International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

A Robust IoT-based Air Quality Monitoring Node for Multi-Location Deployment

Reginald Ekene Ogu
Dept of Software Engineering
Federal University of Technology,
Owerri, Nigeria

Gloria A. Chukwudebe
Dept. of Electrical and Electronic Engineering
Federal University of Technology,
Owerri, Nigeria

Ifeyinwa E. Achumba
Dept. of Electrical and Electronic Engineering
Federal University of Technology,
Owerri, Nigeria

Nkwachukwu Chukwuchekwa
Dept. of Electrical and Electronic Engineering
Federal University of Technology,
Owerri, Nigeria

Isaac A. Ezenugu
Dept of Electrical/Electronic Engineering
Imo State University,
Owerri, Nigeria

***Abstract*—The target of monitoring the global air quality is facing challenges as existing IoT devices are handicapped, lacking the ability to be deployed in heterogenous environments. Existing IoT devices can connect to the Internet through a designated wireless network. Thus, becoming unsuitable to monitor environments without the communication network they are designed to connect to. This paper presents the development of an Adaptive IoT Node for Air Quality Monitoring. The IoT node developed herein has the capability to connect to the Internet through WiFi, Bluetooth and mobile networks. This capability makes the node versatile and deployable in heterogenous scenarios. The Arduino MKR 1010 ensures that the system can connect to WiFI and Bluetooth networks while the MKR 1400 enables the IoT node to connect to mobile network. Other support modules and components were connected to the controllers to form a functional system. A suitable dashboard was developed to display the air quality in a user-friendly manner using a combination of JavaScript, CSS and HTML. The developed IoT node was able to upload air quality data to Google Firebase cloud database and the ThingSpeak IoT platform on two separate testing instances.**

Keywords—Environmental management, Hazard Identification, Internet of Things, Pollution control, Sustainable Development

I. Introduction

Air pollution (AP) is a highly rated hazard. The Air Quality (AQ) is directly associated with the human health. Good AQ promotes healthy living and promotes human existence while poor AQ threatens the existence of humans [1]–[5].

Despite the efforts channelled towards improving the air quality, AP is on the increase [6]–[9]. AP increases with increase in productivity level of a society [10]–[12]. Specifically, industrialization and urbanization are the main causes of increased air pollution [2], [8], [13]–[19]. Due to industrialization and urbanization, liquid droplets, solid particles and gas molecules are emitted to the atmosphere to cause pollution [11].

Also, the existence of inadequate scheme and infrastructure for effective waste management in developing countries is contributing to air pollution. This is a serious point because air quality is directly linked to waste management. When a waste substance is improperly managed, it pollutes the air [20], [21].

Today, curbing AP is a serious agenda in the world. Consequently, AQ monitoring has become the subject of many discussions and researches [22]–[26]. The goal is to reduce AP because by improving the AQ, cities can reduce the risks of diseases like stroke, heart disease, lung cancer and other respiratory diseases.This is because poor AQ is attributed to cardiovascular diseases, which accounts for 31.85% of death annually [27]. According to the World Health Organization, 91% of the world population were living in places with poor outdoor AQ as of 2016. AP was estimated to cause more than 3.5 million premature deaths worldwide. AP reduces lifespan by three years [28]. AP has an impact on overall health as well as on the reproductive function [29]. Exposure to air pollution increases the chances of infertility by 20% [30]–[32]. Air pollution affects not only the environment but the body organs and respiratory system as well [26], [33]–[39]. Air pollution is one of the biggest environmental risk to health [40].

91% of the premature deaths occurred in low- and middle-income countries [41]. Particle pollution is known to have many environmental effects from poor visibility to more serious consequences such as acid rain, which pollutes soil and water [42].

AP control cannot be achieved only through social legislations and policies. Over the last few years, the IoT paradigm has evolved as one of the biggest technological advancements [43]. AQ monitoring is an area in which IoT is currently being applied [7]. IoT has become useful through the utilization different kinds of sensors and devices to monitor AQ [44]. It is envisioned that rapid deployment of IoT nodes for AQ will foster the attainment of the United Nations Sustainable Goals (SDGs). Hence the necessity for this research.

The long-term impact of the SDGs is to create a smart world. Target 3.9 of the global goals is predicated on reducing the number of deaths and illnesses that are caused by AP and other hazards. Also, indicator 11.6 is concerned with paying

This work is sponsored by the National Research Fund of the Tertiary Education Trust Fund –TETFund NRF 2019.

attention to air quality and other things, as actions to be taken in the development of sustainable smart cities. Hence, the mitigation of air pollution necessitates accurate air quality monitoring and forecast [19], [46]. Smart Environment Monitoring play an important role in achieving the United Nations Sustainable Development Goals (SDGs) [47]. This research is geared towards the attainment of the Sustainable Development Goals – 3 and 11.

