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Development of an IoT based Air Quality Instrument Suitable for Profiling Particulate Matter (PM) Distribution across Nsukka using a PMS5003 and DHT11 Digital Sensors

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Abstract
Informed knowledge on the distribution of dust particles and humidity variations across certain geographical location offers innumerable benefits to humanity. Such information could guide astronomers to make informed decision when locating or carrying out their optical observation; Medical professionals can monitor and predict trends in lung and cardiovascular related diseases, and other host of professions that might find such information invaluable. The work presents the indigenous development of network of Air Quality data loggers that monitors the distribution of PM based on wide range of diameter sizes in microns across a certain geographical distance within the country. The network comprised of a number of standalone sub-stations each of which is a microcontroller-based instrument that incorporates PMS5003 and DHT digital sensors for obtaining metrological parameter, SIM module for cloud-based data storage, and other peripherals for optimal performance. The network features a centralized cloud-based data repository from each of the respective locations of these sub-stations. These data can be used for onward scientific analysis and metrological prediction.

Keywords: Air Quality, Cloud-based, Microcontroller, Particulate Matter

1. Introduction

Clean air is a fundamental necessity for human health and environmental well-being. Air pollution, particularly the presence of Particulate Matter (PM) has become a global concern due to its adverse effects on public health [1], climate change [2] and ecosystem integrity [3]. In many countries including Nigeria, air quality monitoring is crucial to assess the level of pollution, understand its sources and implement effective mitigation strategies. Nigeria with its rapidly growing population and urbanization is facing increasing challenges related to air quality [4], making it imperative to establish a robust and efficient IoT based monitoring system.

The measurement of PM in the air is essential because it consists of tiny solid or liquid particles suspended in the atmosphere [5]. These particles can be inhaled, leading to various health problems including respiratory diseases, heart diseases and even premature death. In Nigeria, the health consequences of poor air quality are evident and the need for accurate monitoring and reporting of PM levels is pressing [6]. However, existing air quality monitoring systems are often sparse, expensive and concentrated in urban areas, leaving many regions without adequate coverage. This deficiency underscores the importance of developing affordable and accessible air quality instruments that can be deployed widely in rural and less-developed areas [7].

In this context, the Internet of Things (IoT) presents a promising solution for improving air quality monitoring. IoT enables the collection, transmission and analysis of real-time data, making it an ideal platform for creating a network of air quality monitoring devices across Nigeria. This network can provide comprehensive insights into PM distribution, contributing to informed decision-making and policy development. To this end, this paper introduces the development of an IoT-based air quality instrument that employs the PMS5003 and DHT11 digital sensors to profile Particulate Matter distribution across Nigeria.

2. Background

2.1 Air Quality Monitoring in Nigeria

Nigeria, the most populous country in Africa is experiencing rapid urbanization and industrialization. This has led to increased emissions of air pollutants, primarily originating from energy production, transportation and industrial activities [8]. Major Nigerian cities, such as Lagos, Port Harcourt, Onitsha, Kaduna and Kano frequently experience poor air quality, which adversely affects the health of the population [9]. The deteriorating air quality in Nigeria is further exacerbated by factors like deforestation [10], open burning of waste and the harmattan season, characterized by dust storms and low humidity [11].

Air quality monitoring in Nigeria, however, has been limited in both scale and coverage. While some cities have established monitoring stations, they are often located in urban areas, leaving rural and peri-urban regions underserved [12]. Moreover, the existing monitoring infrastructure faces challenges in data acquisition, transmission and accessibility [13], hindering timely reporting and public awareness. Inadequate air quality information compromises the ability of health professionals, policymakers and the public to respond effectively to air pollution-related health risks [14].

2.2 The Promise of IoT for Air Quality Monitoring

IoT technology is suitable for addressing the challenges of air quality monitoring in Nigeria. IoT encompasses a network of interconnected devices that collect and transmit data to a central server or cloud-based platform [15]. These devices, often equipped with various sensors, which can monitor air quality parameters, including PM levels, temperature, humidity and gases. The real-time data obtained from IoT-enabled air quality instruments can be accessed and analyzed remotely, providing stakeholders with the information needed to make informed decisions and implement air quality management measures [16].

The adoption of IoT for air quality monitoring offers several advantages such as real time data, wide coverage, cost efficiency, data accessibility, remote management, scalability. IoT networks can be expanded and adapted to evolving monitoring needs, making them highly scalable [17].

To harness the benefits of IoT technology for air quality monitoring in Nigeria, the development of an affordable, reliable and scalable air quality instrument is essential. This paper proposes the use of the PMS5003 and DHT11 digital sensors in an IoT-based instrument for profiling PM distribution.

