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ANALYSIS OF AVERAGE TEMPERATURE AND HUMIDITY OF LAGOS STATE WITH RESPONSE TO CARBON MONOXIDE EMISSION USING WIRELESS SENSOR NETWORKS

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Abstract

Lagos is the most industrialized state in Nigeria with 68-80% of the country's industries located therein. Rapid and haphazard industrialization has taken place without environmental considerations. The objective of this paper is to describe the use of wireless sensor network (WSN) to measure the concentration of carbon monoxide (CO) concentration in highly polluted areas Lagos state.
This system would measure the CO concentration profile of a location, generate data to plot graphs. This will help to deduce the correlation of this air pollutant with temperature and humidity and determine the environmental risk assessment for specific geographical zone or area.
To achieve these objectives, the method involves the design of a wireless sensor network with two nodes. Each nodes design consists of the group of sensors, arduino processor board, GSM, and GPS modules. Each node is expected to sense pollutants, convert and process the magnitude of pollution to equivalent data output which is transmitted to the remote base station. The expected results would show data of the carbon monoxide sensor for each location and graphical results with response to changes in temperature and humidity.
Moreover, it possible for the public to have access to the air pollution monitoring results in real time as it would contribute to public significance.

Keyword: Air pollution, Wireless sensor networks, temperature, humidity, Environmental risk, carbon monoxide

INTRODUCTION

A sensor is a device that converts physical parameters like temperature, heat, humidity etc, processes into electrical quantities like voltage and current. Sensors helps to link the physical world with the digital world by capturing and revealing real-world phenomena and converting them into a form that can be processed and stored [1]. When many sensors cooperatively monitor large physical environments, they form a wireless sensor network [2].
A Wireless Sensor Network (WSN) is a distributed network, and it comprises a large number of distributed, self-directed, and tiny, low powered devices called sensor nodes alias motes. WSN naturally encompasses many spatially dispersed, petite, battery-operated, embedded devices that are networked to supportively collect, process, and convey data to the users, and it has restricted computing and processing capabilities [1].
WSN application into air pollution monitoring is very important and pertinent due to the increasing side effects including climate change, greenhouse gases effect, diseases and ailments, birth deformities, acid rains etc [3].
The use of WSN in monitoring applications as in air pollution is very important. Air pollution monitoring and the use of indicators are standards in many aspects of government and
business practice as a means of assessing problems, developing policy, and measuring progress [1,3].
The advent of technological processes of production of goods and services has led to manufacturing of vehicles and other products, gadgets etc that has made life comfortable for us like with the vehicles, we can transport ourselves, goods and anything that needs haulage etc. These activities mentioned benefits us but in recent years these human activities ranging from domestic to industrial activities have become to pose the problem of pollution [4]. Domestic cooking activities especially using of biomass results in soot, particulate matters, carbon monoxide CO, trace of sulphur and nitrogen oxides. Industrial activities also provide other pollution of dangerous gases and chemicals. The most notorious of the pollution sources is the vehicle exhaust. The vehicles pollution and industrial wastes are much of a problem because they use fossil fuels and burning of these fossil fuels contributes to the higher percentage of pollution sources [5].
All living things including humans breathe-in air to keep alive and the air that humans breathe everyday of their existence comprises of 21percent of oxygen and 7 percent of nitrogen, with the remaining percentage consisting of trace amounts of rare gases. This is the percentage that is healthy for human and animal existence, but human activities over the centuries resulting in air pollution have gradually shifted this balance such that other gases now add up to the ratios and this trend is increasing with increase in human population and modernization of rural areas to urban settlement structures [4,5].

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The Earth as a planet was designed to do its housekeeping through recycling of energy hence the existence of different cycles like water and Nitrogen cycles. The tremendous pollution of the earth by human activities is growing at a rate faster than the Earth can recycle it, and this is greatly affecting the Earth with the result of global warming due to increase in ratios of greenhouse gases [4].
Air pollution causes some gases in the atmosphere to exist at higher-than-normal temperature and humidity in , and this can be seriously harmful to human health and the environment.
Examples of these gases include the following:

I. Nitrogen oxides (NOx),
II. Sulfur oxides (SOx),
III. Carbon monoxide (CO),
IV. Particulate matter (PM),
V. Photochemical oxidants (e.g., ozone)
VI. Lead (Pb),
VII. Along with a variety of airborne heavy metals and volatile organic compounds (VOCs).