The primary objective of this work is to develop an Adaptive IoT Node that can be deployed in Heterogenous Environments for Air Quality Monitoring to foster the attainment of the sustainable development goals. The IoT node developed herein has the capability to connect to the Internet through Wi-Fi, Bluetooth and mobile networks. This work is a giant in ensuring the rapid development of IoT nodes for AQ monitoring because existing IoT solutions are not suitable to be readily deployed in resource constrained environments where there exists no Wi-Fi network like in the rural places.

The works of [16], [25], [26], [44], [48]–[58] made remarkable efforts towards air quality monitoring. However, the authors could not develop an IoT node with the capability of being deployed in heterogenous scenarios. In plain terms, each of the systems designed a wireless network to connect to the Internet. This fact has made the existing AQ IoT nodes to become handicapped in monitoring the air quality in locations where there is no such network available.

Kumar [59] had identified scalability, modularity, interoperability and openness as key design issues for an efficient IoT architecture in a heterogeneous environment. This implies that IoT architectures must be designed with an objective to fulfil the requirements of cross-domain interactions, multi-system integration with the potentials for simple and scalable management functionalities, big data analytics and storage, and user-friendly applications. Thus, it has become a compelling necessity to develop a versatile AQ IoT node since the existing nodes were proposed without considering the peculiarities of developing countries like Nigeria. Among the peculiarities are unreliable electricity supply and low quality of Internet service. To this end, the IoT node proposed herein considers the two most available network around the globe.

This is because, an AQ IoT node with the capability to connect to more than one form of network will boost the chances of monitoring the air quality around the globe. This will go a long way in the attainment of the sustainable development goals since air quality monitoring is a key indicator of two goals.

II. METHODOLGY

A. System Requirements

The features of air quality monitoring devices stated by [7] were adopted as the requirements for the sensory node developed in this work: low-cost, capability of detecting sufficiently low concentration levels of pollutants, low energy demanding capability, easy to be deployed and silent operation.

This IoT node should be capable to transmit the air quality data to a cloud database using any desired protocol and through any desired Internet connectivity technique.

B. Hardware System Design

With reference to the cost element of the scope triangle, it is practically unfeasible to measure all air pollutants in this research. Hence, the following pollutants are measured in this work: Particulate Matter 2.5, Particulate Matter 10, Carbon II Oxide and Nitrogen IV Oxide. In view of the system requirements above, the block diagram of the IoT node developed in this work is presented in Fig 1.

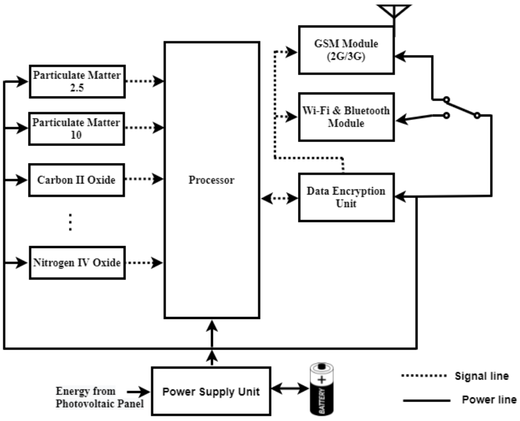

Fig. 1. Block Diagram of the air quality data capturing node.

A 1800mAh Li-Po battery was selected for the system. TP4056 monolithic Integrated Circuit is selected as the charging element for the Li-Po battery. The TP4056 is desired to charge the battery slowly to ensure that the battery life span is not destroyed. Hence, the charge controlled will be programmed to charge the battery with 0.4A. The reason for this choice is because it is not advisable to charge a battery with huge amount of current.

The TPS63805 buck-boost converter integrated circuit is employed to regulate the 3.7V battery voltage to 5V required by the components of the circuit. The choice of the values of the discrete components connected to the above ICs was based on the recommendations in the datasheets.

The DSM501 sensor is employed to measure particulate matter (PM 2.5 and PM 10) while the MICS-6814 module is employed to measure Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2).

The popular Arduino embedded systems development platform was adopted. By this, the Arduino MKR 1010 and Arduino MKR 1400 boards form the hearts of the system. Depending on the environment that the node is to be installed a simple switch is activated to select the available network: Wi-Fi/Bluetooth and mobile network. The circuit diagram of the system is shown in Fig 2.

While the sensors operate on a 5V level, the MKR controllers operates on a 3.3V voltage level and it was recommended that a voltage that is more than 3.3V should not be connected to the pins of the controller. Hence, the addition of voltage divider networks between the sensor outputs and the MKR 1010. By this, resistors R_{10}, R_{11}, R_{12} and R_{13} dorm the upper sides of the networks while R_{14}, R_{15}, R_{16} and R_{17} are the lower side of the voltage divider network.

