The Design and Construction of a Portable Air Quality Detector using the Internet of Things Technology

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Received: Jul 09, 2025; **Revised:** Sep 17, 2025; **Accepted:** Sep 25, 2025

Abstract

Air pollution is a major concern as it directly affects human health, leading to serious illnesses and, in some cases, premature death. It also has economic consequences, including increased healthcare costs. To address these issues, this research presents the design and development of a portable air quality detector utilizing Internet of Things (IoT) technology. The device, controlled by the NodeMCU ESP8266 microcontroller, provides real-time air pollution data to users, enabling continuous environmental monitoring. The detector categorizes air quality into five levels, ranging from good to poor, using a color-coded system: green, yellow, orange, red, and purple. It measures key environmental parameters, including particulate matter (PM2.5), temperature, humidity, carbon dioxide (CO_2), total volatile organic compounds (TVOCs), and Ozone (O_3), displaying real-time color-coded alerts to inform users about air quality conditions. Additionally, integration with the Blynk application allows for remote monitoring, enhancing the device's usability and practicality. This air quality detector serves as an effective tool for individuals, households, and workplaces to monitor environmental conditions, take preventive actions, and promote healthier living environments.

Keywords: portable, air quality detector, Internet of Things, microcontroller

1. Introduction

The Internet has become an essential part of modern life, often considered the fifth basic necessity in today's digital era. In the past, computers were primarily used for basic tasks such as sending and receiving emails. However, with the advent of the World Wide Web, people can now access vast amounts of information and communicate instantly. As technology continues to advance, computers and electronic devices have become increasingly intelligent, leading to the rise of the Internet of Things (IoT) [1],[2].

IoT technology enables seamless connectivity between devices, allowing them to communicate and operate efficiently over the Internet. Today, nearly every electrical appliance has evolved into a smart device, enhancing convenience, safety, and efficiency in various aspects of life. From industrial machinery and automobiles to household appliances, IoT has transformed the way people interact with technology. Recognizing the potential of IoT, this research aims to apply IoT technology to the development of a smart air quality detector [3].

Air pollution has increased dramatically in recent years due to environmental changes and human activities, resulting in the presence of invisible dust particles, harmful gases, germs, and unpleasant odors. These pollutants can severely affect the respiratory system and overall health. While air quality monitoring stations exist to measure pollution levels, conventional measurement stations are often expensive, large, and provide limited spatial resolution of data [4]. Establishing and maintaining these stations, known as Continuous Air Quality Monitoring Stations (CAQMs), requires significant financial resources, including costs for installation, calibration, and regular maintenance [5],[6]. Due to their high cost, CAQMs are typically installed in densely populated areas with high industrial activity, leaving many regions under-monitored or lacking sufficient air quality data. Additionally, factors such as sensor degradation, environmental conditions, and improper maintenance can affect the accuracy and reliability of these monitoring systems.

Recent works have explored low-cost IoT-enabled air quality monitoring systems. For example, Pietraru et al. [7] demonstrated effective indoor TVOC monitoring using MOX sensors, highlighting trade-offs between portability and sensitivity. Cavaliere et al. [8] performed field validation of low-cost O_3 and NO_2 stations with pre-deployment calibration frameworks and reported acceptable RMSE under outdoor conditions. Othman et al. [9] developed a low-cost indoor air quality monitoring prototype incorporating multiple sensors and real-time connectivity. A systematic review by García et al. [10] summarizes current advances in IoT-based air quality monitoring and AI, identifying key challenges such as sensor calibration, cross-sensitivity to environmental conditions, and data processing.

Portable air quality monitors offer a more flexible alternative, but each type has its limitations. Electrochemical sensors may lose accuracy over time and require frequent maintenance or replacement [11]. Optical sensors, while effective, have a limited lifespan and may struggle to detect fine dust particles with high precision [12]. Advanced specialized sensors tend to be expensive and complex, requiring technical knowledge for proper setup and operation

DOI: 10.55003/ETH.420406 ISSN: 2985-1688 (Online)

[13]. Ultrasonic sensors may face challenges in noisy environments or fluctuating temperatures, which can impact their performance [14].

