



Design and Implementation of a Solar-Powered Air Quality Monitoring System for Smart Campus Using Internet of Things (IoT)

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ABSTRACT

The high level of air pollution in developing countries such as Nigeria is a cause for concern. Air pollution can cause allergies and harmful diseases such as cardiovascular and lung diseases and can also cause death. This paper describes a low-cost monitoring system for air quality on a university campus. The Internet of Things IoT-based air monitoring system monitors air quality in real-time and transmits data to the dashboard via the ESP32 microcontroller. The device is composed of a microcontroller, pollutant detection sensors, and a solar-powered supply. The device was designed for the study to measure temperature, humidity, Carbon Monoxide (CO), Carbon Dioxide (CO₂), and dust particulate levels at various locations on campus. Data is stored in the ThingSpeak IoT Platform and displayed in real-time on a dashboard to assist officials in taking appropriate action if a certain level of pollution is exceeded.

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INTRODUCTION

Each year, the state of the atmosphere conditions continues to deteriorate due to the rapid population growth and advancement of industries [1][2]. Among the numerous types of pollution, including noise, water, and soil, the most harmful and severe form, which contributes to climate change and causes serious illnesses, is air pollution [3]. Even though everyone needs air to survive, many people are uninformed of how serious the problem of air pollution has become. The World Health Organization (WHO) estimates that 90% of the world's population currently breathes air pollution, which kills 7 million people annually [4]. People need to become aware of how much their actions have an impact on the quality of the air because air pollution is contributing to an increase in health problems like heart disease, lung cancer, respiratory illnesses, and stroke as well as having a negative impact on the ecosystem [5] [6]. As a result, poor air quality has become a major global concern, so it is crucial to continuously monitor air quality to ensure that our surroundings are safe and worth staying in.

Recently, the Internet of Things (IoT) has been used extensively across many

industries and plays a critical part in our system for monitoring air quality [7]. Numerous works have been made to integrate IoT technology with air quality monitoring systems in order to monitor the quality of air in a surrounding environment. For example, Marinov B. et al. [8] monitor environmental parameters with electrical sensors and infrared gas sensors using the PIC18F87K22 microcontroller. Sensor nodes are set up in different locations for real-time monitoring of the environment with results displayed on maps. Shete R. et al. [9] proposes a framework for monitoring the city environment. Raspberry Pi was used for implanting the system. Parameters like carbon monoxide, carbon dioxide, and temperature are measured however particulate matter was not included which makes the environment monitoring incomplete. Recently, Mitar M. et al. [10] presented a system for the measurement and presentation of water and air quality data, and results are stored on the IBM Watson IoT platform. The complete system is powered by a solar panel-based charging unit. Kgotjijo P. et al. [11] presented an air quality monitoring system based on the IEEE/ISO/IEC standard. Concentrations of Carbon Monoxide, Carbon

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dioxide, and Nitrogen oxide were measured using electrochemical and infrared sensors. However, results are only saved in the data server. Somansh K. et al. [12] presented a real-time standalone air quality monitoring system that monitors carbon monoxide, carbon dioxide, temperature, humidity, and air pressure. Low-cost ARM-based minicomputer Raspberry Pi was used. The system was implemented; the parameters measured are shown in the IBM Bluemix Cloud IoT platform.

This study focuses on the development of an IoT-based air quality monitoring system utilizing the ESP32 microcontroller. ESP32 is a powerful microcontroller that is capable of connecting to the internet and collecting data from various sensors. This makes it an ideal candidate for air quality monitoring. In order to achieve cost efficiency and resource management, we have proposed a solar-powered IoT-based air quality monitoring system that will sense and show the real-time surrounding data of temperature, humidity, CO, CO₂, and dust particulate levels and help to

guard against extreme events by alerting people and initiate actions regarding it.

PROPOSED SYSTEM ARCHITECTURE

The developed IoT-based air quality monitoring system is based on the block diagram shown in Figure 1. The model was created and implemented using IoT technology. It is a low-cost, low-power, and portable IoT-based air quality monitoring system with a highly flexible microcontroller that gathers real-time environmental data using four sensors: the MQ135 gas sensor for sensing carbon dioxide (CO₂), the MQ7 sensor for measuring carbon monoxide (CO) gas, the GP2Y1010AU0F sensor for dust level monitoring and the DTH11 sensor for temperature and humidity sensing. These readings are sent to the microcontroller as a processing unit, and the system then uploads the detected data to the internet. Hypertext transfer protocol (HTTP) is used to store and retrieve data on the ThingSpeak open cloud platform through the internet. The obtained data can be plotted in a graphical form with the aid of the ThingSpeak platform.

