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Procedia Computer Science 245 (2024) 815–824

Procedia Computer Science

www.elsevier.com/locate/procedia

9th International Conference on Computer Science and Computational Intelligence 2024 (ICCSCI 2024)

Smart Air Monitoring with IoT-based MQ-2, MQ-7, MQ-8, and MQ-135 Sensors using NodeMCU ESP32

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Abstract

The increasing population and number of vehicles lead to a significant growth in air pollution. This occurrence causes a serious issue that may impair the environment and public health. To monitor the level of air pollution, it is necessary to develop a device capable of accurately assessing pollution levels. Therefore, this research aims to implement the Internet of Things (IoT) to develop an air monitoring system. This system collects sensor data and transmits data to a cloud-based platform for analysis and visualization. Integrating multiple sensors enhances the system's ability to detect various pollutants commonly found indoors and outdoors. In addition, the air monitoring device includes a sensor to detect fire-causing gas such as hydrogen gas, and a sensor to measure the temperature and humidity levels of the surrounding areas. The effectiveness of the system is demonstrated through experimental tests conducted under various environmental conditions. The test results showed CO2 levels below 5,000 ppm, CO gas levels below 25 ppm, and other gases within safe limits, indicating that air pollution in Semarang on April 14, 2024, was considered safe or normal. The temperature and humidity levels experienced a decrease of 0.008495% and 0.6787%, respectively. Meanwhile, CO2 and H2 decreased exponentially by 0.1697% and 0.0269%, respectively. The error analysis between the DHT11 sensor and BMKG data indicates that the temperature measurements have an error rate of 1.05%, while the humidity measurements have an error rate of 1.04%. The results show that the developed system offers an efficient and cost-effective solution for continuous air quality monitoring, with potential applications in smart cities, industrial environments, and indoor spaces to reduce health risks associated with air pollution.

Keywords: Air Quality; Air Pollution; Air Monitoring; Internet of Things.

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Peer-review under responsibility of the scientific committee of the 9th International Conference on Computer Science and Computational Intelligence 2024
10.1016/j.procs.2024.10.308

1. Introduction

Air constitutes a vital element for the sustainability of life forms on Earth[1]-[3]. Air quality greatly affects the environment and individual health [4][5]; hence, clean air is indispensable for daily existence. Air quality may be compromised by polluted gases such as carbon monoxide (CO) [6][7], carbon dioxide (CO2) [8][9], methane (CH4) [10][11], and other toxic gases. These emanations originate from transport, industry, waste burning, and other human activities [11]-[14]. Carbon monoxide (CO) is a colorless, tasteless, and odorless gas [15][16] produced by burning fossil fuels and exhaust emissions [17][18]. The carbon monoxide exposure limit allowed by OSHA (Occupational Safety and Health Administration) is 35 ppm for an 8-hour workday [19]. Carbon dioxide (CO2) is a significant contributor to the greenhouse effect [20][21]. Alongside CO and CO2, methane (CH4), a combustible component of natural gas [22], is used for energy generation and heating purposes [23]-[25], playing a pivotal role in driving climatic changes [26][27]. These harmful gases if exceeded the threshold, can disrupt the metabolism of the body's organs [28][29], cause respiratory diseases [30][31], affect digestion [32][33], lead to poisoning [34], and even long-term effects such as reproductive problems [26], cancer [11], and death [34][35].

Problems arising from air pollution can be addressed early by determining the air quality at a location using an air quality monitoring device. Current technological developments enable more accurate air quality monitoring by applying systems that monitor pollution levels. Air monitoring is essential to ensure that the environment remains clean, maintained, and most importantly, protected from diseases, thereby maintaining public health and environmental sustainability. Numerous researchers have developed air monitoring technologies to observe and evaluate air quality in real time. In developing various air monitoring devices, researchers employ a variety of methods, including research, system design, testing, and analysis. Various types of microcontrollers, sensors, and other software are also used in the system design. For instance, research [1] implemented Wemos D1 mini, MQ-135, and MQ-9 sensors for air monitoring on IoT-based Android smartphones. Another study [36] used NodeMcu ESP32 connected to MQ-7 and MQ-135 sensors integrated with Telegram, Additionally, research [37] monitored air quality using an Arduino Wemos, MQ-135 sensor, and ThingSpeak to display the resulting data.