To address these challenges, this research aims to develop a cost-effective and portable air quality detector [15],[16] using low-cost sensors [17],[18]. The device will provide real-time air quality measurements, enabling users to monitor pollution levels in their surroundings and take necessary precautions. By integrating IoT technology, the proposed system will offer an efficient, accessible, and affordable solution for individuals and communities to stay informed about air quality. This will help mitigate the adverse effects of pollution, protecting users from exposure to harmful particles that can impact respiratory health, reduce work efficiency, and contribute to economic burdens [19].

2. Research methodology

2.1 Portable air quality detector structure

The portable air quality detector has a compact design, measuring 10 cm in width, 20 cm in length, and 6 cm in thickness. It comprises several key components, including a PM2.5 dust sensor, Total Volatile Organic Compounds (TVOCs) detector, a carbon dioxide sensor, a humidity and temperature sensor, and an Ozone sensor. The device features a 2.8-inch TFT LCD for data display and is powered by a 12V 18650 lithium-ion battery with a 10,000 mAh capacity. It is controlled by a NodeMCU (ESP8266) microcontroller and includes a three-level battery indicator along with a built-in charging circuit, as illustrated in **Figure 1**

Figure 1 Portable air quality detector taken from real images

2.2 Selection of microcontroller

This research utilizes the NodeMCU ESP8266 microcontroller, which features the ESP8266 module for Wi-Fi communication. It operates within a voltage range of 3.0–3.6V and consumes an average current of 80 mA. To optimize power efficiency, it supports deep sleep mode, reducing power consumption to less than 10 µA and enabling wake-up for data transmission in under 2 milliseconds. The microcontroller includes a 32-bit low-power MCU, allowing for programmable control. Additionally, it features an analog-to-digital converter (ADC) with a 10-bit resolution for reading analog values. The ESP8266 is designed to function reliably across a wide temperature range of -40°C to 125°C.

2.3 Selection of display screen

This research employs the Nextion NX3224T028 2.8" TFT LCD. Nextion is a seamless Human Machine Interface (HMI) that provides an intuitive control and visualization interface between users and processes, machines, applications, or devices. Commonly used in the IoT and consumer electronics fields, Nextion offers an excellent alternative to traditional LCD and LED Nixie tubes. The interface for the portable air quality detector is designed using the Nextion Editor software, allowing users to create and customize the display. The display utilizes an Arduino-based method in the Nextion Editor, as shown in **Figure 2**

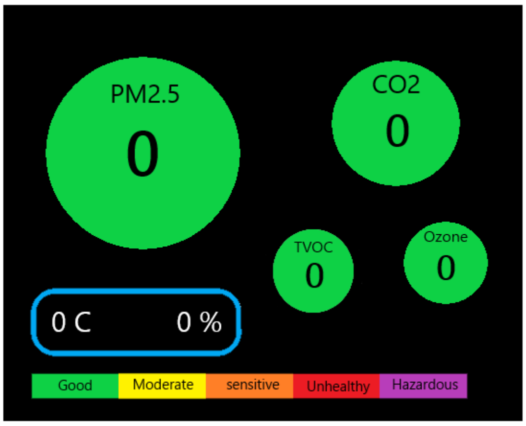


Figure 2 Display screen of portable air quality detector

2.4 Operation control program

The portable air quality detector measures the air quality index across five levels, ranging from good to poor air quality, as illustrated in **Figure 3**