2.3 The PMS5003 and DHT11 Sensors

2.3.1 PMS5003 Sensor

The PMS5003 sensor, produced by Plantower Technology is a compact and efficient sensor designed for the precise measurement of Particulate Matter (PM) concentrations in the atmosphere [18]. It uses laser scattering to determine the concentration of PM1.0, PM2.5 and PM10 particles, providing real-time data on these particulate sizes. The PMS5003 sensor is highly regarded for its accuracy, reliability and ease of integration, making it a suitable choice for air quality monitoring applications [19]. The PMS5003 sensor offers several key features such as Laser Scattering, Real-Time Data, High Precision and Compact Design.

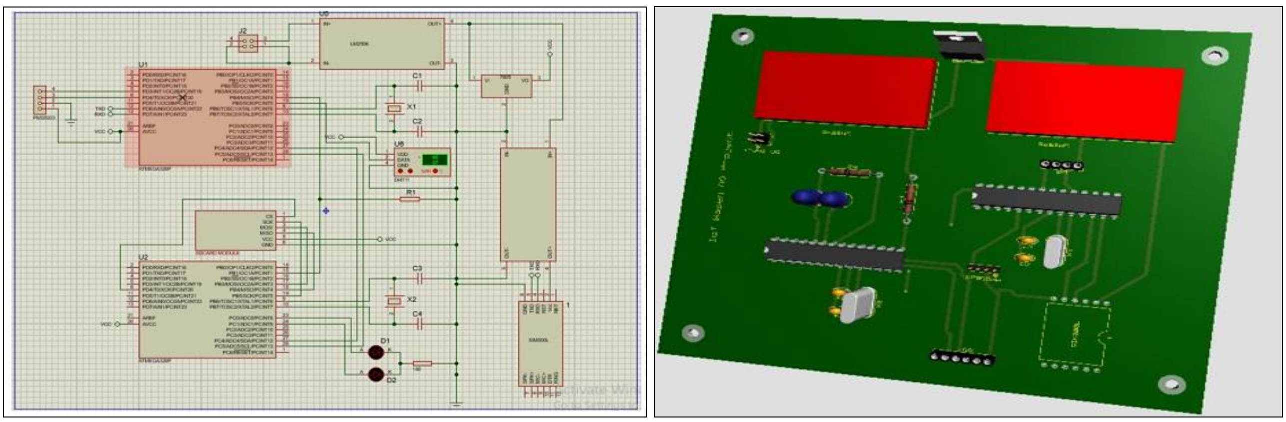
2.3.2 DHT11 Sensor

The DHT11 sensor is a cost-effective and widely used digital sensor for measuring temperature and humidity [20]. Developed by Aosong Electronics, this sensor is popular in IoT applications due to its simplicity, affordability and ease of use. In air quality monitoring, temperature and humidity data are crucial as they can affect the behavior and dispersion of PM in the atmosphere. The DHT11 sensor offers the following features such as Temperature and Humidity Measurement, Digital Output, Low Cost and Simplicity [21].

3. System Development

3.1 Design Tools/Material Consideration

The system was developed using both Hardware and Software design tools. The hardware tool consists of various electronic component parts, plastic casing, and mount/ Installation structure. Various software tools were used in developing this system. The microcontrollers that were used for the work were programmed using arduino language. The control board circuitry was developed in Proteus Application environment. Fig 1 presents the systems' design (Schematics and 3D render) in Proteus application environment.



(a) (b)

Fig 1: Proteus Development environment

3.2 Experimental Setup

The system is made up of four units viz: The Coordinating unit, the Sensory unit, the Data storage unit and the Power unit.

The Coordinating unit comprised of two ATmega328P-PU microcontrollers that communicates with each other using I2C communication protocol. This protocol uses a two-wire communication channel – Serial clock (SCL) and Serial data (SDA) – that allows connection of multiple addressable devices that share information across the channel. These controllers have their respective functions. One of the controllers (MCU A) is responsible for reading parametric values from the sensory unit, making these data available to the SIM module for onward push to cloud for storage and also available to the second controller via the I2C bus for onward storage to the local memory. The second controller (MCU B) is responsible for the on-premise storage feature.

The Sensory unit is made up of the PMS5003 and DHT digital sensors. The PMS5003 sensor measures PM1.0, PM2.5 and PM10 concentrations through laser scattering, while the DHT11 sensor monitors temperature and humidity levels. Both are connected to the Input/Output (I/O) pins of the MCU A.

