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Internet of Things (IoT) Based Real-Time Pollution Monitoring System for Awka Metropolis

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ABSTRACT

Internet-of-Things (IoT), the interconnected networks of millions of smart and intelligent objects, machines, sensors, actuators have evolved in solving myriads of problems in different human domains. Of recent is the proliferation of IoT paradigm in environmental monitoring systems such as air and sound quality of smart cities. Sensors can be used to monitor the thresholds of air pollution in an environment in real time in such a manner that the real-time data from the environmental sensors can be transmitted directly to an online internet cloud server and then to end-users via desktop computers or mobile devices. This will enable citizens and city administrators to know when thresholds of air pollution are exceeded that are dangerous to health of the inhabitants of the city. In this paper a real-time air and sound pollution monitoring system was designed using an open source system known as Smart Citizen Kit (SCK) which allows citizens in different countries of the world to monitor their environments for air and sound pollution levels in order to determine the air quality and concentration of pollutants that exceeds the benchmark thresholds that are harmful to human health and environment via an intelligent real-time cloud-based server or station. The various air pollutants such as particulate matters (PM1.0, PM2.5 and PM10) as well as green house gas carbon dioxide (CO2), Total Volatile Organic Compounds (TVOCs) such as organic gases, benzene, toluene, etc. as well as weather or meteorological parameters such as air temperature, biometric pressure (BP), relative humidity (RH) and light intensity (LI).

The system has the capability to capture sensor readings/dataset online and stored in flash memory, SD card and can be retrieved as historical dataset in .CSV format for further machine learning modeling and statistical analysis. The system was deployed outdoor and experimental and implementation results showed that the proposed IoT based pollution monitoring solution produced reasonable sensor readings for different locations within Awka Metropolis. The maximum Relative Humidity (RHMAX=86.81%), minimum Relative Humidity (RHMIN =29.13%), Average Relative Humidity, RHAVG = 71.68% while Air Temperature (AT) readings give maximum AT (ATMAX=56.86 OC), minimum AT(ATMIN=25.35OC, average AT (ATAVG=31.91OC). For Barometric Pressure (BP) sensor readings: maximum BP, BPMAX=100.91KPa, minimum BP, BPMIN=100.31KPa and average BP, BPAVG=100.59 KPa. Equivalent Carbon dioxide (eCO2) readings give maximum value=2506 PPM, minimum eCo2=400 PPM and average eCO2=644.01 PPM. For Total Volatile Organic Compounds emission (TVOC), the maximum reading=1794 PPB, the minimum value =0 PPB and the average value=48.1696 PPB. For Light intensity, the maximum value is 50,700 lux, the minimum value is 0 lux and the average value is 2305.73 lux. For particulate matter emissions, PM1, the maximum value is 41µg/m3, the minimum value is 0 µg/m3, the average value is 5,192µg/m3. .Particulate matter emission PM2.5, the maximum sensor reading is 72µg/m3, the minimum sensor reading is 0 µg/m3 and the average sensor reading is 8.490µg/m3.. The particulate matter emission PM10, the maximum, minimum and average sensor readings are respectively 76µg/m3, 0µg/m3 and 9.542µg/m3. The sensor readings for Noise pollution are 90.47 dB, 35.91dB and 50.58dB respectively.

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1. INTRODUCTION

Air pollution is one of the major problems of major urban areas, cities and metropolis in developing and industrial countries, especially where air quality measuring and monitoring systems or measures are not are not available or implemented. In such places, citizens are exposed to the dangers of various types of air pollutants that are dangerous to health and environment. According to [1], it is estimated that about 91% of the world's population live in places where air quality exceeds World Health Organization (WHO) thresholds or guidelines, and that about 4.2 million deaths occur every year as a result of direct exposure of citizens to both ambient (outdoor) and indoor air pollution. Life-threatening health challenges and diseases such as cardiovascular and respiratory diseases can be contracted or aggravated as a result of chronic exposure to air pollutants; these diseases have the capacity to increase the risk of cardiovascular and respiratory mortality and morbidity, while acute short-term inhalation of pollutants can induce changes in lung function and the cardiovascular system exacerbating existing conditions such as ischemic heart disease. Respiratory diseases such as Chronic Obstructive Pulmonary Disease (COPD), Asthma, Bronchiolitis, and also lung cancer, cardiovascular events, central nervous system dysfunctions, and cutaneous diseases are all caused by these air pollutants [2]. Air pollution affects world's climate changes radically which in turn increases premature deaths and diseases among humans. Air pollutant such as carbon dioxide (CO2) and ozone (O3) causes earth's global warming and terminal diseases such as cancer. Air pollutants such as carbon monoxide (CO) can even provoke direct poisoning when breathed in at high levels. Air pollutants such as nitrogen oxide, sulfur dioxide, Volatile Organic Compounds (VOCs), dioxins and polycyclic aromatic hydrocarbons (PAHs) are very harmful to human health such as DNA damage and genomic instability in lung epithelial cells [3].

Air quality monitoring and control is an essential part of the concept of smart city which is becoming the standard worldwide to which both developing and developed countries aspire to achieve and have. Recently, many of the world governments and city administrators have deployed and implemented air pollution monitoring stations or sub-stations which have the capacity to monitor and manage air pollutants concentrations within the city and make the sensor data available publicly via open-connected networks and cloud servers. This is achievable as a result of the proliferation of IoT systems and technology in the world.