Air monitoring utilizing the IoT (Internet of Things) has become an urgent necessity for maintaining air quality in our surroundings [38][39]. The Internet of Things generally refers to a system within our environment where various devices interact with each other through the Internet [37]. The Internet of Things (IoT) can monitor the world around us to activate, assist, or automate the response to a change in the system [40][41] through wired or wireless networks [42][43]. The existence of IoT in the context of air monitoring provides significant innovations in improving and maintaining clean air quality. One of the main benefits of adopting IoT in air monitoring is its ability to provide real-time data on air conditions. Through IoT, connected sensors can measure and monitor air pollutant levels accurately and continuously [44]. The advantages of IoT are efficiency and timeliness [45][46], data accuracy [47], wise decision-making [48][49], and integration of various systems [48][50]. This ensures that the information obtained is comprehensive and easily accessible to various parties such as the government, research institutions, and the general public [36]. The presence of IoT in air monitoring not only helps maintain healthy air quality but also strengthens mitigation efforts against the negative impacts caused by air pollution on the environment and human health.

Based on the explanation above, researchers utilized MQ-2, MQ-7, MQ-8, and MQ-135 gas sensors to measure air quality with the assistance of the IoT-based NodeMCU ESP32. The results are displayed on a 16x2 I2C LCD. The MQ-2 gas sensor measures methane (CH4), the MQ-7 gas sensor measures carbon monoxide (CO), the MQ-8 gas sensor measures hydrogen (H2), and the MQ-135 sensor measures carbon dioxide (CO2). MQ gas sensors are used due to several potential advantages. These sensors are noted for their low cost [51][52], compact size [52][53], lightweight design [54], and low power consumption [55][56]. They effectively detect atmospheric components, including air pollutants such as CO, NOx, O3, and SO2, and greenhouse gases such as CO2 and CH4 [57]-[59]. The microcontroller module used in this research is the NodeMCU ESP32, which can integrate various sensors into an IoT-based air monitoring system. ThingSpeak assists visualization. The NodeMCU ESP32 has advantages in connectivity and data processing capabilities [60]-[62]. The relationship between temperature and humidity can affect the gas sensor readings, which can be demonstrated by the following equation [63].

$$ppm\ CO_{2\ corrected} = ppm\ CO_{2\ measured} \times \left(\frac{T_{measured} \times P_{ref}}{P_{measured} \times T_{ref}}\right) \quad \ldots (1)$$

$T_{measured}$ = current absolute temperature (K)
$P_{measured}$ = current pressure in the same units as the reference pressure
T_{ref} = reference temperature (K)
P_{ref} = barometric pressure reference.

Implementing these four sensors provides comprehensive information about air quality in the surrounding environment, specifically CO2, CO, H2, and CH4 gases. These measurements are displayed on the 16x2 I2C LCD for local users and are accessible remotely via the ThingSpeak website. Based on the monitoring results obtained from the device, researchers can accurately identify the level of air pollution and take appropriate steps to maintain clean and safe air quality for living organisms.

2. Research Methodology

The air quality monitoring device prototype was designed using several components, including the MQ - 135 gas sensor to detect carbon dioxide (CO2) levels, the MQ - 8 gas sensor to detect hydrogen (H2) levels, the MQ - 7 gas sensor to detect carbon monoxide (CO) levels, and the MQ-2 gas sensor to detect methane gas (CH4). Additionally, a DHT11 sensor was utilized to detect temperature and humidity. The NodeMCU ESP32 served as the microcontroller and was programmed with the Arduino software. The measurement results are displayed on a 16x2 I2C LCD and collected in ThingSpeak website for visualization.

2.1. Research Process

The research process is illustrated in the research flow chart which can be seen in Figure 1 as follows.