It is often a combination of both natural factors as well as human activities that lead to highly unhealthy conditions in air quality [3]. The vehicles pollution and industrial wastes are much of a problem because they use fossil fuels and burning of these fossil fuels contributes to the higher percentage of pollution sources [3,4].

Carbon Monoxide Emissions; Sources and Effects

Carbon monoxide (CO) is a colorless, odorless, tasteless, and toxic air pollutant and it is produced in the incomplete combustion of carbon-containing fuels, such as gasoline, natural gas, oil, coal, and wood. Carbon monoxide consists of one carbon atom and one oxygen atom, connected by a triple bond that consists of two covalent bonds as well as one dative covalent bond. It is the simplest oxo-carbon and is iso-electronic with the cyanide anion, the nitrosonium cation and molecular nitrogen. In coordination complexes the carbon monoxide ligand is called carbonyl [6]. The largest anthropogenic source of CO in the United States and also in Nigeria is vehicle emissions. Breathing the high concentrations of CO typical of a polluted environment leads to reduced oxygen (O_2) transport by hemoglobin
and has health effects that include headaches, increased risk of chest pain for persons with heart disease, and impaired reaction timing. Carbon monoxide affects healthy and unhealthy people. Increased levels of carbon monoxide reduce the amount of oxygen carried by hemoglobin around the body in red blood cells. The result is that vital organs, such as the brain, nervous tissues and the heart including lungs, do not receive enough oxygen to work properly. No more than 2.5% of haemoglobin can be bound to carbon monoxide before some health effects become noticeable. At very high concentrations of carbon monoxide, up to 40% of the haemoglobin can be bound to carbon monoxide in this way. This level will almost certainly kill humans [5,6].
For healthy people, the most likely impact of a small increase in the level of carbon monoxide is that they will have trouble concentrating. Some people might become a bit clumsy as their coordination is affected, and they could get tired more easily. People with heart problems are likely to suffer from more frequent and longer angina attacks, and they would be at greater risk of heart attack. Children and unborn babies are particularly at risk because they are smaller and their bodies are still growing and developing [7].
In the 1960s, vehicle emissions led to increased and unhealthful ambient CO concentrations in many U.S cities. With introduction of emissions controls, particularly automotive catalysts, estimated CO emissions from all sources decreased by 21% from 1980 to 1999 [8]. Average ambient concentrations decreased by about 57% over the same period.The locations that continue to have high concentrations of CO tend to have topographical or meteorological characteristics that exacerbate pollution; for example, strong temperature inversions or the existence of nearby hills that blocks wind flow may limit pollutant dispersion. Because of the limited dispersion, many of those areas also have unhealthful concentrations of ozone (O3) and year-round particulate matter (PM). Low temperatures also contribute to high CO concentrations. Engines and vehicles emissions control equipment operate less efficiently when cold. Air to fuel ratios are lower, combustion is less complete and catalysts takes longer to become fully operational. This result in byproducts of incomplete combustion including CO are formed in higher concentrations. Sometimes topography, meteorological and emissions combine to cause high concentrations of CO [7,8].

Study Area

The foremost industrial states in Nigeria are Lagos, Rivers, Kano and Kaduna states with Lagos having the largest population density of them all. Lagos state also has the highest concentration of industries, with well over seven thousand medium and large-scale industrial establishments [9]. There is a claim that about 70-80% of the manufacturing facilities operating within the medium and large-scale industries are located there in lagos. The major industrial estates in Lagos are: Ikeja, Agidingbi, Amuwo Odofin (industrial), Apapa, Gbagada, Iganmu, Ijora, Ilupeju, Matori, Ogba, Oregun, Oshodi/Isolo/Ilasamaja, Surulere (light industrial) and Yaba [10,11,12].
The fig.1 shows Lagos state and its environs [9].