The purpose of this research study is to build and implement a reliable, low-cost, real-time, open-source IoT-based air and sound pollution monitoring sub-station for Awka Metropolis to monitor and capture the levels of air pollutants in Awka Metropolis and to generate historical dataset that will be used to build an efficient air quality prediction/forecasting model for Awka using machine learning (ML) algorithms. Invariably Awka which is a growing and populated city and administrative capital of Anambra State of Nigeria has no single air pollution monitoring station in use to date.

1.1. Impacts of Meteorological Parameters on Air Quality Index (AQI)

The concentration of air pollutants in the atmosphere or ambient environment is affected directly by the presence of meteorological parameters such as atmospheric or air temperature, pressure, wind speed, wind direction, light intensity or Ultra Violet radiation, relative humidity and even precipitation or rainfall.

Air pollutants are being dispersed or emitted into the atmosphere from different variety of sources. The concentration of air pollutants in the atmosphere or ambient environment is directly dependent on two factors – the quantities that are released into the atmosphere as well as the ability of the atmosphere to absorb or disperse these air pollutants.

Understanding the behavior of meteorological parameters in the boundary layer is very important because the atmosphere is the medium in which air pollutants are transported away from the source.

The atmosphere is controlled by the meteorological parameters such as atmospheric air temperature, relative humidity, wind speed, wind direction, precipitation or rainfall etc. The pollution concentration in an urban area or metropolis is a direct correlation or relationship with parameters such as mixing depth, wind speed, and physical size of the city. The average windspeed varies depending on the location or time of the day or the month of the year. The average wind speed in the afternoon may be different from that of night or morning. The average wind speed during Harmattan by December/January cannot be the same with the average windspeed during months of rainy season. In this paper the meteorological or weather variables used include air temperature, barometric pressure, light intensity (UV radiation), and relative humidity (RH).

2. REVIEW OF RELATED WORKS

Authors in [4] proposedan IoT based air and noise pollution detection system in an Indian city, to detect and monitor harmful gases in the atmosphere such as

Ammonia (NH3), alcohols, benzene, smoke and carbon dioxide. Arduino Uno open source board with Atmega128P microcontroller as well as MQ-135 gas sensor was used to build the system. LM393 Sound Sensor was used to measure the levels of noise pollution in the atmosphere. Wi-Fi connectivity module ESP8266 was used to transmit the sensor readings and air pollutant data to the internet cloud server. The sensor readings were also displayed using 16X2 LCD module. The experimental results showed good sensor readings for the project.

Authors in [5] designed an IoT air and sound pollution monitoring system to detect dangerous and poisonous chemicals such as Ammonia (NH3), benzene; smoke and carbon dioxide (CO2) using air pollution sensors. The system was also designed to continuously monitor sound levels and activates a buzzer if the sound level exceeds the set threshold. Experimental results showed the objectives of the air and sound monitoring system was achieved.

Authors in [6] developed an IoT based Air Pollution monitoring system using Arduino Uno open source board and ATmega328 microcontroller. The system deployed MQ-135 gas sensor to detect and measure Ammonia (NH3), Nitrogen Oxide (NOX), Alcohols, Benzene (C6H6), smoke and carbon dioxide (CO2). The ESP8266 Wi-Fi module was used to establish wireless connection between the devices. The system was connected to open source cloud server, ThingSpeak, to store and visualize the sensors' data on real time. The system worked well but has several shortcomings – only one sensor, MQ-135, was used to monitor and detect several gases at the same time. The MQ-135 sensor cannot measure each of the pollutant gas distinctly and clearly without some supporting gas sensors. Particulate matters were also not considered by this system. Also, there was no effort to backup the supply using solar energy in order to support the battery energy of the system.

Authors in [7] proposed and implemented an IoT Enabled Air Pollution monitoring and Awareness Creation system. The system used Arduino Uno board and ATMega328 microcontroller integrated with Gas sensors – MQ-135, MQ-7, MQ-2, particulate matter sensor DSM501A and a humidity sensor to detect and measure hazardous gases such as Ammonia, Carbon Monoxide (CO), Methane (CH4), smoke, etc. as well as particulate matter (PM2.5) floating in the air. An Ethernet shield was connected to the Arduino Uno microcontroller to connect the sensors' data to an open source cloud server, ThingSpeak, for storage and visualization by Android users. The results of the experiment seem okay as visualized via Android App and Arduino Ethernet shield. The system did not detect and measure other poisonous gases such as SO2, NO2, Ozone (O3) and other particulate matters such as PM1.0 and PM10. There was no power backup such as solar to support the battery power used by the system as power supply.

Authors in [8] proposed a Smart Industrial Pollution Monitoring system using IoT. The system used Arduino Uno based open source board and ATMega328 microcontroller to interface about five sensors- MQ-7, M213, LM35, SY-HS220 and LDR to measure and detect Carbon Monoxide (CO), Noise, temperature, Relative humidity and light intensity respectively of an ecological environment. The Arduino Uno board and microcontroller were connected to a Wi-Fi module, ESP8266, to send the sensors' data to an internet web page. The system integrated several pollutant sensors but still left out the major industrial pollutant gases such as CO2, NO2, O3, SO2 and particulate matters. The system did not mention how the sensors' data was deployed to a cloud server. The security of the sensors' data was not also considered in this system.