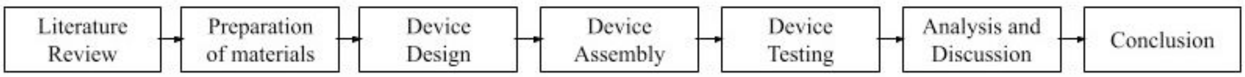

Fig. 1. Research Flowchart

Based on Figure 1, the first step of the research was conducting a literature review. In this stage, researchers find and study a variety of literature studies from numerous references, including journals, books, and websites. The literature review was conducted to determine parameters and develop a theoretical framework. Following the literature review, the researchers prepared the components used in this study. Subsequently, the researchers designed the device using a simple prototype model in the form of a schematic drawing, which was then realized through the physical construction of the device. The construction phase also included testing the MQ-135 gas sensor, MQ-8 gas sensor, MQ-7 gas sensor, MQ-2 gas sensor, and the DHT11 temperature sensor. The next step involved designing the hardware system using the ESP32 microcontroller. This was followed by creating a program in the Arduino IDE and field-testing the device to collect data. The collected data was then analyzed and discussed further, leading to the conclusions drawn from the research results.

2.2. Sensor Data Acquisition

The device consists of an MQ-135 gas sensor, MQ-7 gas sensor, MQ-8 gas sensor, MQ-2 gas sensor, I2C LCD, and ESP32, as shown in Figure 2. The ESP32, programmed with the Arduino IDE, serves as the microcontroller. The MQ-135 gas sensor measures carbon dioxide (CO2) levels and its A0 pin is connected to D4 on the ESP32. The MQ-7 gas sensor measures carbon monoxide (CO) levels and its A0 pin is connected to D18 on the ESP32. The MQ-8 gas sensor measures hydrogen (H2) levels and its A0 pin is connected to D5 on the ESP32. The MQ-2 gas sensor measures methane (CH4) levels and its A0 pin is connected to D2 on the ESP32. The DHT11 sensor measures temperature and humidity and its data pin are connected to the RX2 pin on the ESP32. The GND and VCC 5V pins of the sensors are connected to the respective GND and VCC 5V pins on the ESP32. The measurement results are displayed on the I2C LCD with the SCL and SDA pins connected to D22 and D21. The tool is assembled as shown in Figure 3.