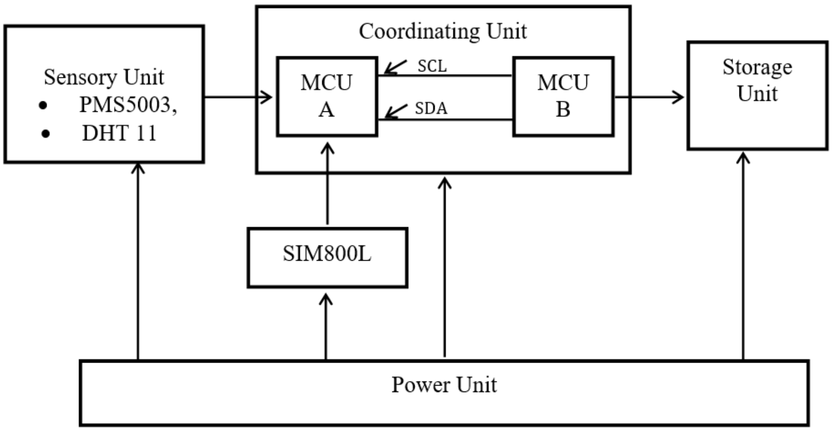


Fig 2: System Architecture

The Storage unit comprised majorly of a Secured Data (SD) card module for the local storage.

The Power unit is a configuration that provisioned power across these units from an 18VDC 20W solar system with a series-parallel cascade of lithium-ion battery bank to ensure power reliability of the system.

3.3 Operational Procedure

The operation of the system can be expressed with the aid of a flowchart as shown in Fig 3. When initialized, the system obtains the parametric values and proceeds to store these values to cloud and the local storage for further scientific purposes.

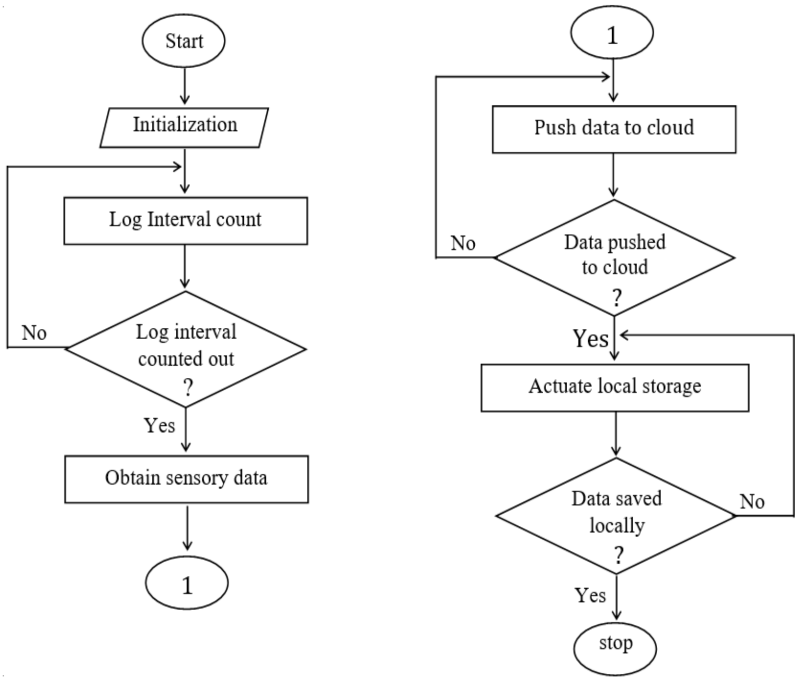


Fig 3: Operational flowchart

3.4 IoT Connectivity

The instrument is equipped with IoT capabilities to enable real-time data transmission and remote access. A Sim800L wireless communication module was integrated to the system to transmit parametric sensor data to a central server or cloud-based platform. This allows for continuous monitoring and access to data from remote locations.

3.5 Power Supply

An efficient and reliable power supply is essential for the continuous operation of the IoT-based air quality instrument. The system draws its power from 18VDC 20W solar system. A maximum power point tracking (MPPT) module was integrated to the system to ensure effective charging of the lithium-ion battery bank at varying weather conditions.

4. Performance Result

A well-labeled pictorial design outlook of the system is as shown in Fig 4 followed by screenshots of performance analysis results outlook on ThinkSpeak cloud services website [22].

