Development of a Smart Air Quality Monitoring System Using Wireless Sensors

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

With the fast-growing urbanization and increased industrialization around cities in Nigeria, the quality of the air we breathe has become a paramount concern. There is a need for an accurate, real-time air quality monitoring system to monitor and evaluate the air quality we inhale. This article presents the development of a Smart Air Quality Monitoring System (SAQMS) utilizing wireless sensor technology. The SAQMS was designed to provide a comprehensive and intelligent solution for monitoring air quality index, including but not limited to particulate matter (PM2.5 and PM10), volatile organic compounds (VOCs), carbon monoxide (CO), temperature and humidity. Leveraging wireless sensor nodes and advanced IOT, the system offers real-time data collection and analysis, enabling immediate response to environmental changes. Key features of the SAQMS include a network of wireless sensors (MQ 135 and DHT11) strategically deployed across targeted areas, data transmission through secure communication protocols, cloud-based data storage and processing, and a user-friendly interface for data visualization and interpretation. As we confront the challenges of air pollution and its impact on human well-being, the development of the SAQMS

presents a significant step towards informed decision-making and a more sustainable future as the experiment shows our developed system can detect air quality in parts per million (ppm), with other environmental factors such as temperature and relative humidity.

Keywords: Air quality; internet of things; MQ 135 sensor; DHT11 sensor; air quality index.

1. INTRODUCTION

An atmosphere free of pollution is pivotal to the environment, plants, animals and human health. Any alteration in the natural composition of air has detrimental consequences on humans, animals, plants, economic growth, social wellbeing and the environment around us [1,2]. The biggest problem of every nation, developed or developing, is air pollution, which emanates from natural and human activities and grows rapidly due to motorization, construction, mining, agriculture, gas flaring, industrialization, deforestation and population increase [3-6]. The result of these activities is the release of gaseous emissions and particulate matter that contaminates the air and these include ground-level Ozone, Methane, SO_2, CO, CO_2, NO_2, PM, and Pb [7-9].

The rise in health-related issues has necessitated the importance of monitoring air quality and has led to several inventions for real-time monitoring of air quality [10-14]. The authors in [15] proposed a low-cost air sensing model based on IoT, to monitor air quality over a cloud-based platform that triggered an alarm whenever air quality went above the recommended threshold. With the use of MQ135 gas sensor, LPG, SO_2, NO_2, smoke and CO_2 gas were monitored. Data collected were stored in ThinkSpeak API via ESP8266 wireless module. The monitored air quality were displayed in parts per million on the internet-based platform for ease of monitoring. In [16], a novel approach to measure indoor CO_2 using MH-Z19 NDIR infrared gas module was presented. This system was developed using an Arduino Uno microcontroller interfaced with the LCD1602. The microcontroller was connected to MH219 and AM2302 sensors to measure CO_2, temperature and relative humidity respectively. At every five minutes interval, the collected data was displayed on the LCD screen in the form of line chart.

An air quality monitoring system using Wireless Sensor Network (WSN) to monitor air pollution like NO_X, SO_2, CO and other environmental factors such as relative humidity, temperature and wind speed was put forward by [2]. The WSN was developed by assembling sensor nodes and hosting a web server. The system was made up of 3 sensor nodes, each placed on a pole at a different height level. Each sensor node consisted of ADC5669 16 Bit 8 channel, power supply, Mobile Wi-Fi (MiFi) and five sensors, one each for measuring SO_2 (MQ-136), NO_X sensor, CO sensor, air temperature and humidity (SHT15) and wind speed (anemometer). The sensors measured data in analog, except for digital data measurement from the SHT15 sensor. Analog data were converted into digital data by 16-bit ADC, then transmitted to Web Server by WiFi. Data from the three sensor nodes were displayed in the form of graphs and tables through a web server and accessed online in real-time, through smartphones. Using MQ135 sensor, an IFTTT application, an ESP8266 Wi-Fi enabled chip and a NodeMCU V1.0 microcontroller, [17] constructed a smart air pollution monitoring system. The gas sensor was used in monitoring the concentration of SO_2, NO_2, CO_2 and CO in the air. Data was transmitted via the microcontroller to the internet, through a WiFi enabled chip. Whenever the pollution level of each measured pollutant exceeded the threshold level, an alert message was sent to the user via the IFTTT application. To build-up security in the server, AWS IoT device SDK was used to authenticate messages over the internet network. The advantage of this system was that, whether the system is connected to the internet or not, alerts sent by the system were received by users on mobile phone from any distance.

