B measurements showed fluctuations in PM2.5 and PM10 during the observation period. PM10 was generally higher than PM2.5. The highest values reported in the source study were 36 µg/m³ for PM10 and 30 µg/m³ for PM2.5 at 12:40 WIB. The calibrated average errors were 5.01% for PM2.5 and 4.35% for PM10. These results indicate that the ZH03B was able to follow changes in particulate concentration and provided sufficiently consistent readings for the developed monitoring prototype.

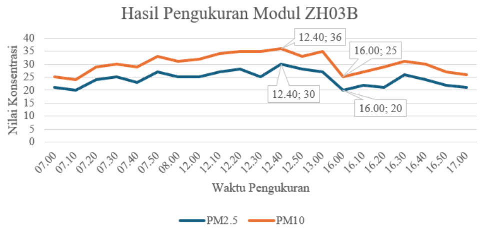

Fig. 2. ZH03B measurement results.

B. MQ135 Performance

The MQ135 produced estimated CO concentrations ranging from 1.01 to 1.09 ppm during the test. After calibration, the average error relative to the reference instrument was 19.4%. The larger error is consistent with the characteristics of the MQ135, which responds to multiple gases rather than CO alone. Differences in measurement resolution between the prototype and the reference instrument also contributed to the observed deviation. Therefore, the result should be interpreted as estimated CO rather than a specific CO measurement.

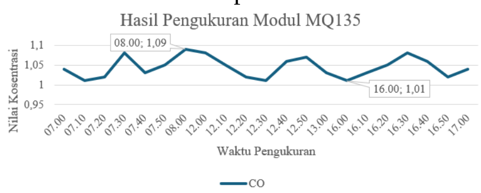

Fig. 3. MQ135 estimated CO measurement results.

C. DHT22 Performance

The DHT22 recorded temperature values between 28.3 °C and 31.1 °C, while humidity ranged from 75.5% to 86.4%. After calibration, the average errors were 0.42% for temperature and 0.98% for humidity. The relatively small errors indicate that the DHT22 provided stable environmental measurements for the monitoring system.

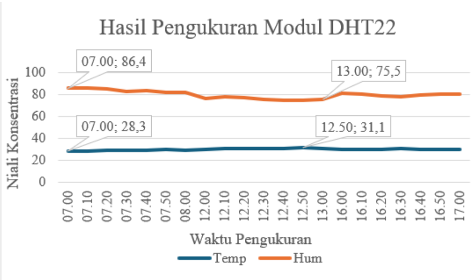

Fig. 4. DHT22 temperature and humidity measurement results.

D. LoRa Communication Performance

LoRa communication was tested under two deployment scenarios. In the rooftop-to-ground-level scenario, data could be transmitted beyond 263.59 m but the connection was lost at 628.24 m because of physical obstructions from buildings. In the rooftop-to-rooftop scenario, where the communication path had fewer obstacles, the system successfully transmitted data up to 1.4 km under NLoS conditions. This result demonstrates the advantage of LoRa for extending the communication range of the monitoring system beyond the immediate measurement area.

E. Overall Measurement Performance

TABLE III. SUMMARY OF SYSTEM TEST RESULTS

TABLE III. SUMMARY OF MEASUREMENT RESULTS	RESULT
PM2.5 average error	5.01%
PM10 average error	4.35%
Estimated CO average error	19.4%
Temperature average error	0.42%
Humidity average error	0.98%
Maximum LoRa range	1.4 km (rooftop-to-rooftop, NLoS)
ISPU range	56–68 (Moderate)

The ISPU calculations produced values between 56 and 68, placing all observations in the Moderate category. The combined results show that the prototype can collect multiple environmental parameters, transmit the data over a long-range wireless link, and present the information locally and online. The strongest measurement performance was obtained from temperature and humidity, followed by PM10 and PM2.5. Estimated CO had the largest error because of the non-specific gas sensitivity of the MQ135. Thus, the prototype is suitable as a monitoring platform, while CO measurement should not be interpreted as equivalent to measurement with a dedicated CO sensor.

IV. CONCLUSION

An open-environment air quality monitoring prototype based on Long Range (LoRa) was successfully designed and developed using the V-Model. The system integrates a ZH03B sensor for PM2.5 and PM10, an MQ135 sensor for estimated CO, a DHT22 sensor for temperature and humidity, Arduino Uno R3 and ESP32 controllers, an E32-900T20D LoRa link, a 20×4 LCD, and Blynk. The calibrated average errors were 5.01% for PM2.5, 4.35% for PM10, 19.4% for estimated CO, 0.42% for temperature, and 0.98% for humidity. The LoRa link reached 1.4 km in the rooftop-to-rooftop NLoS scenario, while the ISPU results were within the Moderate category at values of 56–68. The main limitation is the MQ135-based CO estimation, which has a higher error because the sensor is sensitive to multiple gases. Future development should add other pollutant parameters such as CO2, NO2, SO2, and O3, provide a local display on the transmitter, and consider solar-panel-based power to support deployment in locations with limited access to conventional electrical power.

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