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IMPLEMENTATION OF A REAL-TIME INTERNET OF THINGS-BASED AIR QUALITY MONITORING DEVICE FOR INDUSTRIAL AREAS USING THE BLYNK PLATFORM

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Abstract

Air quality in industrial environments is influenced by machine emissions, vehicle traffic, and dust particles, and therefore requires continuous monitoring. This study aims to design, implement, and test an Internet of Things-based air quality monitoring device that displays data in *real time*. The device was built using an Arduino Mega 2560 microcontroller and an ESP-01 module as the Wi-Fi network connector, with an MQ-7 sensor for carbon monoxide (CO), an MQ-135 sensor for mixed pollutant gases read as carbon dioxide (CO_2), a DHT11 sensor for temperature and humidity, and a DSM501A sensor for dust particles. The measurement results are displayed on a 20×4 LCD and in the Blynk application, while a buzzer and LEDs provide warnings when values exceed the programmed thresholds. Testing was carried out on July 27, 2025, from 12:00 to 15:00 at 30-minute intervals. All readings fell into the good air classification based on the device thresholds, with CO_2 levels of 0.03–0.43 ppm, CO levels of 3.77–4.95 ppm, and dust sensor output of 674–1175. Data were sent to Blynk in real time and are available as historical graphs. For regional context, the Windy map for the same date showed a highest CO of 2470 ppb (2.47 ppm), PM10 of 717 μg/m^3, and AQI of 290. The device works well as an initial monitor, but calibration against a reference measuring instrument is still required before its values are compared with quality standards.

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INTRODUCTION

Clean air is a basic necessity for the health of humans and other living beings. With the rapid development of industry and the growing number of vehicles, air quality tends to decline due to increasing emissions of gases and dust particles. The most dominant human factors in air pollution are transportation and industrial activities. Decree of the State Minister of Environment Number 45 of 1997 states that air pollution can harm human health, aesthetic values, and other living beings (Menteri Negara Lingkungan Hidup, 1997).

In factory environments, the operation of machinery and heavy vehicle traffic are sources of pollutants such as carbon monoxide (CO) and dust particles to which workers may be directly exposed. In addition to pollutants, the temperature and humidity of the workspace also need to be monitored; the generally required temperature is 18–30 °C and humidity is 40–60%. Air quality is expressed through the Air Pollution Standard Index (Indeks Standar Pencemar Udara, ISPU) with

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five categories, namely good (1–50), moderate (51–100), unhealthy (101–200), very unhealthy (201–300), and hazardous (above 300) (Menteri Negara Lingkungan Hidup, 1997; Kurniawan, 2018). The ISPU has been used to analyze air quality and pollutant distribution in urban areas (Imas Agista et al., n.d.). Advances in sensor technology and the Internet of Things (IoT) make it possible to monitor air quality in real time and remotely. Hakim and Susanto (2020) built an IoT-based air quality monitoring prototype using the ThingSpeak platform to monitor motor vehicle exhaust pollution in the city of Bandung. Hanum and Elfizon (2023) designed an ESP32-based indoor CO and CO_2 monitor with notifications through a Telegram bot. Iskandar et al. (2024) developed an IoT-based indoor air quality monitoring system, while Anwar et al. (n.d.) built a device for measuring PM2.5, NO_2, and CO based on the Arduino Mega 2560 for the city of Tasikmalaya. Satryawan and Susanti (2023) designed an ESP32-based air quality detector with an MQ-135 sensor for CO_2, an MQ-7 sensor for CO, and a DHT22 sensor for temperature and humidity, equipped with a buzzer, LEDs, and monitoring through the Blynk application. Wirawan et al. (2023) built a real-time air quality monitor based on the NodeMCU ESP8266 with MQ-135 and DHT11 sensors, whose data are displayed on an LCD and in Blynk.

These studies generally focus on a single type of pollutant or a single type of information output. This study integrates a CO gas sensor, a mixed-pollutant gas sensor, a temperature and humidity sensor, and a dust particle sensor in a single device based on the Arduino Mega 2560 and ESP-01, with three layers of output: a local display on an LCD, local warnings in the form of a buzzer and LEDs, and remote monitoring through the Blynk application. In addition, the local measurement results are positioned against the regional distribution on a Windy map to provide context on broader air conditions. The objectives of this study are to design and implement the monitoring device and to test its performance in measuring CO, CO_2, temperature, humidity, and dust particles.

METHODS

Time and Place of the Research

The research lasted three months: one month for data collection and two months for data processing and device fabrication. The research was conducted in Tangerang City, Banten. The test data were collected on July 27, 2025.