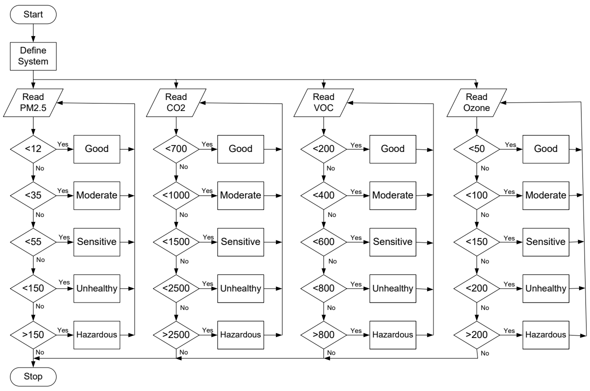


Figure 3 Operation Control Program

2.5 Operation control circuit

The first component is a battery voltage level display circuit, where the green light indicates a voltage level of 60 to 100%, the yellow light represents a voltage level of 30 to 70%, and the red light signals a voltage level below 30%. The second part involves the microcontroller circuit, which uses the ESP8266 board as the main processor. It is connected to several sensors: the DHT22 temperature and humidity sensor, the MQ-131 Ozone sensor, the CCS811 carbon dioxide sensor, the MiCS-5524 volatile organic compound sensor, and the PMS3003 dust sensor (PM2.5). These sensors are affordable, economical, and available locally. The processed values from these sensors are displayed on a 2.8-inch LCD screen, as shown in **Figure 4–5**

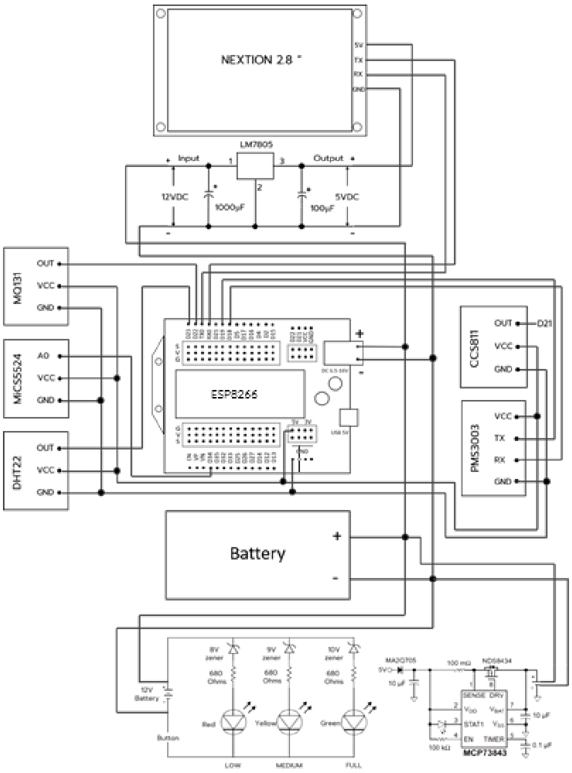


Figure 4 Operation Control Circuit Diagram

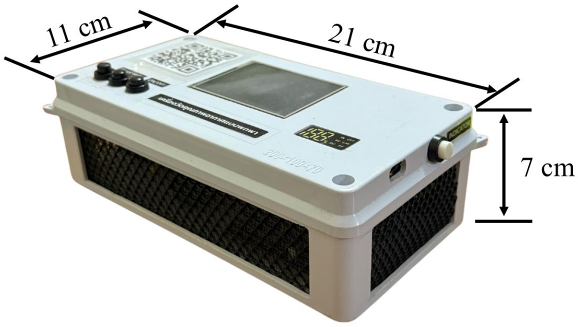


Figure 5 Operation Control Circuit taken from real images

2.6 System operation

The operation of the system follows these steps:

1. The user turns on the device by pressing the ON/OFF switch. A double press will turn the device on, while a long press will turn it off.

2. To reset the WiFi connection, the user presses the Reset + WiFi switch. If connecting to a new WiFi network is needed, pressing the Reset + ON/OFF switch will reset the entire device.

3. The indicator switch will display the battery status.

4. Pressing the WiFi + ON/OFF switch will activate the WiFi on the air quality detector.

5. Using a mobile phone or tablet, the user turns on WiFi, searches for "Air Quality," and connects to the device.

6. The user clicks on "Configure WiFi."

7. After connecting to WiFi, the user presses "Save."

8. To test the portable outdoor air quality detector, the user compares the measured values with the Air Quality Detector VT-9IN1 and Ozone Meter by recording the values every 10 minutes for 10 repetitions.