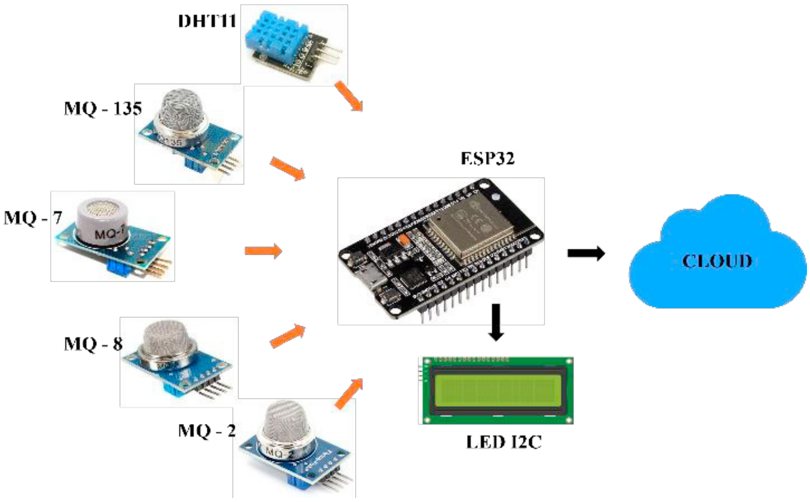

Fig. 2. Research Prototype

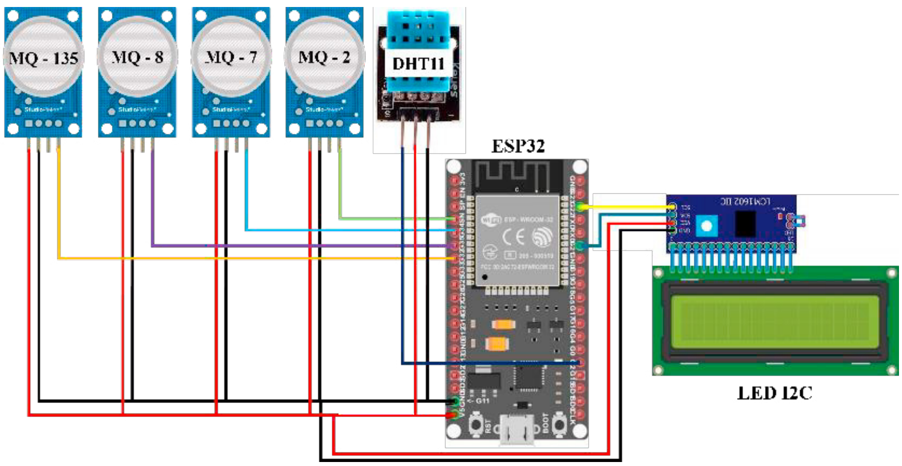

Fig. 3. Electronic Circuit

The ESP32 was selected due to its built-in Wi-Fi capability, which enables seamless data transmission from the sensors to the server. This server, utilized for data visualization, is a cloud-based platform hosted by thingspeak.com.

3. Result and Discussion

3.1. Device Actualization

The actualization of the device system can be seen in Figure 4 below.

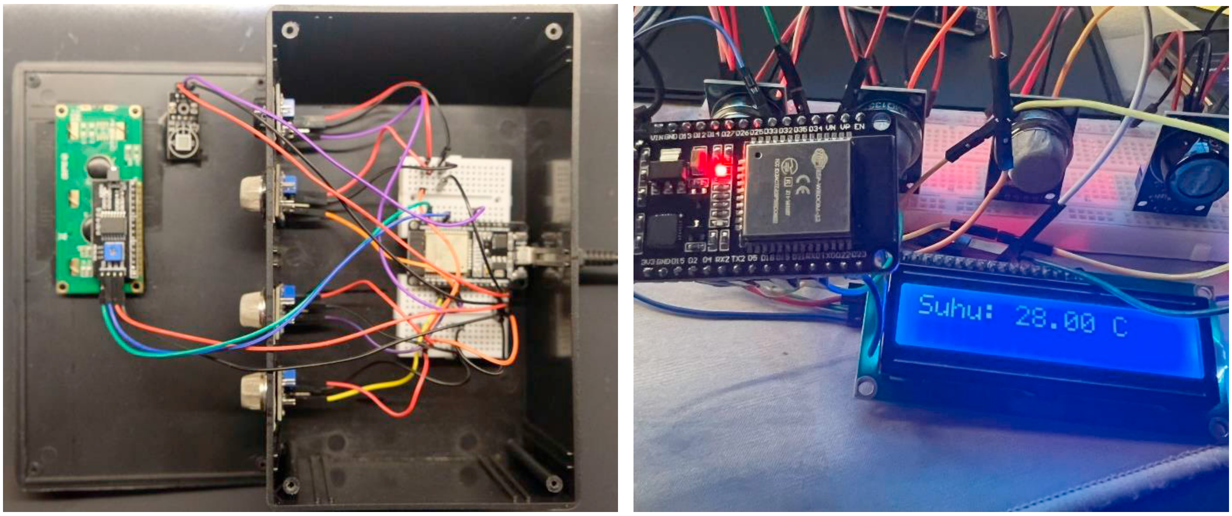

Fig. 4. Internal *Blackbox*

Inside the black box, the device's internals reveal a PCB with several cables connecting the five sensors: the MQ-135 gas sensor, MQ-8 gas sensor, MQ-7 gas sensor, MQ-2 gas sensor, and DHT11 temperature sensor. Additionally, an LCD 16x2 I2C and a USB cable are to link the device to the power supply. The design of the black box serves as a structured enclosure, ensuring the circuit is neatly organized. From a side perspective, the five sensors are positioned inside the black box, facing outward. In contrast, the device's top or front view showcases the centrally located LCD 16x2, where measurement results are prominently displayed, as depicted in Figure 5. The arrangement of the sensors protruding on the surface aims to facilitate easy monitoring access. The arrangement of the sensors protruding on the surface aims to facilitate easy monitoring access. After assembly, the device can be connected to a cloud server for data visualization.

Fig. 5. Front and side view.