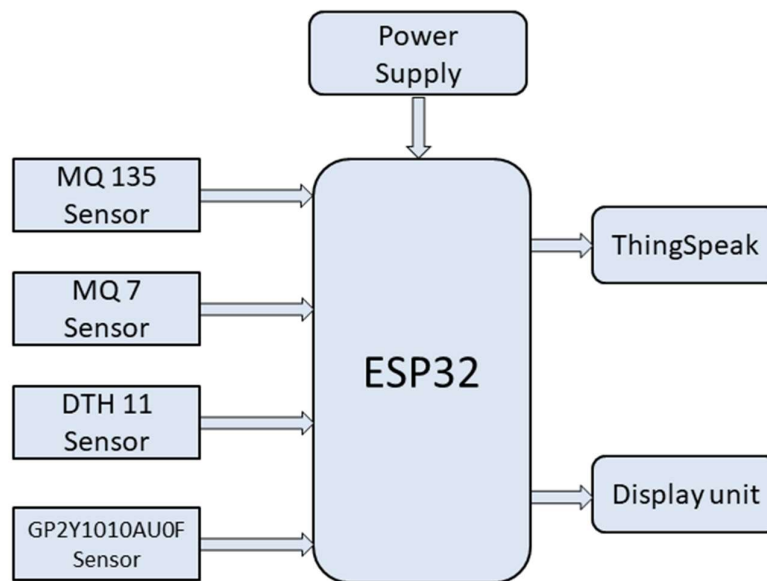


Figure 1: Block diagram for the IoT-based air quality monitoring system

Proposed System Architecture

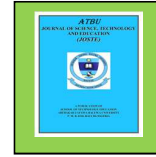
A small integrated circuit called a microcontroller is utilized in embedded systems

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to process data from various sensors. In this project, ESP 32 GP2Y1010AU0F from Espressif Systems was used. It is designed for high-performance applications and has features such as Wi-Fi, Bluetooth, and multiple

UARTs. The ESP32 is often used in Internet of IoT applications due to its connectivity capabilities and low power consumption. Table 1 summarizes the specifications of the ESP32 microcontroller [13].

Table 1: Specification of the ESP32 microcontroller

Specification	Value
Instruction set	Dual-core LX6 (32-bit)
SRAM (system)	520 Kbytes
12-bit ADC number of channels	18
Maximum CPU frequency	240 MHz
Operating voltage	2.7 V to 3.6 V
Operating temperature	-40 to 85 Celsius

Dust Sensor

An infrared dust sensor, model GP2Y1010AU0F made by Sharp Electronics was used to measure the dust concentration in the air. It works by emitting infrared light and measuring the reflected light that has passed through the dust in the air, allowing it to determine the dust density. The main features of the sensor are high sensitivity and accuracy

in the range of 0 - 500 $\mu\text{g}/\text{m}^3$. It is commonly used in air purifiers and other applications that require monitoring of air quality. This model also has a quick response time that can output real-time accurate data. The main specifications of the fine-dust sensor are provided in Table 2 [14].

Table 2: Specification of the infrared dust sensor

Specification	Value
Measurement range	0 to 500 $\mu\text{g}/\text{m}^3$
Operating temperature	-10 to 65 Celsius
Operating humidity	0 to 95 % RH
Operating voltage	V to 5.5 V

Carbon Dioxide Sensor

Carbon dioxide (CO_2) is one of the greenhouse gases that contribute to global warming. To measure and track CO_2 concentrations, the CO_2 gas sensor module MQ135 is fitted into the device. The sensor is mainly used to detect the presence of volatile organic compounds (VOCs) such as ammonia, benzene, and CO_2 in the air. The sensor works by measuring the resistance of the sensing material, which changes in response to the concentration of VOCs in the air. The change in resistance is then converted into an electrical signal, which can be read and analyzed by a control system. The sensor features excellent long-term stability with low power consumption. The detailed specifications of the sensor are listed in Table 3 [15].

Table 3: Specification of the CO_2 sensor

Specification	Value
CO_2 measurement range	10 to 1000 ppm
Response time	30 s
Operating temperature	-20 to 70 Celsius
Operating humidity	0 to 96 % RH
Operating voltage	2.5 V to 5.0 V
Power consumption	

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Carbon Monoxide Sensor

Carbon monoxide (CO) is a harmful byproduct of incomplete combustion of carbon molecules. When CO gas enters the body, it causes hypoxia by cutting off the flow of oxygen [16]. Therefore, a CO sensor module MQ7 from Hanwei Electronics is mounted in

the device to detect and monitor CO. It is a metal oxide semiconductor device that has a high sensitivity to CO and can be used in a variety of applications, including home safety devices, indoor air quality monitoring, and industrial process control. The specifications of the CO sensor are listed in Table 4 [17].