For adequate environmental and health protection, an effective air quality monitoring system is a necessary instrument. This creates a need for measurement and analysis of real-time air quality monitoring so that appropriate decisions can be taken by scientist, policy makers and residents in a timely period for the improvement of the living environment [18,19]. This research proposes a smart air quality system for real-time monitoring of air quality in Nigeria. The proposed system is necessary as an alternative solution to quashing the hurdles experienced by air quality monitoring stations in

Nigeria, either due to absence or damaged equipment.

1.1 Statement of the Problem

The fourth most polluted country in the world is Nigeria. In Bayelsa State, for instance, air pollution caused 4960 respiratory ailments in children, 120 asthma attacks and 49 premature deaths yearly [20]. According to WHO report, millions of people die yearly because of breathing disorders emanating from air pollution and 90% of the world's population are exposed to high level of pollutants which exceed WHO limits [6]. The harmful effects of air pollution have become evident, yet in Nigeria, we do not have access to real-time air quality data. Air quality monitoring systems in Nigeria are all imported and very costly and once they are faulty, they are abandoned. Most air quality systems are launched into space and data collected by such systems are predicted since measurement is not done in situ. This research proposes an IoT-based system for real-time monitoring of air quality in Nigeria.

2. METHODOLOGY

To develop this system, the following stages were utilized; circuit design and operation, PCB fabrication, firmware development, mobile app development, cloud server setup and integration. The above listed steps led to the IoT air quality system.

2.1 Circuit Design and Description

The circuit diagram of the air quality monitoring system is shown in Fig. 1. The system is based on printed circuit board (PCB) that supports high end microcontroller. The sensors communicate with the system serially, using serial communication protocol based on I^2C communication protocol, so that the serial clock (SCL) sensor modules and serial data (SDA) pins wires to the corresponding I^2C pins on the PCB. The sensors run on 3.3V and 5V DC, so its V_{CC} pin is connected to the 5V output on the PCB and the GND pin. The sensor interfaces with the system and communicates with the controller through a serial interface that works at 5V logic level, while the RX logic level works at 3.3V. The touch display uses serial communication while two transistors are used in switching the sensor heaters. A real time clock module keeps track of the time when storing the sensor values using the I^2C communication

protocol. The entire device is powered with 5V through a custom-made power supply.

The system is based on ESP8266 embedded WIFI Module that runs on 5V DC source. Power supply for the system is derived from a fabricated DC-to-DC converter module capable of supplying up to 5V, 2amp DC. A step-down DC-to-DC converter module is used in the system to allow a wide range of DC source.

The sensors are connected to the ESP8266 Wi-Fi module for data exchange in digital and analog form. V_{CC} and the ground pin of the sensors connect to the 5V and ground terminal of the power supply circuit, while the analog pin of the MQ135 gas sensor is connected to the analog-to-digital converter pins of the Wi-Fi module. Connected to digital pin D4 of the ESP Wi-Fi microcontroller module is the DHT11 temperature/relative humidity sensor. In place of a buzzer, a push notification feature has been added to the system to allow notifications to be sent out when air quality is above the WHO recommended threshold level.

The LCD display is connected to the ESP module using serial communication based on I^2C protocol, while power supply pins of the LCD display are connected to the appropriate supply lines to enable the correct supply to be sent to the display. Screen contrast of the LCD would is handled and managed through software.