Authors in [9] proposed and developed a real-time IoT based Air and Noise Pollution Monitoring system to measure and detect air and noise pollution in an area and alert relevant authorities when there is a breach of the standard thresholds. The system employed Arduino Uno board and ATMega3280 microcontroller for data processing and to interface about five sensors- MQ-135 gas sensor, KY038 noise sensor and DHT11 temperature sensor. The software sub-system of the system was developed using Arduino IDE V1.85, NETBEANS IDE and MySQL DBMS to test the sensors' data. The experiment posted good results in the test environment and Google Map. However, the authors have did not test the system on a live cloud server in real-time. Equally, the MQ-135 gas sensor was not adequate to cover the entire spectrum of pollutant poisonous gases such as CO, SO2, NO2, O3, etc.

3. METHODOLOGY

This section describes the methodology that was used to design, build and implement the real-time air and sound pollution monitoring system for Awka Metropolis. The methodology was in two parts- hardware and software implementation.

3.1. System Architecture

The system is composed of several hardware and software sub-systems that work together and each subsystem is dedicated to different system objective. The hardware sub-system consists of the Smart Citizen Kit (SCK) Main Board and Urban Sensor board. The Main Board consists of the Wi-Fi internet module, Flash disk, microcontroller and connectors to the Urban Sensor Board, etc. The Urban Sensor Board consists of all the air pollutant and weather sensors and the connector for particulate matter sensor that measures PM1, PM2.5 and PM10. The hardware sub-system also contains the power supply unit. The software sub-system consists of Smart Citizen Cloud server known as the Smart Citizen Station (SCS) and the **Smart** Citizen Mobile App. The working principle or methodology of the system architecture is presented in Fig.1.

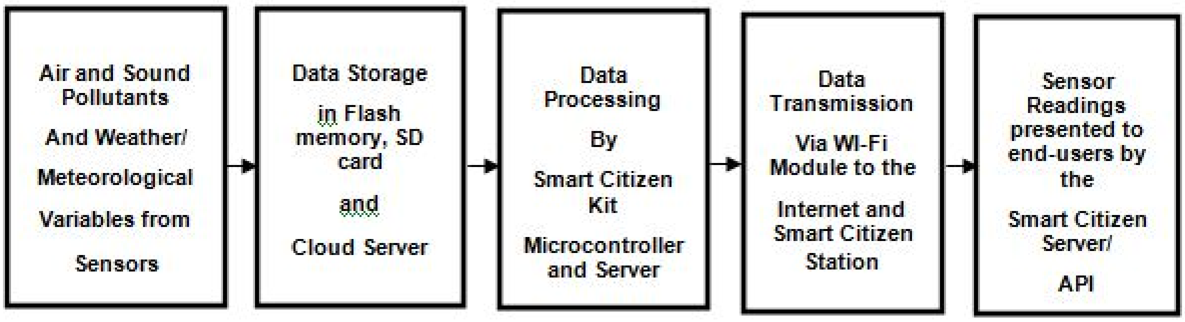


Fig 1 The Working methodology of the proposed Awka Metropolitan Pollution monitoring system

Fig 2 The Urban Sensor Board and Particulate matter sensor (PMS 5003) on breadboard

Fig 3 The Air and Sound Pollution Monitoring System packaged in a IP66 enclosure

Experimental Setup

The proposed Awka Pollution Monitor was implemented using the Smart Citizen Kit (SCK) to measure and sample several air pollutants, sound and weather parameters such as equivalent carbon dioxide, (CO_2), Total Volatile Organic Compounds (TVOC), particulate matters (PM1, PM2.5, PM10), Noise as well as weather parameters such as air temperature and barometric air pressure and Light Intensity, timestamp and battery levels of the system were also monitored and captured. The system was packaged in IP66 weather/water proof casing, preventing it from being affected by dust, humidity and rainwater during outdoor deployment for three consecutive days. A Wi-Fi 4G Mifi Router was setup and used to connect the system to Smart Citizen Station/Platform online. The power supply of 5V DC using a lithium polyphosphate battery of 2200mAh was used to power the system; the battery was backed up with a 20,000mAh rechargeable solar power bank. The lithium rechargeable battery of the Smart Citizen Kit can last up to 8 days for full deployment but with the 20,000mAh 5V powerbank it can last for several weeks when deployed outdoor for monitoring. It can also be supported with 5V Solar panel to increase the duration of outdoor deployment. The packaging of the system for Awka Sound and Air Pollution Monitoring was done using breadboard for testing and IP66 enclosure for final deployment are depicted in Fig.2 and Fig.3 respectively.