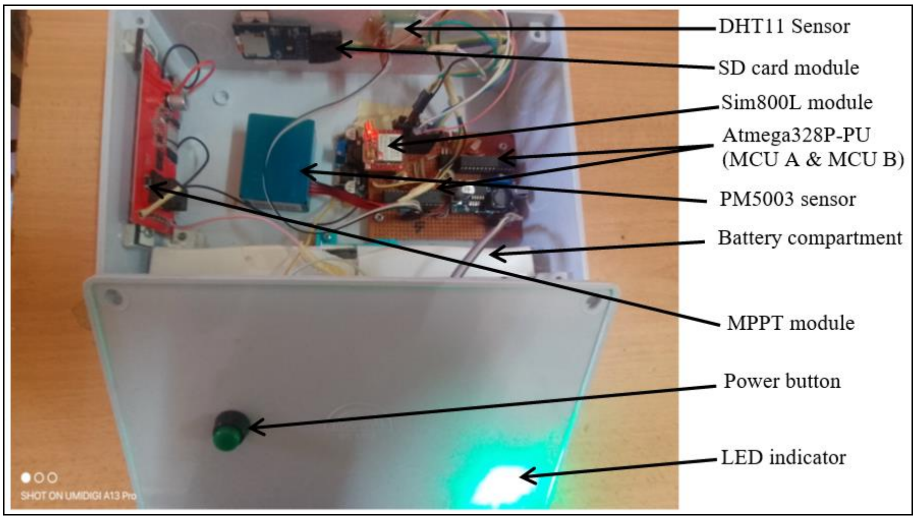
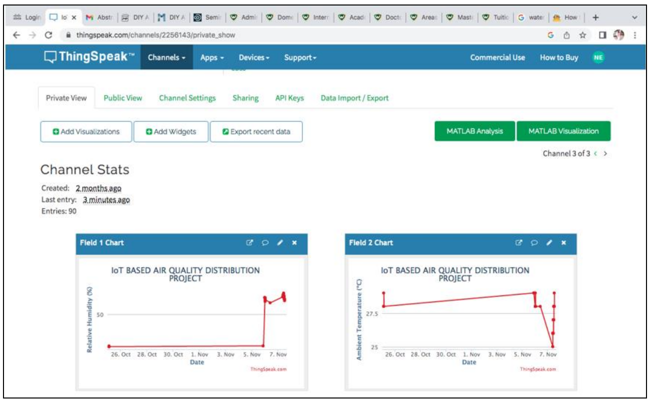


Fig 4: Low-cost IoT based Air Quality device

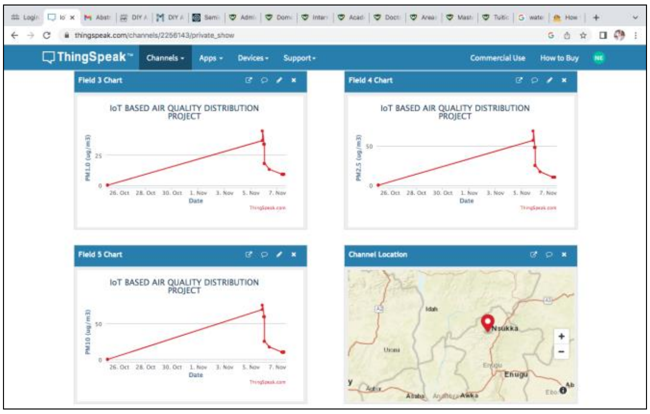
The ThingSPeak channel was created on 25th of October 2023 but no parametric data was uploaded to it until 6th of November 2023. So, the actual sensor values as can be seen from the performance graph started on 6th through 7th November 2023.

The result obtained from the one-day performance evaluation showed that the system can successfully obtain PM parametric data (PM1.0, PM2.5 and PM10), relative humidity data and ambient temperature data from the deployed location, push this information to ThingSpeak cloud, generate their real-time performance analysis plot, and also attach the coordinate location map of the deployed system.

However, more work still needs to be done to improve the energy efficiency of the device. This would ensure sustainable power supply even on a stretch of some cloudy days. This would probably be presented in subsequent work on optimizing the performance of the system.



(a)



(b)

Fig 5: System performance outlook on ThingSpeak cloud platform

5. Conclusion

Air quality monitoring is crucial for assessing the health and environmental impacts of air pollution. In Nigeria, the need for effective, affordable, and widespread air quality monitoring is particularly pressing due to rapid urbanization and industrialization. This work presented the development of IoT-based air quality instrument that employed PMS5003 and DHT11 digital sensors, and other necessary components. The system offers a promising solution to profile Particulate Matter distribution across Nigeria. This distribution information offers several significant advantages such as identifying the source of pollution, localization of the health impact, monitoring of seasonal trends, ensuring regulatory compliances, engaging communities in air quality awareness, and a host of others.

Importantly too, the work will assist stakeholders and policy makers in Nigeria to make an informed decision policies that would ensure Responsible Research Innovations (RRI) that will consider public health, and take effective measures to combat air pollution.

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