Power supply of the entire system is derived from custom design standalone power supply with support for solar renewable energy. Data pins used in communicating with the ESP8266 WIFI microcontroller development board are; pin D4, connected to data pin of the temperature/relative humidity sensor; pin D1, D2 of the ESP module connects to SDA, SCL of the seral LCD module while pin A0 of ESP8266 module is connected to the analogue pin of the MQ 135 gas sensor module.

2.2 Designing of Schematic, Layout Diagram and PCB Production

As a design requirement, the circuit was first developed and simulated using proteus and multism. These programs aided the simulation of the project before it was implemented, making it easier to ascertain, do corrections and take decisions before final implementation.

The program used in creating both the PCB and schematic diagram for the developed air quality

system were Dip Trace, Eagle schematic capture program and Altium designer.

After designing the schematic diagram, it was converted to PCB art work. The converted PCB art-work was then printed into a special PCB printing film (Press n Peel sheet), a transfer film used in printed circuit board production.

2.3 System Operation

The device takes readings from its sensors and sends the data to an android device via WiFi in every 5 seconds, using a third-party mobile App, Blynk. The device sensor detects and measures the air quality, temperature and relative humidity and communicates with the ESP WIFI module via internet to access the Blynk server so as to display the air quality information. All collected and measured data from the sensors are sent through The Blynk server for easy access. The device supports 16x2 character serial LCD display that displays the sensor data sent to the mobile device through the Blynk Mobile App. A gauge gadget in the Blynk mobile app displays a user-friendly result of the air quality data during operation. The LCD display also shows data sent to the mobile device.
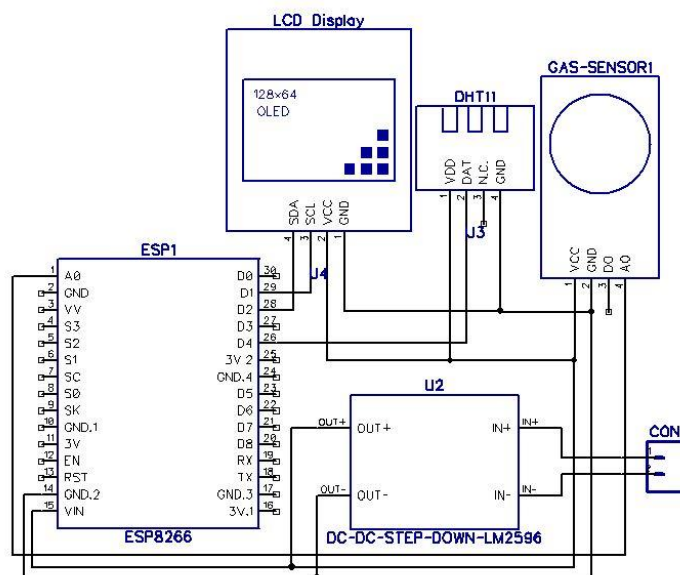

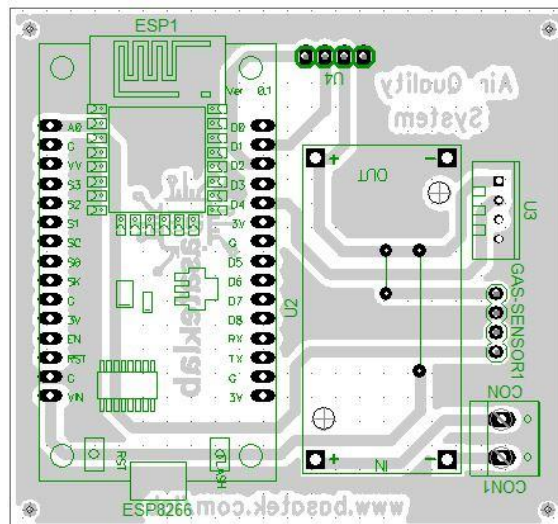**Fig. 1. Circuit diagram of smart air quality monitoring system**