Table 4: Specification of the CO sensor

Specification	Value
Sensor input voltage	5 V
Reaction time	1 s
Recovery time	Less than 30 s
Working temperature	-20 to 50 Celsius
Working humidity	Less than or equal to 95% RH
Sensitivity	Greater than or equal to 3%
Power consumption	

Temperature and Humidity Sensor

Temperature and humidity have a significant impact on how comfortable the surrounding environment is. In order to measure temperature and humidity, a temperature-humidity sensor, model DHT11 from OSEPP Electronics, is installed in the system. DHT11 is a simple, inexpensive digital

temperature and humidity sensor. It measures the ambient air using a thermometer and a capacitance humidity sensor and forwards a digital signal to a microcontroller to give the relative humidity and temperature values. The specifications of the temperature-humidity sensor are listed in Table 4 [18].

Table 5: Specification of the temperature-humidity sensor

Specification	Value
Operating voltage	3.5 V to 5.5 V
Humidity range	20 to 80 % RH
Temperature range	0 to 50 Celsius
Humidity accuracy	± 5 % RH
Temperature accuracy	± 2 Celsius
Response time	to 15 s

Working Principle

The PM sensor GP2Y1010AU0F is attached to the ESP32. The middle of the dust sensor is hollow. Therefore, the fine particles can only be sensed when they are in the hollow detecting area, and correspondingly, the proper values may be achieved. The output, which is expressed in mg/m³, was derived using the dust density characteristic curve. The analog pins of the ESP32 are linked to MQ135 and MQ7, respectively. ESP32's digital pin is coupled to DHT11. The ESP32 digital module is also linked to the beeper. MQ135 and MQ7

are preheated and calibrated before used. The preheating requires a 5V power supply for at least 24 hours. The values of the gas sensors are converted to PPM using their individual sensitivity characteristic curves. A Bluetooth module is also connected for easy access to the data in case of an emergency. The dashboard of ThingSpeak can be accessed from any location in real-time. Figure 2 illustrates the system flow chart for an IoT based air quality monitoring and control system.

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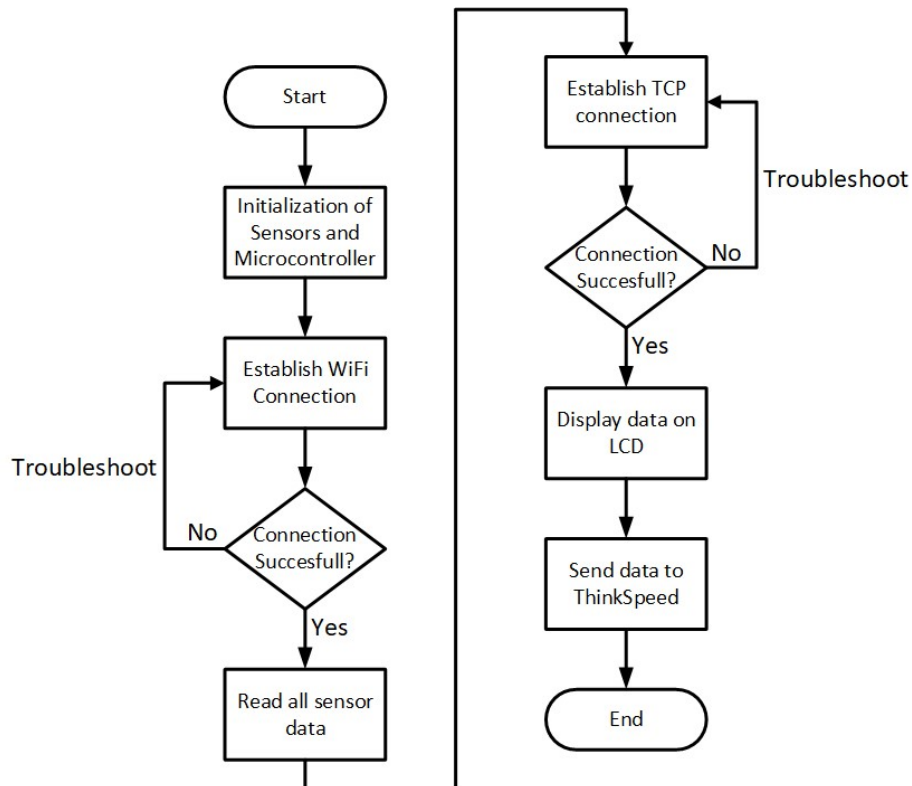


Figure 2: Flowchart of the working model

PROTOTYPE RESULTS AND DISCUSSION

The prototype developed IoT-based air quality monitoring system Figure 3. All sensors send data to ESP 32 microcontroller

and published on ThingSpeak. The result is published on the LCD display unit and the data plot graphically for analysis.