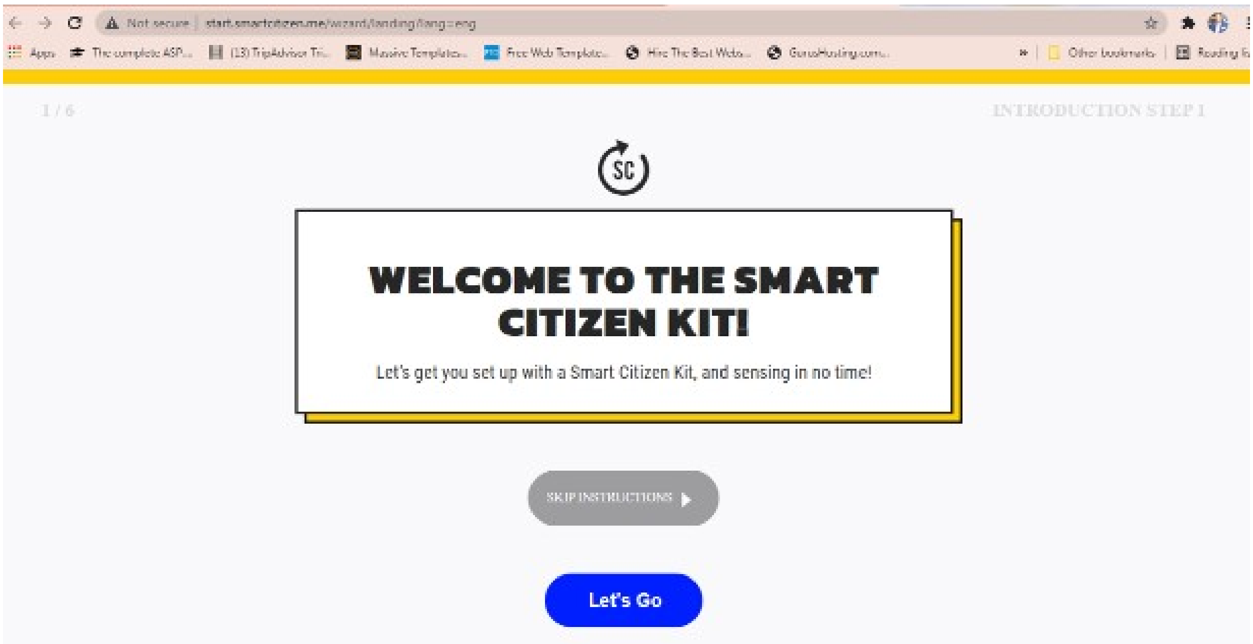


Fig 4 The first step of the on boarding process of the Smart Citizen Kit

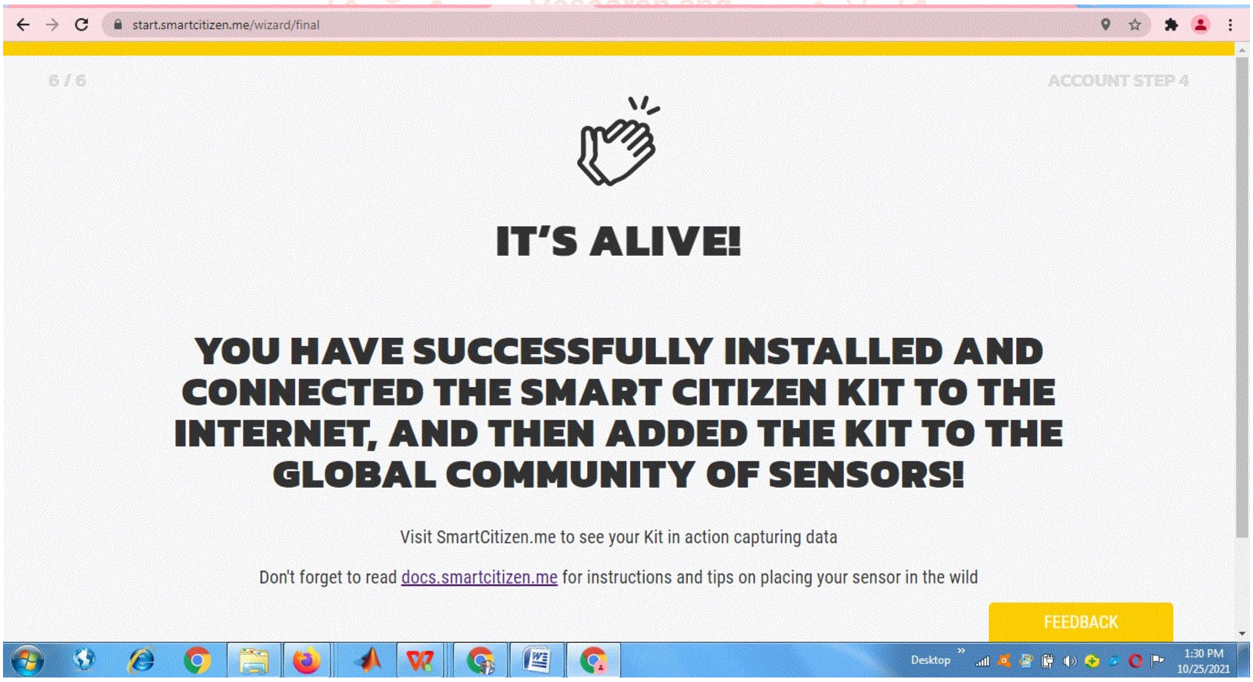
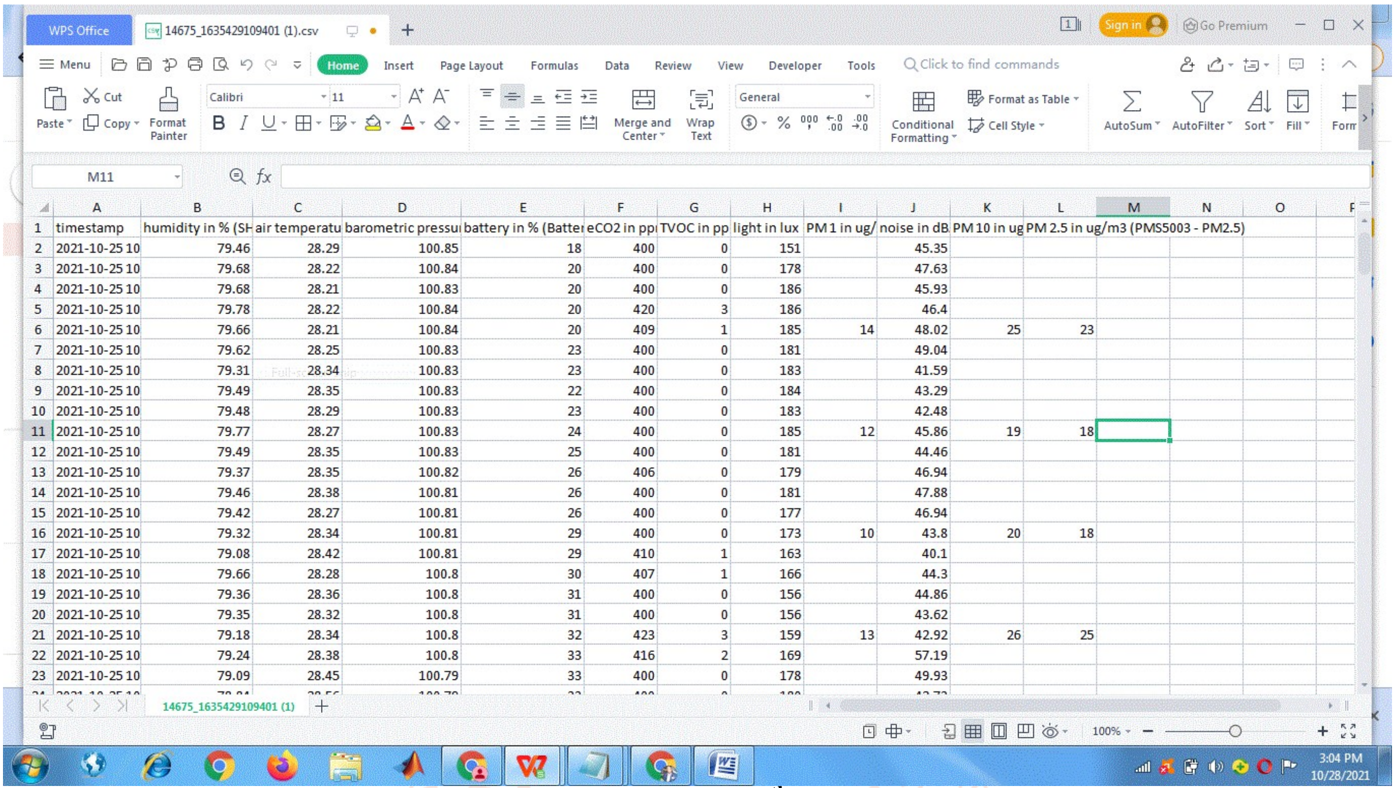


Fig 5 Screenshot of successful on boarding or connectivity of Awka Pollution Monitor Smart Citizen Kit to the World Community of Sensors

4. RESULT AND DISCUSSION

4.1. Data Acquisition/Sensor Readings

The sensors in the system were calibrated and deployed outdoor for real-time air and sound pollution measurements/monitoring. After three days of continuous taking of sensor readings, the following results were obtained as shown in Fig.13 which consists of about 1550 dataset samples of one minute sensor readings. The air quality sensors sample readings every 60s while the particulate matter sensors give readings every 5-7 minutes depending on the Wi-Fi network availability. The sampling interval of the sensors can be reconfigured to give the same or different reading intervals as desired. The sensor readings consist of the following features or fields- timestamp, humidity, air temperature, barometric pressure, battery level, eCO_2, TVOC, light intensity, PM_1, Noise, PM_{10}, $PM_{2.5}$ in that order as shown in Fig.6.