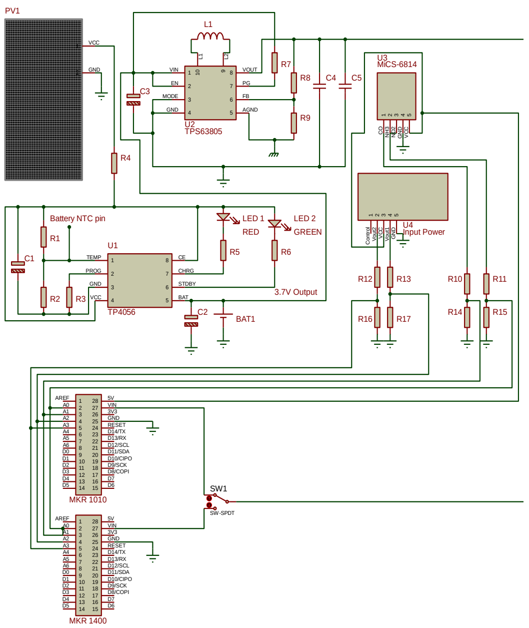

Fig. 2. Circuit Diagram of the air quality data capturing node.

C. *Software System Design*

An embedded system is incomplete without the software component. This is because it is the software the governs the operation of the system. Hence, the system is programmed according to

the flow chart of the Fig 3 is the algorithm of the system under development.

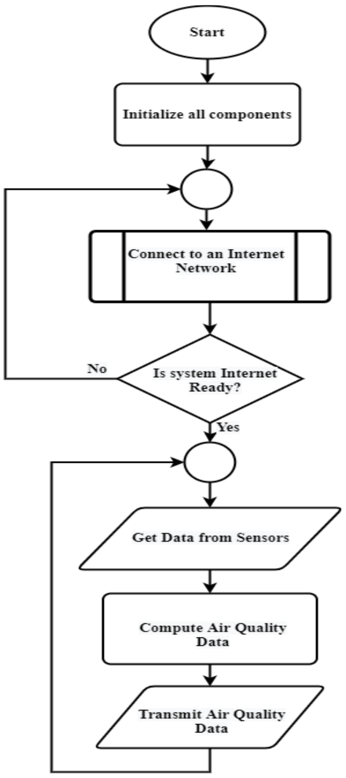

Fig. 3. Algorithm of the system.

The Arduino Integrated Development Environment (IDE) was used in the development of the software for the embedded system. The source code/sketch was written in a mixture of C++ and Arduino Processing Language.

D. *System Testing*

The components of the system were connected as shown in Fig 4, tested and confirmed to be working.

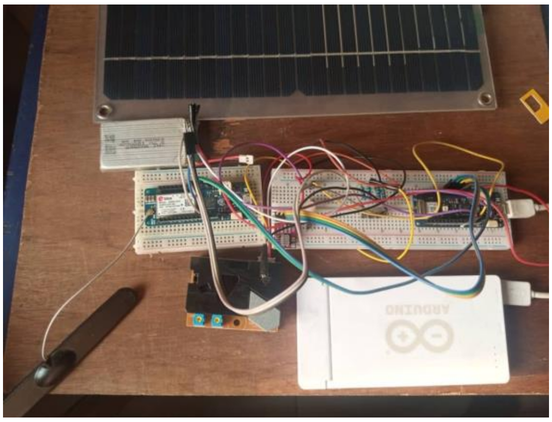

Fig. 4. Experimental set-up of the key components of the node.

III. RESULTS AND DISCUSSIONS

During testing, the AQ node successfully connected to available WiFi, bluetooth and mobile networks as designed. Subsequently, AQ data from the IoT node was successfully transmitted two different cloud databases. Specifically, data was logged to the Google Firebase Cloud database as shown in Fig 5 using WebSocket.

In another test instant, AQ data from the IoT node was successfully logged to the ThingSpeak platform. The dashboard of the ThingSpeak channel (https://thingspeak.com/channels/146226) for the IoT node is shown in Fig 6 while Fig 7 shows a user-friendly dashboard developed in this work for easy visualization of AQ.

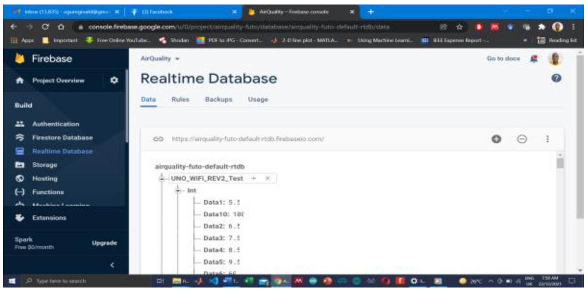

Fig. 5. Snapshot of AQ data readings on the Firebase Database.