Tools and Materials

The main components of the device and their functions are presented in Table 1. The supporting equipment used included a laptop, a smartphone, an electric soldering iron, a multimeter, screwdrivers, and wire cutters. The supporting circuit materials included 5 mm LEDs, capacitors, resistors, transistors, PCB boards, solder, connectors, and sockets.

System Design

The overall system design is shown in the block diagram in Figure 1. The Arduino Mega 2560 acts as the main processor that reads the outputs of the four sensors. The ESP-01 module receives data from the Arduino Mega 2560 and forwards it to Blynk over a Wi-Fi network, so that the data can be monitored on a smartphone or computer in the form of numbers and graphs. The LCD displays the measurement results locally, while the buzzer and LEDs serve as the warning outputs.

Table 1. Main components and their functions

No	Component	Function
1	Arduino Mega 2560	Main microcontroller: reads the sensors, processes data, and controls the outputs
2	ESP-01 module	Wi-Fi connector for sending data to Blynk via serial communication
3	MQ-7 sensor	Detects carbon monoxide (CO) gas
4	MQ-135 sensor	Detects mixed pollutant gases, read as carbon dioxide (CO_2)
5	DHT11 sensor	Measures air temperature and humidity
6	DSM501A sensor	Detects dust particles
7	20×4 I2C LCD	Displays measurement results in real time
8	Buzzer and 5 mm LED	Warning output when values exceed the threshold
9	LM2596 and AMS1117 modules	Power supply voltage regulators
10	12 V DC fan	Air circulation (still operated manually)

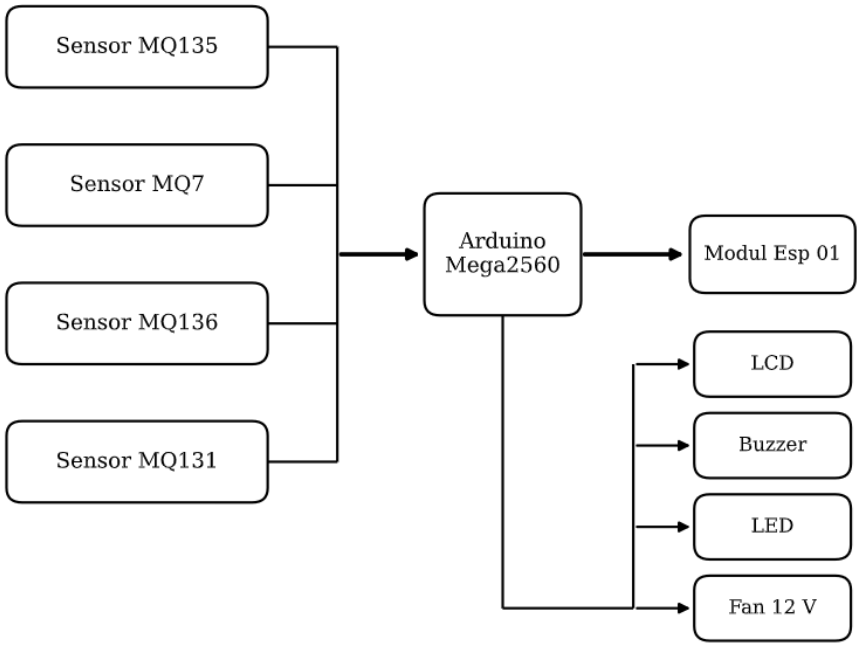


Figure 1. System block diagram

The program flow is shown in the flowchart in Figure 2. After initialization, the Arduino Mega 2560 connects the ESP-01 to Wi-Fi and to Blynk, then reads the temperature, humidity, CO_2, CO, and dust data. Thresholds are programmed for three sensors: the buzzer is activated when the MQ-135 value exceeds 70 or the MQ-7 value exceeds 10, while for the DSM501A dust sensor the buzzer and LEDs are activated when the value exceeds 10000.