timestamp	humidity in % (SH	air temperatu	barometric pressu	battery in % (Batter	eCO2 in pp	TVOC in pp	light in lux	PM 1 in ug/	noise in dB	PM 10 in ug	PM 2.5 in ug/m3 (PMS5003 - PM2.5)
2021-10-25 10	79.46	28.29	100.85	18	400	0	151		45.35		
2021-10-25 10	79.68	28.22	100.84	20	400	0	178		47.63		
2021-10-25 10	79.68	28.21	100.83	20	400	0	186		45.93		
2021-10-25 10	79.78	28.22	100.84	20	420	3	186		46.4		
2021-10-25 10	79.66	28.21	100.84	20	409	1	185	14	48.02	25	23
2021-10-25 10	79.62	28.25	100.83	23	400	0	181		49.04		
2021-10-25 10	79.31	28.34	100.83	23	400	0	183		41.59		
2021-10-25 10	79.49	28.35	100.83	22	400	0	184		43.29		
2021-10-25 10	79.48	28.29	100.83	23	400	0	183		42.48		
2021-10-25 10	79.77	28.27	100.83	24	400	0	185	12	45.86	19	18
2021-10-25 10	79.49	28.35	100.83	25	400	0	181		44.46		
2021-10-25 10	79.37	28.35	100.82	26	406	0	179		46.94		
2021-10-25 10	79.46	28.38	100.81	26	400	0	181		47.88		
2021-10-25 10	79.42	28.27	100.81	26	400	0	177		46.94		
2021-10-25 10	79.32	28.34	100.81	29	400	0	173	10	43.8	20	18
2021-10-25 10	79.08	28.42	100.81	29	410	1	163		40.1		
2021-10-25 10	79.66	28.28	100.8	30	407	1	166		44.3		
2021-10-25 10	79.36	28.36	100.8	31	400	0	156		44.86		
2021-10-25 10	79.35	28.32	100.8	31	400	0	156		43.62		
2021-10-25 10	79.18	28.34	100.8	32	423	3	159	13	42.92	26	25
2021-10-25 10	79.24	28.38	100.8	33	416	2	169		57.19		
2021-10-25 10	79.09	28.45	100.79	33	400	0	178		49.93		

Fig 6 Sensor data captured from October 27, 28 and 29th 2021 by Awka Pollution Monitor using the Smartcitizen kit setup in .csv

The system was deployed outdoor and experimental and implementation results showed that the proposed IoT based pollution monitoring solution produced reasonable sensor readings for different locations within Awka Metropolis. The maximum Relative Humidity (RH_{MAX}=86.81%), minimum Relative Humidity (RH_{MIN} =29.13%), Average Relative Humidity, RH_{AVG} = 71.68% while Air Temperature (AT) readings give maximum AT (AT_{MAX}=56.86 ^{O}C), minimum AT(AT_{MIN}=25.35^{O}C, average AT (AT_{AVG}=31.91^{O}C). For Barometric Pressure (BP) sensor readings: maximum BP, BP_{MAX}=100.91KPa, minimum BP, BP_{MIN}=100.31KPa and average BP, BP_{AVG}=100.59 KPa. Equivalent Carbon dioxide (eCO_2) readings give maximum value=2506 PPM, minimum eCo_2=400 PPM and average eCO2=644.01PPM. For Total Volatile Organic Compounds emission (TVOC), the maximum reading=1794 PPB, the minimum value =0 PPB and the average value=48.1696 PPB. For Light intensity, the maximum value is 50,700 lux, the minimum value is 0 lux and the average value is 2305.73 lux. For particulate matter emissions, PM_1, the maximum value is 41$\mu g/m^3$, the minimum value is 0 $\mu g/m^3$, the average value is 5,192$\mu g/m^3$. Particulate matter emission $PM_{2.5}$, the maximum sensor reading is 72$\mu g/m^3$, the minimum sensor reading is 0$\mu g/m^3$ and the average sensor reading is 8.490$\mu g/m^3$. The particulate matter emission PM_{10}, the maximum, minimum and average sensor readings are respectively 76$\mu g/m^3$, 0$\mu g/m^3$ and 9.542$\mu g/m^3$. The sensor readings for Noise pollution are 90.47 dB, 35.91dB and 50.58dB respectively.

Fig.7 depicts the real-time sensors' readings displayed in the Smart Citizen Station (SCS) Cloud server showing map of Awka, Nigeria.