9. The device will display a status bar during operation. The colors represent different air quality levels: Green for Good, Yellow for Moderate, Orange for Sensitive, Red for Unhealthy, and Purple for Hazardous.

10. The device operates automatically until the process is complete. The LED battery status display has three levels: 60%–100% (3 LEDs: red, yellow, green), 30–59% (2 LEDs: red and yellow), and 0–29% (1 LED: red). The device will indicate the battery status at the end of the operation.

3. Experimental results

The performance test of this portable air quality detector is divided into six parts: testing the temperature measuring device, testing the humidity measuring device, testing the dust measuring device (PM2.5), testing the carbon dioxide measuring device, testing the total volatile organic compound (TVOC) measuring device, and testing the Ozone measuring device. The comparison test will be conducted using the Air Quality Detector VT-9IN1 reference meter and the Ozone meter at Northeastern University, Khon Kaen, outside the building, as shown in **Figure 6**

Figure 6 Testing of portable air quality detector taken from real images

Portable air quality detector, measuring the Air Quality Index (AQI) [20], there are 5 levels in the meter, starting from good air quality to poor air quality, and will display the results in the device, which is arranged in the following colors: green, yellow, orange, red, purple, as shown in **Table 1**

Table 1 Device Alert Thresholds and Display Colors (Not AQI)

PM2.5 (μg/m^3)	CO_2 (ppm)	TVOCs (ppb)	Ozone (ppb)	Danger level	color
<12	<700	<200	< 50	Good	green
<35	<1000	<400	<100	Moderate	yellow
<55	<1500	<600	<150	Sensitive	orange
<150	<2500	<800	<200	Unhealthy	red
>150	>2500	>800	>200	Hazardous	purple

For each parameter, the results of the proposed device were compared with those from the reference meter. In addition to the mean values and percent error, statistical validation was performed. The standard deviation (SD) was calculated to describe the dispersion of repeated measurements, and the root mean square error (RMSE) was used to quantify the overall deviation between the two devices, as defined by Eqs. (1)–(2).

$$\boldsymbol{SD} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (1)$$

$$\boldsymbol{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2} \quad (2)$$

where x_i is the measurement of the proposed device, y_i is the measurement of the reference device, $\bar{x}$ is the mean of x_i, and N is the number of paired samples.

3.1 Testing temperature measuring device

To evaluate the accuracy of the portable air quality detector and determine the average and error values for temperature measurement, a comparison test was conducted using a reference meter, as shown in **Table 2**.

Table 2 Test results of temperature measuring devices

Times	Time (p.m.)	Reference meter (°C)	Proposed device (°C)	Error value (%)
1	3.00	33	32	3.03
2	3.10	32	32	0.00
3	3.20	33	33	0.00
4	3.30	33	32	3.03
5	3.40	32	32	0.00
6	3.50	32	31	3.12
7	4.00	32	31	3.12
8	4.10	32	31	3.12
9	4.20	31	31	0.00
10	4.30	32	31	3.12
Average value		32	31.5	1.56
Standard Deviation		0.63	0.70	-
RMSE		0.77		-

From **Table 2**, it can be observed that the highest recorded temperature was 33°C at 3:20 p.m., while the lowest was 31°C at 4:30 p.m. When comparing these measurements with those from the reference meter, the average percentage error was found to be 1.56%, which is within an acceptable range.

3.2 Testing of humidity measuring devices

To evaluate the accuracy of the portable air quality detector and determine the average and error values for humidity measurements, a comparison test was conducted using a reference meter, as presented in **Table 3**.

Table 3 Test results of humidity measuring devices

Times	Time (p.m.)	Reference meter (%)	Proposed device (%)	Error value (%)
1	3.00	40	38	5.00
2	3.10	40	38	5.00
3	3.20	38	37	2.63
4	3.30	37	36	2.70
5	3.40	37	36	2.70
6	3.50	38	37	2.63
7	4.00	38	38	0.00
8	4.10	38	37	2.63
9	4.20	37	37	0.00
10	4.30	37	36	2.70
Average value		38	37	2.63
Standard Deviation		1.15	0.82	-
RMSE		1.18		-

From **Table 3**, the highest recorded humidity value was 38% at 3:00 p.m., while the lowest was 36% at 3:40 p.m. When compared with the reference meter, the average percentage error was 2.63%, which is within an acceptable range.