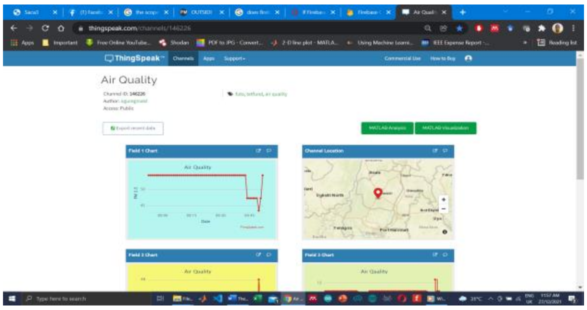

Fig. 6. Dashboard of the ThingSpeak IoT platform.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

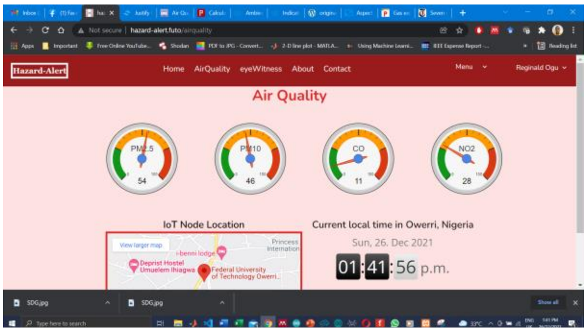

Fig. 7. A User-friendly dashboard for AQ.

The ability of the IoT AQ node to transmit data securely to two different cloud-based databases shows interoperability. Furthermore, the successful tunneling and visualization of the AQ data on a different web application is a further prove of the interoperability inherent among the microservices.

The results clearly proves that IoT nodes connected to any form of Internet ready wireless communication network (WLAN, Bluetooth, LoRa, ZigBee or 2G/3G/4G/5G) can be part of the IoT architecture. As a result of success of using two different communication protocols: REST over HTTP and WebSocket, it means any other protocol can still be used for data transmission to the cloud.

The adoption of REST over HTTP of the ThingSpeak platform is good choice. In as much as data tunnelling through REST over HTTP is characterized by higher latency than Message Queue Telemetry Transport (MQTT), tunnelling AQ data using RESTFUL APIs require less bandwidth as per the findings of [4]. Hence, there is no shortfall to employing REST over HTTP because air quality monitoring is not considered mission critical. Thus, little latency is allowable.

The format of the data stored on the ThingSpeak database is similar to that of [56]. This is because the data transmission protocol employed in the two studies are the same: HTTP (POST) request using necessary APIs. Here, interoperability was achieved through the tunnelling of AQ data as JavaScript Object Notation (JSON) objects to cloud centric databases. According to [60], cloud-based IoT applications help smart cities in gathering data. Thus, this work was geared towards making the world smart by employing microservices based cloud-based databases.

For IoT development, cloud computing provides platforms for storing and processing device data [60]. The application of cloud computing is to make the IoT systems robust and cost effective. The adoption of cloud services ensure that IoT node data and services are available in real-time. Through cloud centric IoT applications, accurate data can be accessed and analyzed to assist experts, businesses, and people in making smarter policies to enhance the standard of peoples' life.

The realization of smart city is promoted through the integration and interoperation of IoT and cloud computing [4]. Through this, there is interactions among different components of the IoT ecosystem assist in improving performance, efficiency, QoS, and intelligent decision-making [61].

Air quality monitoring is an essential feature of smart cities [4]. This approach of this work is in line with state-of-the art practice in IoT development. Remarkably, the ThingSpeak IoT platform employed in this work is among the notable Cloud-Based IoT Solutions mentioned by [60].

The addition of artificial intelligence to the architecture proposed in this work covers the phase two (data tracking and analytics) and three (analysis of data using machine learning) stated among the six-phases of the start-up model for the development of a smart city by [60].

The approach towards the implementation of the components of the IoT architecture in this work was simple as recommended by [61]. The reason for being simple was to create a foundation through which future development can be made and scalability of the entire IoT ecosystem being easy to do.

IV. Conclusion

This work has been able to achieve its primary objective of developing an adaptive IoT Node in Heterogenous Environments for Air Quality Monitoring as an enablement for the attainment of the SDGs. Specifically, an AQ node capable for connecting to the Internet using Wi-Fi, Bluetooth and mobile network (2G/3G) was proposed and prototyped. In addition, a web dashboard was developed based to serve as the user interface.

To this end, this research has made a remarkable effort towards the attainment of the United Nation Sustainable Development Goals (UN SDGs) by developing a system that can be easily deployed in many locations to measure air quality which is a key indicator to SDGs 3 and 11.

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