3.2. Discussion

This research has produced a prototype for monitoring air quality, specifically gasses such as carbon dioxide (CO2) using the MQ-135 gas sensor, hydrogen (H2) using the MQ-8 gas sensor, carbon monoxide (CO) using the MQ-7 gas sensor, methane (CH4) using the MQ-2 gas sensor, as well as temperature and humidity using the DHT11 sensor. The prototype can monitor these gases in parts per million (ppm) and display the results on a 16x2 I2C LCD located at the top of the device's black box. The NodeMCU ESP32 allows integration of various sensors into an Internet of Things (IoT)-based air monitoring system, with visualization available on ThingSpeak. ThingSpeak is a web-based platform commonly used for storing, processing, and visualizing data online, making it easier for users to monitor air quality in real-time.

The NodeMCU ESP32 has advantages in connectivity and data processing, which are essential for monitoring air quality in real-time. Furthermore, the NodeMCU ESP32 comes with a built-in Wi-Fi module, eliminating the need for an additional Wi-Fi module, unlike Arduino boards. The ESP32 microcontroller acts as the main control center, connecting the sensors and the network. Data obtained from the sensors is processed by the ESP32 and transmitted to the ThingSpeak.com server.

The data collection and testing process was conducted in Semarang City on 14 April 2024, from 08.00 Western Indonesia Time to 22.00 Western Indonesia Time with a data acquisition interval of approximately 1000 ms. The obtained data is retrieved from ThingSpeak.com and presented in Figure 6, which includes values for temperature, humidity, CH4 gas, CO2 gas, H2 gas, and CO gas. The data is presented in a table and visualized in graphs as shown in Figure 7.

created_at	entry_id	temperature	humidity	CH4	CO2	H2	CO
2024-04-14T05:51:34+00:00	5979	38.5	60	7.9475	2.77191	53.78088	0.61552
2024-04-14T05:51:58+00:00	5980	38.5	59	8.08456	2.66927	51.65353	0.62941
2024-04-14T05:52:21+00:00	5981	38.5	58	8.04698	2.50447	50.5773	0.65753
2024-04-14T05:52:44+00:00	5982	38.5	59	8.08456	2.87745	54.13234	0.67176
2024-04-14T05:53:07+00:00	5983	38.5	59	7.81242	2.83312	52.18844	0.65281
2024-04-14T05:53:30+00:00	5984	38.5	59	7.70336	2.66084	50.75728	0.62477
2024-04-14T05:53:54+00:00	5985	38.5	59	7.39551	2.76325	49.49223	0.68611
2024-04-14T05:54:17+00:00	5986	38.6	58	7.57181	2.54494	51.65353	0.73968
2024-04-14T05:54:40+00:00	5987	38.5	59	7.75167	2.81553	52.01037	0.67176
2024-04-14T05:55:03+00:00	5988	38.5	60	7.32596	2.68618	51.65353	0.63406

Fig. 6. Results of measurement data using ThingSpeak

Fig. 7. Visualization of measurement data results using ThingSpeak

The graph in Figure 7 visualizes the measurement results from the MQ-135, MQ-8, MQ-7, MQ-2 gas sensors, and the DHT11 sensor. Based on the graph above, it can be observed that the ppm readings from the MQ sensors, and the DHT11 sensor, exhibit different sensitivity levels. The graph visualization was taken from 17:40 Western Indonesia Time to 18:10 Western Indonesia Time. Temperature and humidity measurements showed fluctuations between 18:00 Western Indonesia Time and 18:10 Western Indonesia Time, while the readings for CO2, H2, CO, and CH4 gases also showed fluctuations with a general downward trend around the same time. These fluctuations in the readings are due to the data collection being conducted outdoors. Several factors affect the measurements of CO2, H2, CO, and CH4 gases, such as wind speed, temperature changes, rainfall, and the humidity of the surrounding environment during monitoring.