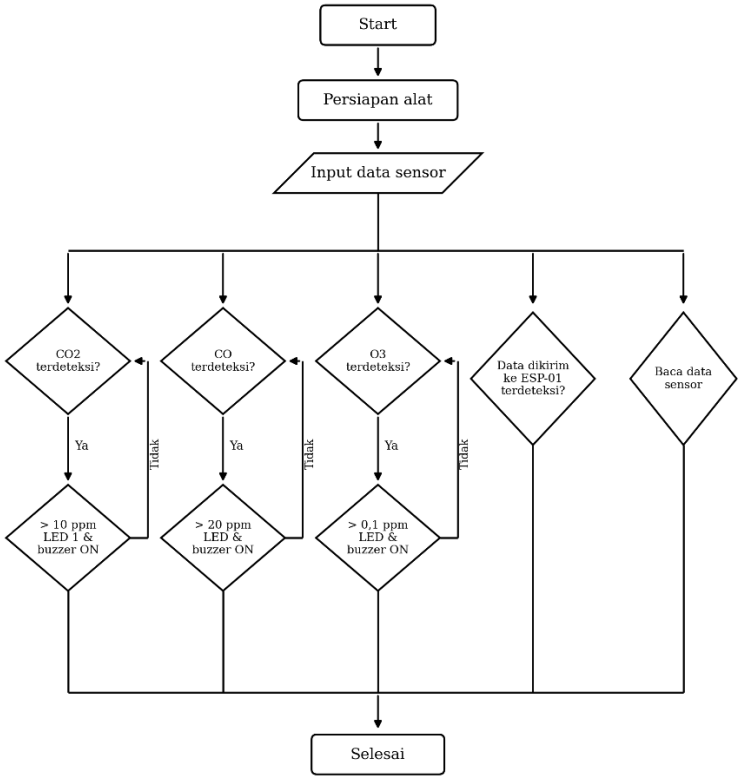


Figure 2. Flowchart of the data transmission system

Hardware Design

The hardware schematic is shown in Figure 3, and the pin mapping between the components and the Arduino Mega 2560 is summarized in Table 2. All sensors are powered at 5 V. The buzzers and LEDs are connected through transistors and resistors as current limiters. The circuit is placed in a protective enclosure measuring 21.5 × 14.5 × 8.5 cm with the mechanical design shown in Figure 4.

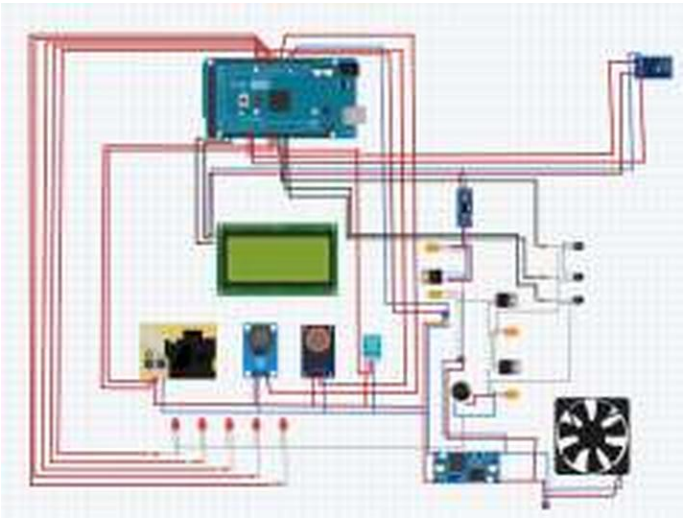


Figure 3. Hardware schematic

Table 2. Component pin mapping on the Arduino Mega 2560

No	Component	Pin on Arduino Mega 2560
1	ESP-01	RX3 to ESP-01 TXD; TX3 to ESP-01 RXD
2	DHT11 sensor	D4 (data)
3	MQ-135 sensor	A1 (analog output)
4	MQ-7 sensor	A0 (analog output)
5	DSM501A sensor	D2 (VOUT1) and D3 (VOUT2)
6	20×4 I2C LCD	SDA (D20) and SCL (D21)
7	Buzzer (DSM501A, MQ-7, MQ-135)	D5, D6, and D7 through transistors and resistors
8	5 mm LED	A2–A6 through 220 Ω resistors



Figure 4. Mechanical design of the device

Software Design

The program was written using the Arduino IDE with the ESP8266_Lib.h library for the Wi-Fi connection, MQ135.h and MQ7.h for the gas sensors, DHT.h for the temperature and humidity sensor, and LiquidCrystal_I2C.h for the LCD. The data to be sent to Blynk are mapped to virtual pins, each connected to a widget in the Blynk application for CO, MQ-135 gas, temperature, humidity, and dust particles. The program was then compiled and uploaded to the Arduino Mega 2560 after the board type and port were correctly selected.