3.3 Testing of dust measuring devices (PM2.5)

To evaluate the accuracy of the portable air quality detector and determine the average and error values for dust measurements, a comparison test was conducted using a reference meter, as shown in **Table 4**.

Table 4 Test results of dust measuring devices

Times	Time (p.m.)	Reference meter (Ug/m^3)	Proposed device (Ug/m^3)	Error value (%)
1	3.00	10	10	0.00
2	3.10	11	10	9.09
3	3.20	9	8	11.11
4	3.30	9	9	0.00
5	3.40	12	12	0.00
6	3.50	10	11	10.00
7	4.00	13	12	7.69
8	4.10	14	13	7.14
9	4.20	10	10	0.00
10	4.30	8	7	12.50
Average value		10.60	10.20	3.77
Standard Deviation		1.90	1.87	-
RMSE		0.77		-

From **Table 4**, the highest measured dust concentration was 13 µg/m³ at 4:10 p.m., while the lowest was 7 µg/m³ at 4:30 p.m. When compared with the reference meter, the average percentage error was 3.77%, which is considered acceptable.

3.4 Testing of carbon dioxide measuring devices

To evaluate the accuracy of the portable air quality detector and determine the average and error values of carbon dioxide measurements, a comparison test was conducted using a reference meter, as shown in **Table 5**.

Table 5 Test results of carbon dioxide measuring device

Times	Time (p.m.)	Reference meter (ppb)	Proposed device (ppb)	Error value (%)
1	3.00	400	400	0.00
2	3.10	413	406	1.69
3	3.20	418	411	1.67
4	3.30	420	414	1.42
5	3.40	451	431	4.43
6	3.50	426	422	0.93
7	4.00	413	403	2.42
8	4.10	405	400	1.23
9	4.20	400	402	0.50
10	4.30	404	410	1.48
Average value		415	409.9	1.22
Standard Deviation		15.38	10.17	-
RMSE		8.46		-

From **Table 5**, it can be seen that the highest measured carbon dioxide value was 431 ppm at 3.40 p.m., the lowest measured carbon dioxide value was 400 ppm at 3.00 p.m., and when comparing the measured values with the values measured from the reference meter, the average percentage error was 1.22 %, which is considered acceptable.

3.5 Testing of Total volatile organic compounds measuring devices

To test the accuracy of the portable air quality detector and to find the average and error values of TVOCs measurements, a comparison test was performed with a reference meter, as shown in **Table 6**

Table 6 Test results of Total volatile organic compounds measuring devices

Times	Time (p.m.)	Reference meter (ppb)	Proposed device (ppb)	Error value (%)
1	3.00	9	10	10.00
2	3.10	10	11	9.09
3	3.20	12	14	14.20
4	3.30	20	22	9.09
5	3.40	23	23	0.00
6	3.50	24	25	4.00
7	4.00	14	14	0.00
8	4.10	18	19	5.26
9	4.20	20	19	5.26
10	4.30	10	10	0.00
Average value		16.00	16.70	4.37
Standard Deviation		5.68	5.62	-
RMSE		1.14		-

From **Table 6**, the highest measured TVOCs value was 24 ppb at 3:50 p.m., while the lowest was 9 ppb at 3:00 p.m. When compared with the reference meter, the average error percentage was 4.79%, which is within an acceptable range.