Fig. 2. PCB layout diagram of air quality monitoring system

In operation, the Blynk mobile app in the android device displays the air quality and timestamps the received data, then sends them to the Blynk server to be stored in a database. When a user opens the Blynk Mobile App, the application reads from the database and visualizes the data graphically on the Mobile App. This option allows for the access of read data to be seen and accessed anywhere in the world. It uses air quality sensors to collect data and a WiFi connection to send them to the cloud server which in turn display the sensor data on the android device.

Sensor readings are taken every 1 or 2 seconds and passed through low-pass filters to reduce data noise. Every 5 seconds, filtered values are sent to the mobile device via WiFi as a JSON string. The Android application takes the received measurements and timestamps to the received data. Then, it sends the JSON string along with the received data to the web server using HTTP protocol. The web server receives and stores the data in a database thus allowing the data to be retrieved when needed. A flowchart and block diagram of the system is given in the Figs. 3,4.

2.4 Firmware Development

Developing the required firmware for the system involved the use of an integrated development environment (IDE) based on Arduino IDE. The firmware program allowed the system to communicate with the sensor, write to the LCD display and interact with the web server. The Firmware program was written in C. In the firmware development, we used MpLab for debugging.

2.5 Android App Development

The mobile App (Blynk) was developed using Android Studio, the official integrated development environment (IDE) provided by Google. The IDE is built on JetBrains' IntelliJ IDEA software and is available for download on Windows-, macOS and Linux-based operating systems.
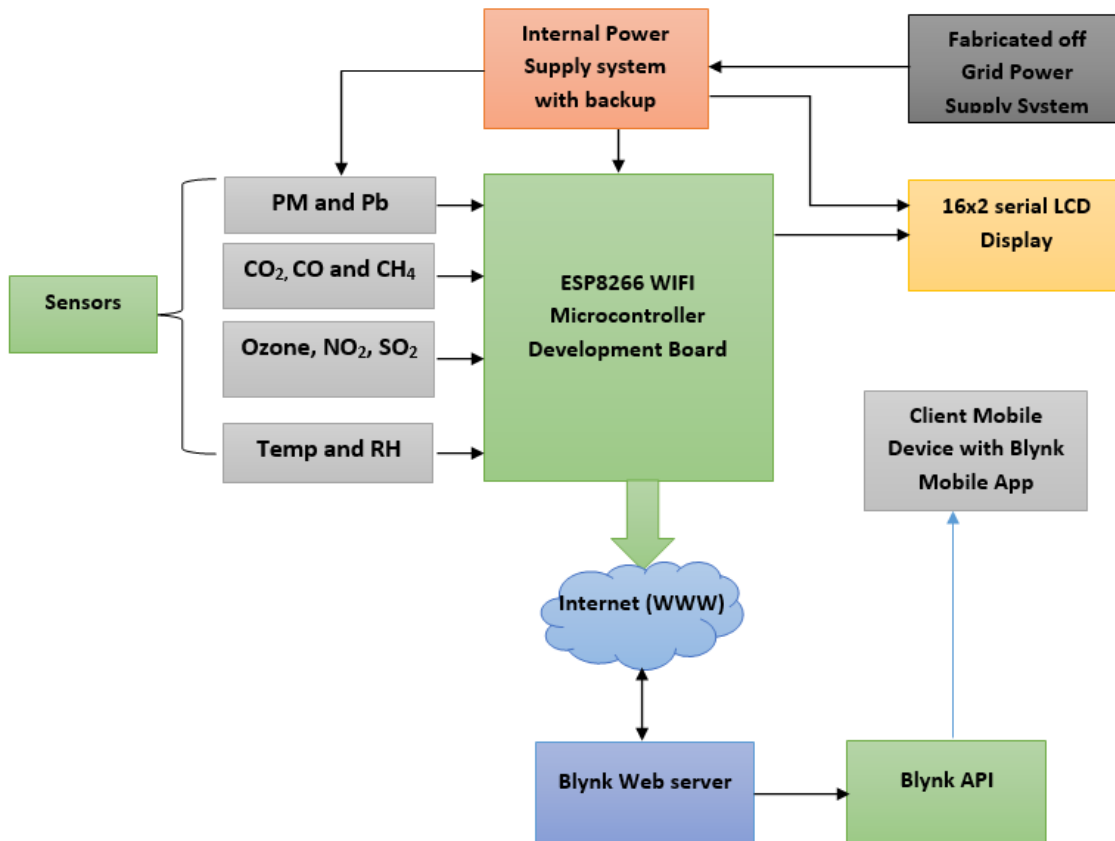