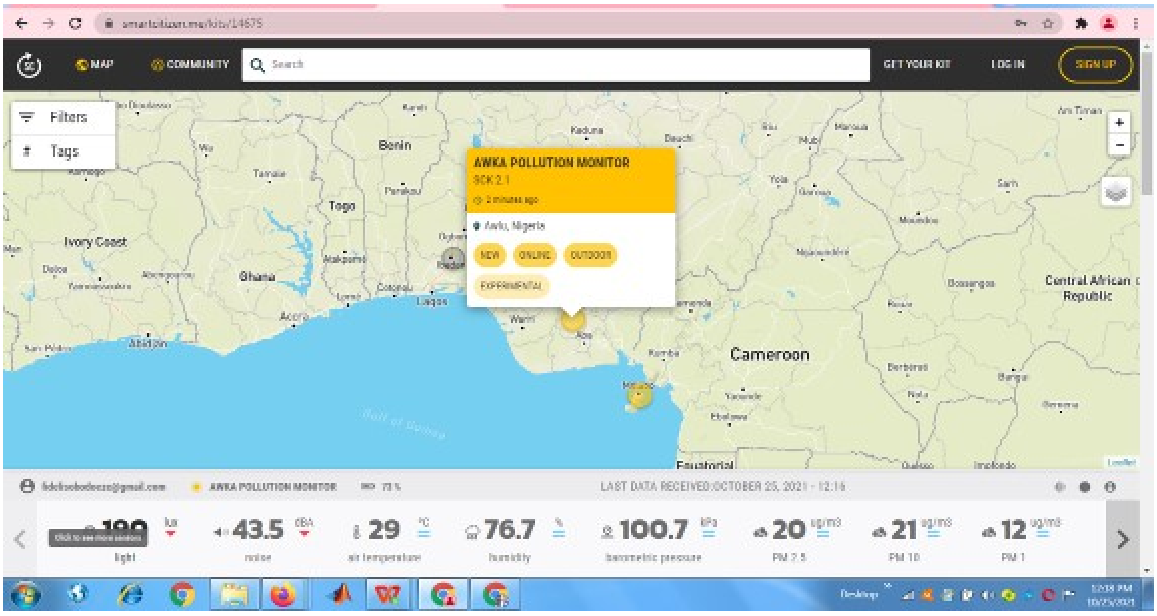


Fig 7 Awka Pollution Monitor showing the sensor readings for Awka Metropolis on Smartcitizen cloud portal

Figs.8-12 show the plots of various sensor readings obtained with time.

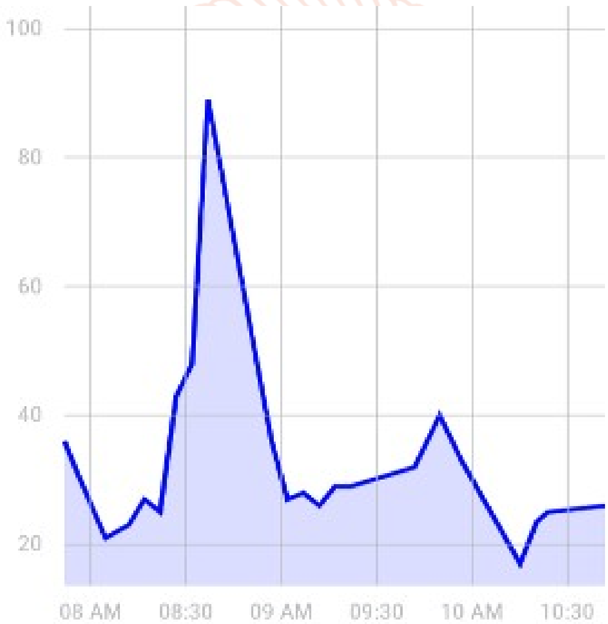


Fig 8 Plot of PM10 Concentration versus Time on November 4th, 2021

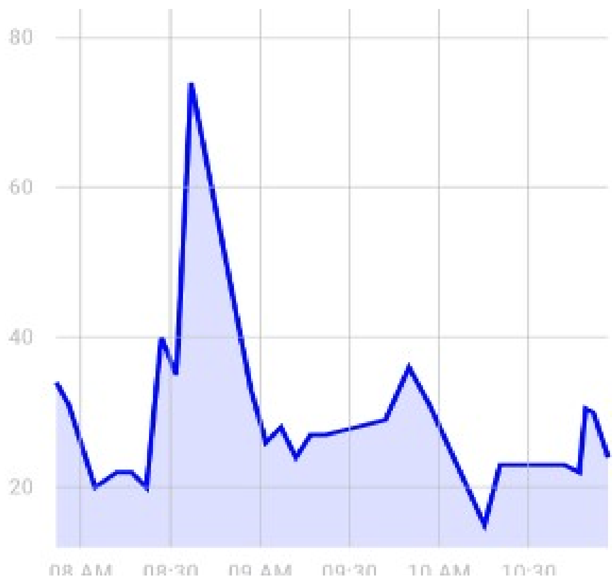


Fig 9 Plot of PM2.5 Concentration versus Time on November 4th, 2021

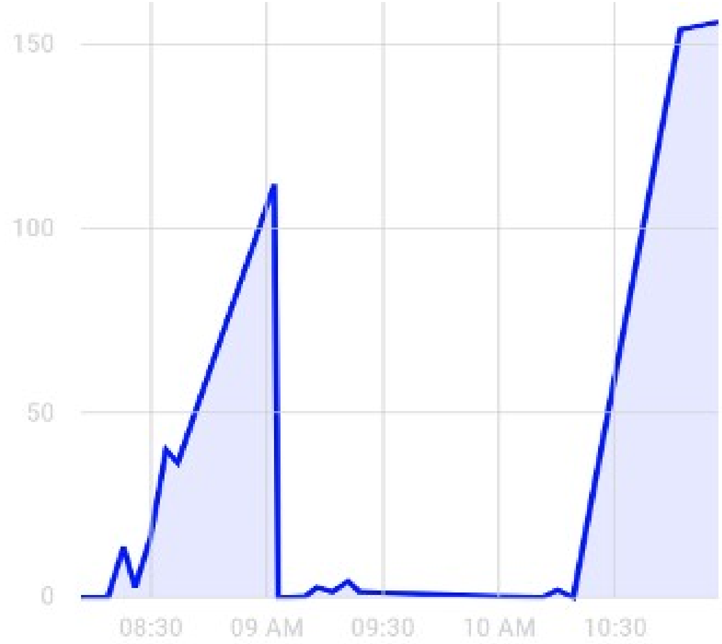


Fig 10 Plot of TVOC Concentration versus Time on November 4th, 2021

Fig 11 Plot of Air temperature versus Time on November 4th, 2021

Fig 12 Plot of Relative Humidity versus Time on November 4th, 2021

Fig 13 Plot of Air Temperature against PM2.5 Emission

Fig 14 Plot of Relative Humidity against PM2.5 Emission

Discussion

Different sensor readings from the proposed Awka Pollution Monitor were obtained from the Smart Citizens Station account for air pollutants such as PM_1, $PM_{2.5}$, PM_{10}, TVOC, eCO_2 and Noise as well as meteorological variables such as air temperature (AH), barometric pressure (BP), relative humidity (RH) and light intensity (LI). From the results obtained from the different experimental runs outdoor in different locations within Awka Metropolis, it showed there is correlation between weather/meteorological variables and air pollution concentrations.