Testing Procedure and Data Analysis

Each sensor was tested seven times on July 27, 2025, from 12:00 to 15:00 at 30-minute intervals. The measurement results were classified using the device thresholds, namely CO_2 levels below 70 ppm, CO levels below 25 ppm, and dust sensor output below 50000 pcs/0.01 cf, which were categorized as good air. The DSM501A dust sensor was also tested with cigarette smoke as a trigger when the value exceeded the threshold. The data were processed descriptively as minimum, maximum, and average values. As a regional comparison, the Windy map dated July 27, 2025 was used for CO (ppbv), PM10 (μg/m^3), and AQI. The conversion of CO units from ppbv to ppm used Equation (1).

$$ppm = ppbv / 1000 \quad (1)$$

RESULTS AND DISCUSSION

Device Realization and Data Display

The realized device displays the measurement results on the 20×4 LCD and in the Blynk application, as shown in Figure 5. The LCD displays the particle value (PM10), air status, CO_2, temperature, CO, and humidity, while the LED indicators light up to mark the condition. The Blynk application displays each parameter in a separate widget along with historical graphs that can be viewed per one hour, six hours, one day, one week, or up to one month. The example display in Figure 5(b) shows CO of 0.092 ppm, MQ-135 gas of 3.984 ppm, a temperature of 34.20 °C, and a humidity of 65.00%. The temperature and humidity in that display are above the generally required ranges (18–30 °C and 40–60%), which is consistent with tropical climate conditions and rooms with limited air circulation.



Figure 5. Device data display: (a) LCD on the device and (b) Blynk application interface

Sensor Test Results

The test results of the three sensors are shown in Table 3. The CO_2 level from the MQ-135 sensor ranged from 0.03 to 0.43 ppm with an average of 0.13 ppm, so all values were below the 70 ppm threshold. The CO level from the MQ-7 sensor ranged from 3.77 to 4.95 ppm with an average of 4.43 ppm, far below the 25 ppm threshold. The output of the DSM501A dust sensor ranged from 674 to 1175 with an average of 959.1, far below the 50000 pcs/0.01 cf threshold. Thus, all readings fell into the good air classification.

Table 3. Sensor measurement results on July 27, 2025

Time	CO_2 (ppm)	CO (ppm)	Dust (sensor output)	Classification
12:00	0.03	4.39	1175	Good air
12:30	0.43	4.69	1162	Good air
13:00	0.15	4.46	1015	Good air
13:30	0.03	3.77	674	Good air (CLEAN status)
14:00	0.15	4.95	1005	Good air
14:30	0.05	4.16	675	Good air (CLEAN status)
15:00	0.07	4.59	1008	Good air
Average	**0.13**	**4.43**	**959.1**	**–**

For the dust sensor, the readings at 13:30 and 14:30 dropped below 1000 and the LCD displayed the CLEAN status with only one LED lit. In the other readings, two LEDs lit to indicate good conditions, while all five LEDs lighting together with the buzzer indicate a danger warning. The fluctuation of dust values between readings was fairly wide (674–1175), and its cause cannot be determined from the data of this study because air circulation conditions during testing were not recorded.

Comparison with Regional Distribution

The Windy map dated July 27, 2025 in Figure 6 was used as a regional comparison. The highest CO concentration on the map reached 2470 ppbv, which, through Equation (1), is equivalent to 2.47 ppm, seen in the western corridor of Java Island to southern Sumatra. The highest PM10 concentration reached 717 μg/m^3 around Bandar Lampung and the western part of Java Island, labeled unhealthy on the map, and the highest AQI reached 290 in the very unhealthy category. The wind patterns on the map show that the pollutants were dispersed toward the east and southeast, affecting Semarang and Surabaya, so air pollution is not only local in nature.