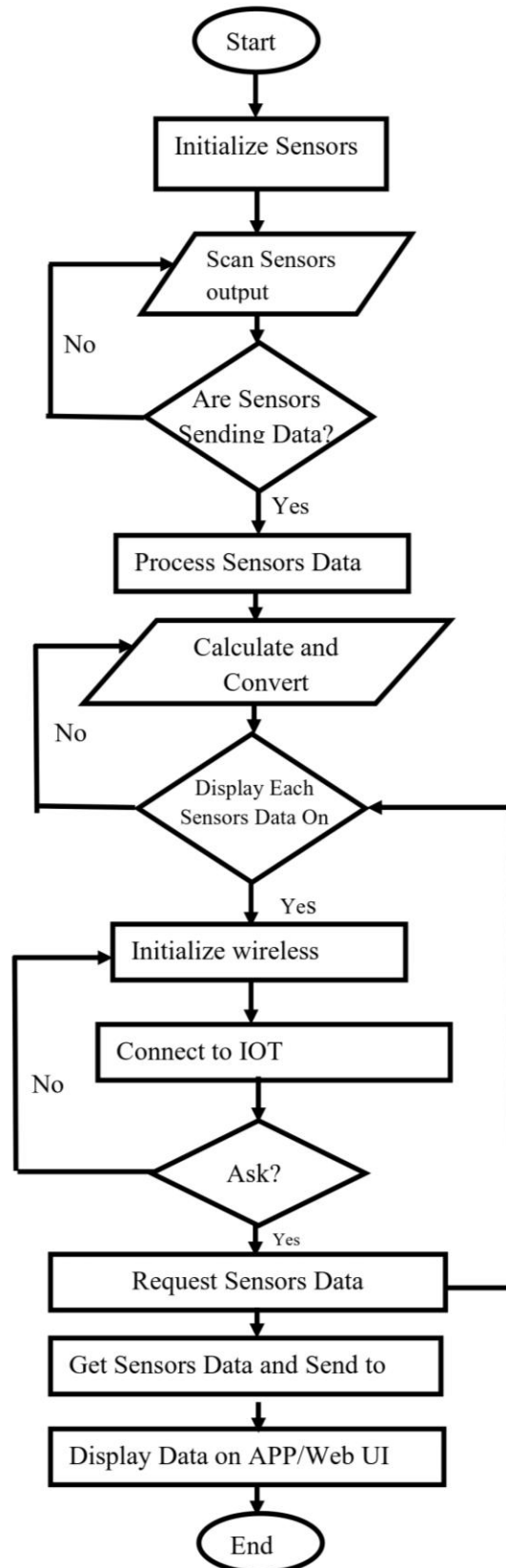**Fig. 3. Block diagram of air quality monitoring system**

Fig. 4. Flow chart for the developed air quality

2.6 Cloud Service Setup

In setting up the cloud service, a Blynk account was created to allow access to the service backend. The HTML/JavaScript frontend for the web application was made to interface with the android application via HTTP protocol. The database used in storing sensor data from the IoT device and the "Plotly" JavaScript library that makes all graphical visualizations in the webpage was developed.