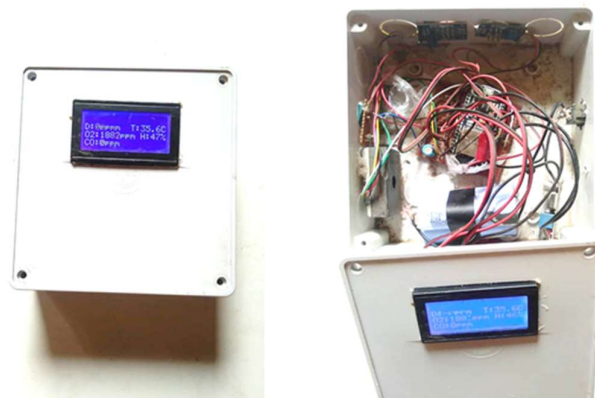


Figure 3: Prototype of the developed IoT-based air quality monitoring system

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The air quality monitoring device was placed outdoors for 24 hours to collect the air quality parameters on the 14th January, 2022. There are five parameters collected by exposing the device to the air and these parameters are dust level, CO, CO₂, temperature, and humidity. The collected data are then transmitted to the server via ESP32 microcontroller and stored on ThingSpeak platform. Figure 4(a) shows the reading obtained for dust, CO, and CO₂ starting from

6:00 am. It can be observed that readings for all the pollutants were slightly stable from 6.00 am until 6.00 pm. While the CO and dust level has decrease after 6:00 pm, the CO₂ increased. The CO decreased from 500 to 300 ppm after 6:00 pm, it remains stable between 6:00 pm to 12:00 am and suddenly increased to 500 ppm after midnight. The CO₂ has a slightly increased between 6:00 pm to 12:00 am, and the dust level continued to decrease after 6:00 pm.

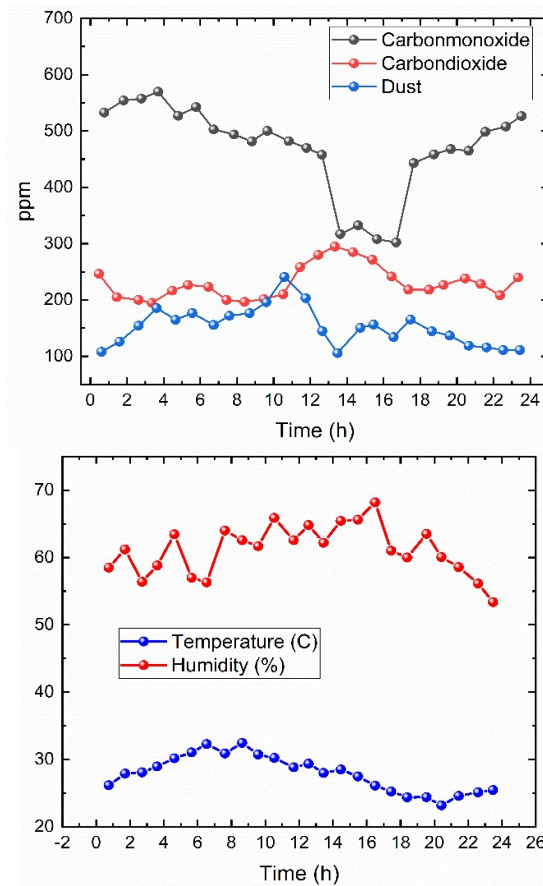


Figure 4: Results of (a) CO, CO₂ and dust reading (b) temperature and humidity reading

Figure 4(b) shows the result for temperature and humidity for a period of 24 hours. It can be observed that, the temperature dropped during the night and humidity was higher at night. The temperature increased rapidly until it reached the peak just after midday. Temperature value can reach up to 32

°C during the day. It then decreased during the night to 23 °C.

CONCLUSION

This study presents the design of an air quality monitoring system based on the ESP32 that is less expensive and less complicated. The sensors can gather

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information from the surrounding environment. It will be useful to keep track of the air quality in a specific area or location so that the necessary steps may be made to clean it up. Real-time measurements of the air quality will also help us better understand how it affects the climate system and people's health.

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