3.6 Testing Ozone gas measuring device

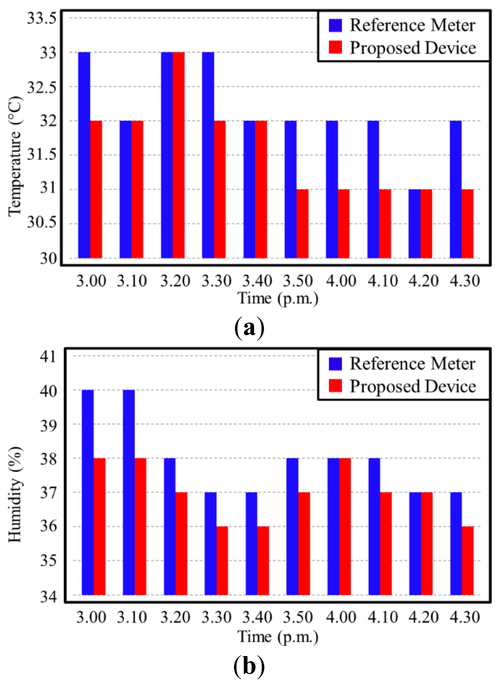
To test the accuracy of the portable air quality detector and to find the average and error values of ozone gas measurements, a comparison test was performed with a reference meter, as shown in **Table 7**

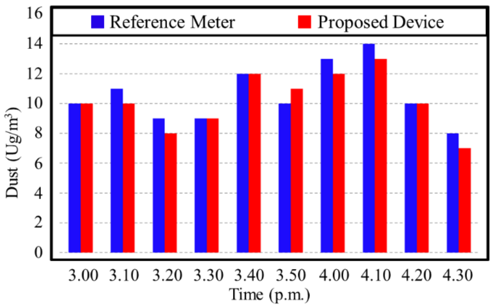
Table 7 Test results of Ozone gas measuring device

Times	Time (p.m.)	Reference meter (ppb)	Proposed device (ppb)	Error value (%)
1	3.00	25	26	3.84
2	3.10	26	28	7.14
3	3.20	30	32	6.25
4	3.30	31	30	3.33
5	3.40	28	29	3.44
6	3.50	25	28	10.7
7	4.00	25	26	3.84
8	4.10	26	25	4.00
9	4.20	25	25	0.00
10	4.30	25	26	3.84
Average value		26.60	27.50	3.38
Standard Deviation		2.36	2.32	-
RMSE		1.48		-

From **Table 7**, the highest measured Ozone value was 31 ppb at 3:30 p.m., while the lowest was 25 ppb at 4:20 p.m. When compared with the reference meter, the average percentage error was 3.27%, which is considered acceptable.

Based on the test results, a graph can be generated to illustrate the relationship between the measured values and those recorded by the reference meters for various measuring values, as shown in **Figure 7**.





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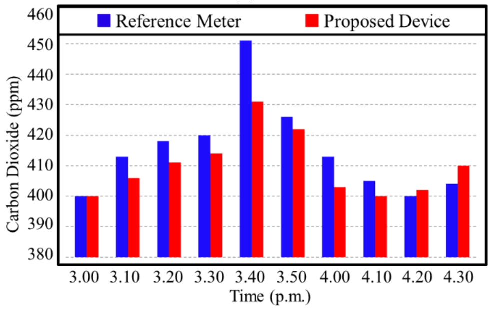

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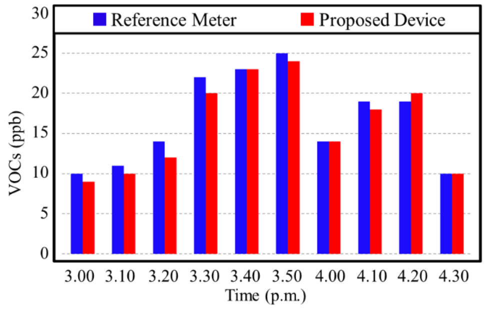