2.7 Receiving Data from the IoT Device

In receiving data from the IoT device, the code in charge of retrieving the measured data received from the device was written to handle communication. This code is responsible in retrieving the received JSON string known as Callback from the IoT device. This callback is executed when data available in the IoT device to be read by the android device.

2.8 System Interaction with Web Server

For the system to interact with the web server, Every JSON string received from the IoT device is sent to the web server, along with additional data gathered from the mobile device itself. Moreover, the sensor data is downloaded and visualized on the GUI result screen.

2.9 Testing and Calibration

Testing and calibration of the system was carried out in two stages; hardware testing and software testing. Hardware testing involved the testing of all physical hardware including the sensor, power supply and other circuit components. Software testing involved the writing and debugging of the firmware as well as testing of the system using the Blynk android mobile app codes to ensure that everything corresponds to the technical specification of the system.

3. RESULTS AND DISCUSSION

Below are component connections of the air quality system. After connecting all the components according to the schematic diagram, the firmware program was uploaded to the controller. The uploaded firmware allowed the system to communicate and interact with the web server in order to read and send the measured data from the sensors.

After the successful upload of the firmware, power was connected to the DC jack using external DC adaptor. The LCD screen turns-on, showing square boxes. This means that the system is initializing and trying to establish a connection with the Wi-Fi Network.

On successful connection to the network, the system displays the temperature, relative humidity and air quality data as seen in the Figs. 8,9,10,11.

The displayed data seen on the LCD are also sent to a cloud server (Blynk) for access anywhere in the world.

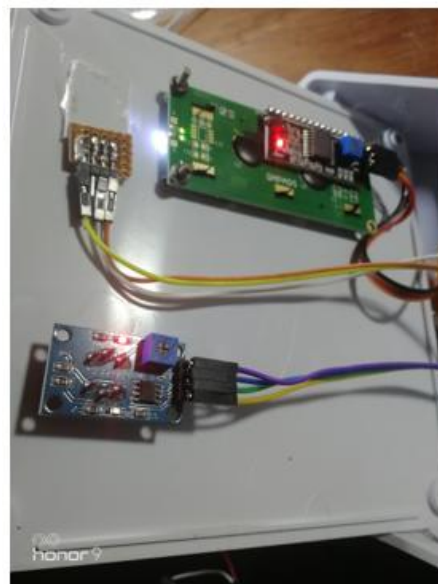

Fig. 5. Inside view of the air quality system

Fig. 6. Inside view of air quality system

Fig. 7. Initialization screen of air quality monitoring system

Fig. 8. Data of Temperature on LCD Screen

Fig. 9. Data of relative humidity on LCD Screen

Fig. 10. Result screen of air quality monitoring system in ppm

Fig. 11. Data of temperature, relative humidity an air quality on mobile app

4. CONCLUSION

A smart air quality monitoring system has been developed for the measurement of Air quality index, as well as relative humidity and temperature. The air quality monitoring system is based on ESP8266 embedded WIFI Module that runs on a 5V DC source. The device takes readings from the MQ135 and DHT11 sensors and sends the data to an android device via Wi-Fi in every 5 seconds, using a third-party mobile App, Blynk. The device sensor detects and measures the air quality index, temperature and relative humidity and communicates with the ESP WIFI module via internet to access the Blynk server so as to display the air quality information. All collected and measured data from the sensors are sent through The Blynk server for easy access. The device supports 16x2 character serial LCD display that displays the sensor data sent to the mobile device through the Blynk Mobile App. A gauge gadget in the Blynk mobile app displays a user-friendly result of the air quality data during operation. The LCD display also shows data sent to the mobile device. The designed system will be useful in monitoring air quality across Nigeria.

ACKNOWLEDGEMENT

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/106071