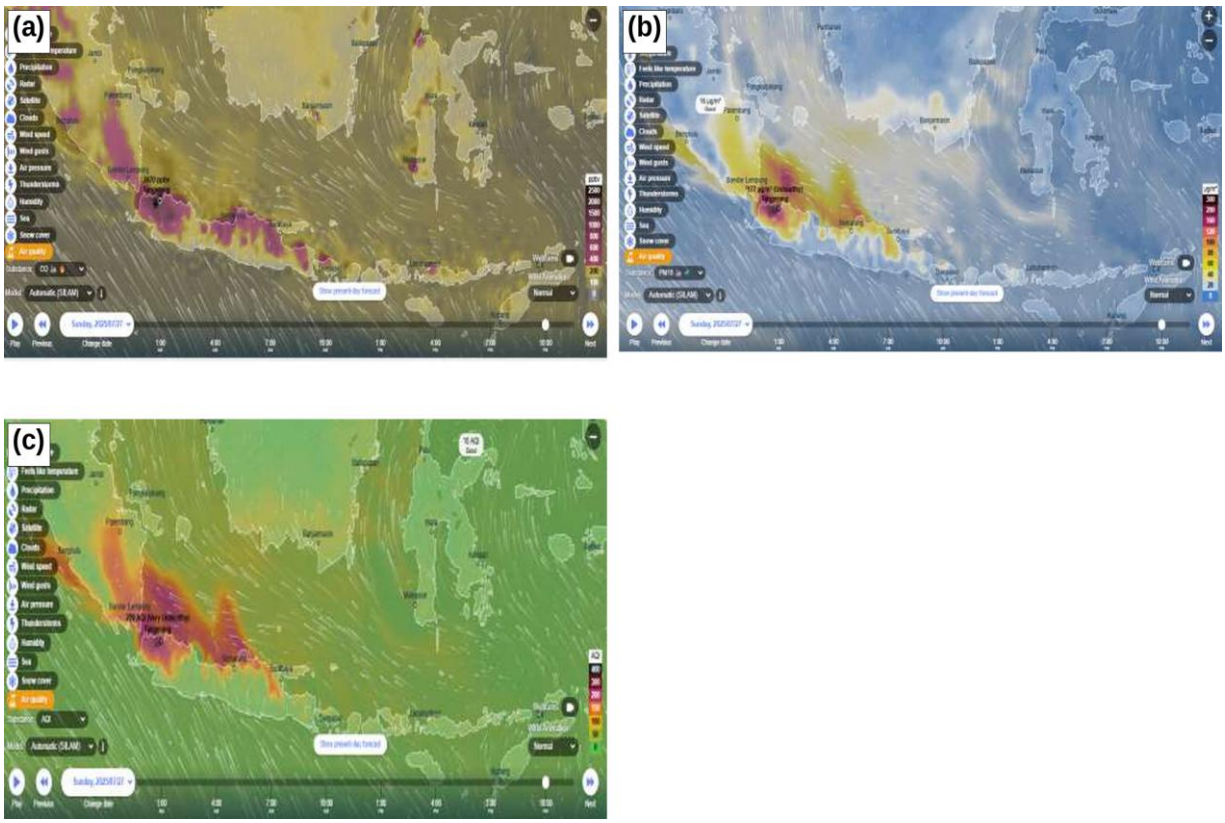


Figure 6. Distribution maps for July 27, 2025: (a) CO, (b) PM10, and (c) AQI (Source: Windy, 2025)

The comparison of the two data sources is summarized in Table 4. The average CO of the local sensor (4.43 ppm) was higher than the highest CO value on the map (2.47 ppm), and the good air status on the device differs from the AQI of 290 on the map. This difference cannot be regarded as a contradiction because the two sources differ in scale: the map represents atmospheric model values over broad grid cells, whereas the sensor measures a single point. In addition, the MQ-7 sensor has not been calibrated and is sensitive to other gases, while the dust sensor output has not been converted to μg/m^3. Therefore, the Windy map is used as context, not as a quantitative comparison.

Table 4. Comparison of local sensor data and the regional map

Parameter	Local sensor (average)	Windy map (highest)	Remarks
CO	4.43 ppm	2.47 ppm (2470 ppbv)	Different scales; sensor not calibrated
Particles	959.1 (sensor output)	717 μg/m^3 (PM10)	Different units; not comparable
AQI	Not calculated	290 (very unhealthy)	Regional context only

Limitations

The results of this study need to be interpreted with caution. First, testing lasted one day with a duration of three hours, yielding seven data points per sensor and no reference measuring instrument. Second, the DSM501A sensor has not been calibrated according to its datasheet. Third, the CO_2 level from the MQ-135 of 0.03–0.43 ppm is far lower than typical atmospheric CO_2 concentrations (about 400 ppm), so these values are only suitable as a relative indicator, not an absolute concentration. Fourth, the good air classification follows the thresholds programmed in the device and has not been aligned with the ISPU categories.

CONCLUSION

The IoT-based air quality monitoring device using the Arduino Mega 2560, ESP-01, and MQ-7, MQ-135, DHT11, and DSM501A sensors has been successfully realized and is able to display data in real time on the LCD and the Blynk application, with a buzzer and LEDs as local warnings. In the July 27, 2025 test, all readings fell into the good air classification based on the device thresholds: CO_2 0.03–0.43 ppm, CO 3.77–4.95 ppm, and dust sensor output 674–1175. The Windy map provides regional distribution context (CO 2.47 ppm, PM10 717 μg/m^3, AQI 290), showing that pollution can spread across regions following the wind direction. For further development, it is recommended to: (1) calibrate the sensors, especially the DSM501A, against a reference measuring instrument and align the classification with the ISPU; (2) connect the LEDs and the 12 V fan as automatic outputs for all sensors; (3) conduct longer testing in an actual factory area; (4) perform regular sensor maintenance; and (5) disseminate the use of the application and an understanding of the air quality index to users.

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