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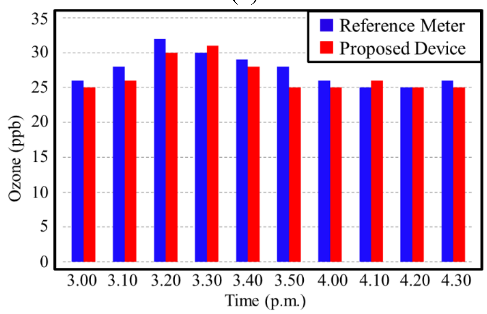
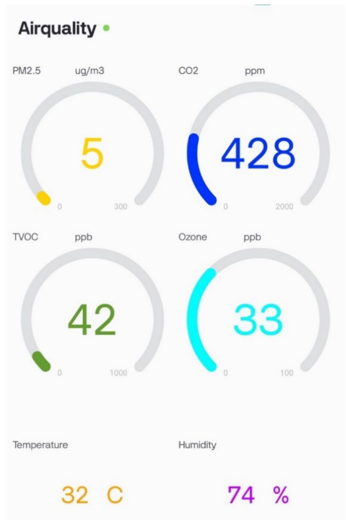


(**f**)

Figure 7 Comparison of various measuring values (**a**) temperature (**b**) humidity (**c**) dust (**d**) carbon dioxide (**e**) volatile organic compounds (**f**) Ozone gas.

Subsequently, real-time measurements of PM2.5 dust, temperature, humidity, Ozone, TVOCs, and carbon dioxide were displayed on the Blynk application on a smartphone. The testing took place at Northeastern University, Khon Kaen; Ban Kok Community, Nai Mueang Subdistrict, Mueang District, Khon Kaen Province; and the Central Intersection, Mittraphap Road, Mueang District, Khon Kaen Province. Measurements were taken outdoors at 3:00 p.m. to evaluate and compare the accuracy of the portable air quality detector under different environmental conditions, as shown in **Figure 8**.



(**a**)

(**b**)

(**c**)

Figure 8 Air quality display via Blynk application on smartphone (**a**) at Northeastern University Khon Kaen (**b**) at Ban Kok Community, Nai Mueang Subdistrict, Mueang District, Khon Kaen Province (**c**) at the Central Intersection, Mittraphap Road, Mueang District, Khon Kaen Province

4. Conclusion

This study presented the design and evaluation of a low-cost, portable air-quality detector integrating IoT technology. The prototype successfully measured six key parameters PM2.5, CO_2, TVOCs, O_3, temperature, and humidity and demonstrated close agreement with a commercial reference device, with overall errors remaining within ±5%. The detector operates continuously for at least six hours per charge and transmits real-time data via the Blynk mobile application, making it suitable for personal and community-level monitoring. With an estimated cost of 1,000 baht compared to 39,800 baht for similar commercial products, the device provides an affordable and practical alternative for air-quality awareness. While the current prototype has limitations in terms of size, assembly, and reliance on short-term testing, it offers a promising platform for accessible monitoring. Future work will focus on miniaturization, integration of higher-precision sensors, and the application of AI-based models for predictive air-quality assessment.

5. Discussion

5.1 Summary and interpretation of accuracy

Field co-location results indicate that the proposed device tracks the reference meter closely across all monitored parameters. Using per-sample statistics, the root-mean-square error (RMSE) was 0.77 °C (temperature), 1.18 %RH (relative humidity), 0.77 µg m^{-3} (PM2.5), 8.46 ppm (CO_2), 1.14 ppb (TVOCs), and 1.48 ppb (O_3). The corresponding standard deviations (SD) of repeated measurements were modest for both the reference and the device (e.g., temperature: 0.63/0.70 °C; humidity: 1.15 /0.82 %RH; PM2.5: 1.90/1.87 µg m^{-3}), suggesting stable repeatability. These error magnitudes are consistent with indicative-monitoring use cases and support the feasibility of a compact, low-cost IoT platform for routine awareness and trend tracking.

5.2 Working principles and sensor-specific limitations

Optical particulate matter (PM2.5). The PM sensor operates on light scattering: particles traverse an illuminated chamber and scatter light toward a photodetector; firmware maps scattering intensity to mass concentration using assumed particle size distributions and refractive indices. Key limitations include i) humidity-dependent hygroscopic growth that inflates apparent particle size and thus PM readings, ii) composition dependence (refractive index), and iii) limited sensitivity to very coarse particles and ultra-fines outside the calibration envelope. These factors can introduce positive bias at high RH and during events with atypical aerosol composition.