Based on equation (1), an increase in temperature will affect the ppm levels of CO2. This is evidenced in Figure 7, where the temperature graph shows a decrease from 18.00 Western Indonesia Time to 18.10 Western Indonesia Time, and the CO2 graph also experiences fluctuations that tend to decrease during the same period. The CO2 levels decreased from 1.2 ppm to 0.5 ppm and exponentially decreased until around 0.3 ppm. From 18.00 Western Indonesia Time to 18.10 Western Indonesia Time, the temperature and humidity levels experienced a decrease of 0.008495% and 0.6787% respectively. Meanwhile, CO2 and H2 decreased exponentially by 0.1697% and 0.0269% respectively. Additionally, the DHT11 temperature and humidity sensor was tested using data collected from *Badan Meteorologi, Klimatologi, dan Geofisika* (BMKG). Ten data points were used during testing, and their comparison can be seen in Figure 8 below.

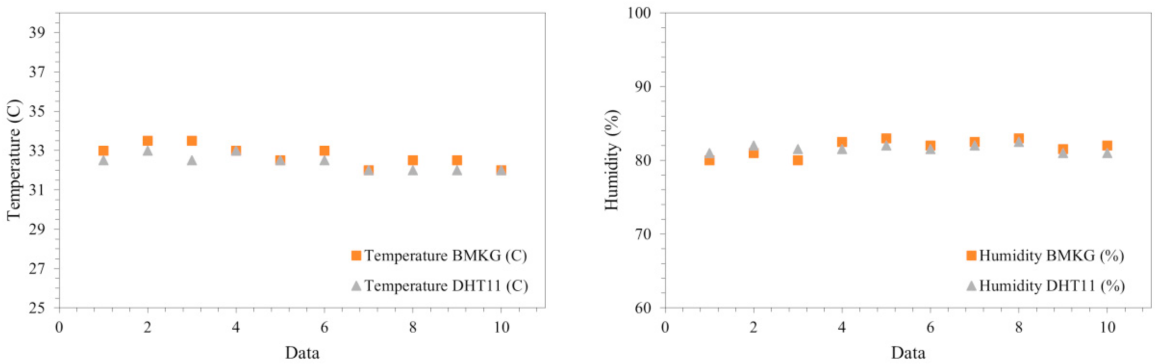

Fig. 8. Comparison of DHT11 Sensor Data with BMKG Data

Based on figure 8, the comparison of data from the DHT11 sensor and the BMKG sensor is shown. The error analysis indicates that the temperature measurements from the DHT11 sensor have an error rate of 1.05%, while the humidity measurements have an error rate of 1.04%. These results suggest that the DHT11 sensor is quite accurate, as its readings are close to those of BMKG's standard equipment. However, some data points show a temperature difference of more than 0.1°C and a humidity difference of more than 1.05%. These discrepancies can be caused due to environmental fluctuations affecting temperature and humidity. Weather influences such as wind speed and rainfall can also affect gas sensor measurements by altering atmospheric pressure. Wind speed can impact the dispersion of gases in the air; if the wind blows very fast, it can dilute or concentrate the gases around the sensor, leading to weakened or intensified readings. Similarly, heavy rainfall can affect sensor readings; if the rain brings certain gases down to the ground or surface, changing the concentration of gases around the sensor.

4. Conclusion

This research successfully developed and evaluated an IoT-based air quality monitoring device utilizing the ESP32 microcontroller, DHT11 temperature and humidity sensor, MQ-2 methane sensor, MQ-7 carbon monoxide sensor, MQ-8 hydrogen (H2) sensor, and MQ-135 carbon dioxide (CO2) sensor. The system produces real-time data accessible on the ThingSpeak server and directly displayed on a 16x2 I2C LCD. Based on the test results, it can be concluded that the air quality monitoring system works accurately, and functions as expected. The test results showed CO2 levels below 5,000 ppm, CO gas levels below 25 ppm, and other gases within safe limits, indicating that air pollution in Semarang on April 14, 2024, was considered safe or normal. The temperature and humidity levels experienced a decrease of 0.008495% and 0.6787% respectively. Meanwhile, CO2 and H2 decreased exponentially by 0.1697% and 0.0269% respectively. The error analysis between the DHT11 sensor and BMKG data indicates that the temperature measurements have an error rate of 1.05%, while the humidity measurements have an error rate of 1.04%. The success of the air quality monitoring system can provide accurate and real-time information, which can be used for making informed decisions and taking further actions related to air quality.

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