For instance, from Fig.13, it can be seen that Air temperature (AT) has a positive correlation or relationship with $PM_{2.5}$ emission in the atmosphere. It can also be observed that when the Air temperature is going up, the particulate matters such PM_1, $PM_{2.5}$ and PM_{10} go up as well. From Fig.13, when the air temperature goes high to 34.28^0C, the $PM_{2.5}$ reading is $50\mu g/m^3$ but when the air temperature goes low to 28.54^0C, the $PM_{2.5}$ sensor reading goes down to $27.5\mu g/m3$. The same thing is applicable to Relative Humidity (RH); when the RH of the air goes low then the $PM_{2.5}$, PM_1 and PM_{10} readings go high; until a time there is saturation in the atmosphere when the $PM_{2.5}$ values begin to fall. For instance, from Fig.14, it can be seen that when RH=49.36%, the $PM_{2.5}$ is $57\mu g/m^3$, then at saturation point RH=61.79% then the corresponding $PM_{2.5}$ falls to $50\mu g/m^3$.

Secondly, all the sensor readings were posted within 60 seconds each to the Cloud based Station on the Map using Open Street Map application except the particulate matter sensor PMS 5003 that posted readings at 5-7 minutes interval to the server. These PMS 5003 readings can be adjusted to reflect the same time interval with the other sensors but this will lead to faster draining of the battery because

PMS 5003 is power hungry. Thirdly, it was observed that air pollution concentrations tend to be higher in the day compared to night except the sensor readings from the particular matter sensor (PMS 5003) for air pollutants PM_1, $PM_{2.5}$ and PM_{10}; were higher in the day than in the night. Equally, readings from the Noise sensor were lower in the nights than in the days. Readings from the barometric pressure were fairly constant for both days and nights.

It was equally observed during the course of the experiments that the type of material used for the enclosure of the pollution monitoring system affects the sensor readings. For instance, we used PVC (Poly Vinyl Chloride) IP55 patch-panel casing and discovered that sensor readings from TVOC readings were high but when the lid or cover was removed the sensor reading of TVOC sensor dropped to zero or to lower readings. This shows that the PVC plastic matter may contain chemicals (ethylene and chlorine) that are being measured by the TVOC sensor. Similarly, when the pollution monitoring system was covered with the PVC IP55 enclosure lid, the light intensity and particulate matter sensors were very low compared to the sensor readings when the enclosure lid was removed and deployed outdoor. When ABS (Acrylonitrile Butadiene Styrene) IP66 waterproof and weatherproof plastic enclosure was used instead, the light intensity and particulate matter readings were normal and okay, with higher readings than when the lid was covered with PVC IP55 plastic material. Because of the effects of the chemical components of PVC plastic enclosure casing to sensor readings, we decided to adopt ABS plastic materials to enclose and encase the pollution monitoring system against rain, dust and weather conditions in order to protect the monitoring system from damage. Equally we used a transparent lid to close the enclosure to enable the light intensity sensor to read the ambient light accurately.

CONCLUSION

Internet-of-Things (IoT) has proven so much relevance in environment monitoring and management towards successful establishment and achievement of smart city goals. This paper presents a practical implementation of real-time air and noise pollution monitoring system or sub-station for Awka Metropolis. It is made up of integrated hardware and software sub-systems cooperating together to enable its functionalities. The system consists of hardware and software sub-systems which consists of wireless pollution sensors, Wi-Fi connectivity module and software sub-systems for efficient data acquisition capturing of basic air pollutants such as the particulate matters ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) as well as one of the green gas pollutants carbon dioxide (CO_2), TVOC (Total Volatile Organic Compounds) gas and noise. It equally incorporates weather or meteorological parameters such as air temperature, barometric pressure, relative humidity and light intensity which affect the emissions of air pollutants in the ambient atmosphere. The deployment and implementation of the system was carried out for several days and the sensors' readings were successfully posted to the end-users in real-time to the internet via a cloud based server - the Smart Citizen Station (SCS). The historical dataset of the pollution sensor readings were captured and saved by the server and saved in .CSV format which can be used for further machine learning modeling and statistical analysis using Python programming language and Python inbuilt machine learning modules such as Tensorflow, Keras and Scikit-learn. The captured sensor data in real-time can also be made publicly available using the Smart Citizen Application Programming Interface (API). The system can be further expanded to include other air pollutants such as CO, NO_2, SO_2 and Ozone. This system can easily be adapted for air and sound pollution monitoring and analysis for other metropolitan cities such as Lagos, Port Harcourt, Abuja, etc in Nigeria.

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