Electrochemical ozone (O_3). Electrochemical cells generate a current proportional to target gas diffusion and redox at the working electrode. Advantages include low power and near-linear response; limitations include cross-sensitivity (e.g., NO_2), temperature/relative-humidity (T/RH) dependence, and zero/span drift over time. Adequate warm-up, T/RH compensation, and periodic zero checks mitigate these effects.

MOX TVOCs and CO_2 proxy. Metal-oxide (MOX) sensors measure changes in film conductivity due to oxidizing/reducing gases and report a total volatile organic compound (TVOC) proxy. Some modules estimate "equivalent CO_2" (eCO_2) from VOC trends via embedded heuristics. These are not direct CO_2 measurements (unlike NDIR) and are influenced by temperature, humidity, and volatile mixtures. Consequently, eCO_2 should be interpreted as an occupancy/ventilation surrogate rather than as regulatory-grade CO_2.

Temperature and relative humidity. Temperature sensing is typically band-gap/RTD-based; RH is often capacitive. Both are subject to placement effects (self-heating, radiant loading, airflow) and require shielding and airflow management to reduce bias.

5.3 Environmental and design factors influencing performance

Environmental factors such as temperature and relative humidity (RH) are known to influence the performance of low-cost air-quality sensors. For example, high RH can cause hygroscopic particle growth and increase the apparent mass concentration reported by optical PM sensors, while electrochemical O_3 sensors show cross-sensitivity to both RH and temperature. Similarly, MOX sensors used for TVOCs and eCO_2 estimation can drift due to ambient T/RH variations. In the present study, we did not perform a residual analysis of sensor bias versus T/RH; however, we acknowledge these limitations and emphasize that such factors may partially explain the observed deviations. Future work will include multi-day measurements and regression models incorporating T/RH to improve accuracy and stability.

5.4 Practical implications, AQI mapping, and future work

Expressing concentrations as AQI improves public interpretability. In this study we compute AQI for pollutants with established breakpoints (PM2.5, O_3) using the EPA linear-interpolation method (Appendix A), while CO_2 and TVOCs are presented as raw values with user-configurable device alert color levels (not AQI). Practically, the observed RMSE values (1 unit for PM2.5 in µg m^{-3} and O_3 in ppb 1 °C and 1.2%RH 8.5 ppm for CO_2 support use in indoor/outdoor awareness, ventilation tuning, and community sensing.

Limitations include environmental cross-sensitivities, sensor aging, and reliance on a field-grade reference. Future work will i) apply multi-point co-location with regulatory monitors, ii) develop calibration models that incorporate T/RH and composition surrogates, iii) extend multi-day/seasonal datasets to assess drift, and iv) refine enclosure airflow and shielding. Together, these steps will narrow bias, stabilize long-term performance, and enhance the utility of low-cost sensing for health-relevant decision support.

6. Appendix

6.1 Table of Abbreviations

All abbreviations used in this article, together with their full terms and descriptions, are shown in **Table 8**.

Table 8 List of Abbreviations

Abbreviation	Full term	Description
PM2.5	Particulate Matter ≤ 2.5 µm	Fine inhalable particles with diameters 2.5 micrometers and smaller
CO_2	Carbon Dioxide	Indoor/outdoor air quality indicator, measured in ppm
TVOCs	Total Volatile Organic Compounds	Combined index of multiple VOCs, measured in ppb
O_3	Ozone	Measured as ppb; secondary air pollutant
IoT	Internet of Things	Network of connected devices used for data transfer
RMSE	Root Mean Square Error	Statistical metric of error between two datasets
SD	Standard Deviation	Statistical measure of dispersion from the mean
AQI	Air Quality Index	Index value converting pollutant concentrations into a 0–500 scale
PCB	Printed Circuit Board	Hardware integration platform
RH	Relative Humidity	Ratio of water vapor in air to maximum possible at same temperature (%)

7. Acknowledgments

Thank you to the Electric Power Research Unit, Major of Electrical Power Engineering, Department of Electrical Engineering, Faculty of Engineering, Northeastern University, Khon Kaen, Thailand for providing equipment, tools, and testing locations.

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