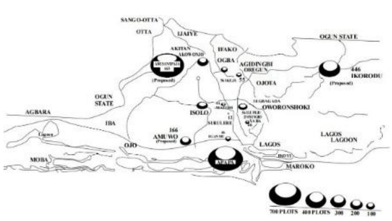

Fig 1. Google map of the Ikeja industrial Estate. Fig 2. Lagos Industrial Estates Mapped for air pollution test

This Ikeja industrial estate was appropriate location as it has industries apart from the busy roads that constantly carry high vehicular traffic loads.
The study area as shown on the Google map has a total area of 7.52km^2 (2.51 mi^2) and a total distance of 10.47km and its GPS coordinates are 6.63026, 3.34569 north, 6.2011, 3.36136 East, 6.61594, 3.33544 West, 6.0016, 3.34668 South.
Ikeja being a capital city of Nigeria is already developed with industries and industrial estates which in turn lead to it being a heavy commercial area/zone and the residential status can be correctly said to be densely populated.
From its history, Ikeja was a well-planned, clean and quiet residential and commercial town with shopping malls, pharmacies and government reservation areas etc and Murtala Muhammed International Airport is also located in Ikeja. One can find Femi Kuti's Africa Shrine and Lagbaja's Motherland and both venue is home for live music and entertainment. The Ikeja City Mall is said to be the largest mall on the Lagos State mainland. Ikeja also has its own radio station, broadcasting both in English (Eko FM) and in Yoruba (Radio Lagos). It is very clear note that the Ikeja axis of Lagos is a beehive of activities which leads to heavy vehicular activities of all sort, and the fact that it is densely populated, means that traffic conditions would be very heavy at certain hours of the day as was discovered during study of the area. The inevitability of this is that the pollution level in this area would definitely be on the high side as it always noticed on developed communities with heavy vehicular activities across the globe and also as was discovered in this study. Ikeja LGA has communities namely; Anifowose. Oregun. Ojodu. Opebi. Akiode. Alausa. Agidingbi. Ogba. Magodo. Maryland. Onigbongbo and Government Reserved Area,(GRA) Ikeja.

Other Application areas of wireless sensor networks
WSNs have been successfully applied in various application domains such as:
Military applications: Wireless sensor networks be likely an integral part of military command, control, communications, computing, intelligence, battlefield surveillance, reconnaissance and targeting systems [13].
Transportation: Real-time traffic information is being collected by WSNs to later feed transportation models and alert drivers of congestion and traffic problems [14].
Health applications: Some of the health applications for sensor networks are supporting interfaces for the disabled, integrated patient monitoring, diagnostics, and drug administration in hospitals, tele-monitoring of human physiological data, and tracking & monitoring doctors or patients inside a hospital [15].
Structural monitoring: Wireless sensors can be utilized to monitor the movement within buildings and infrastructure such as bridges, flyovers, embankments, tunnels etc. enabling Engineering practices to monitor assets remotely without the need for costly site visits [16].
Industrial monitoring: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionalities. In wired systems, the installation of enough sensors is often limited by the cost of wiring [13,17].
Agricultural sector: using a wireless network frees the farmer from the maintenance of wiring in a difficult environment. Irrigation automation enables more efficient water use and reduces waste [18,19].

Sampling apparatus for air pollutant monitoring
A sensor to measure the CO concentration in the environment is designed as a sensor node with processing capability as part of the wireless sensor network architecture. Several nodes in a location-region are connected to a coordinator and to the gateway and from there sent to the base station central control system that collects the data from each sensor nodes from test sites and wirelessly through WSN. The base station with computer serving as the server has all relevant software with database program to record the data for future analysis. This setup was designed and scaled to standard for this research work. The test apparatus was set up to height 1.5 to 2m above ground level, height of average human breathing zone. These tests were carried out for 24hrs/daily foreach session.

Pollution (Gas) Sensor
The pollution gas sensors used in this work come as modules and are low-cost meta-oxide and chemical gas sensors. The MQ series including MQ7 for CO, come with a predesigned signal conditioner that gives logic high output only when the pollution gas exceeds threshold. The modules come with analog output labeled AO and digital output DO apart from the power supply pins. Examples of some the sensors and components used are shown in fig 3.

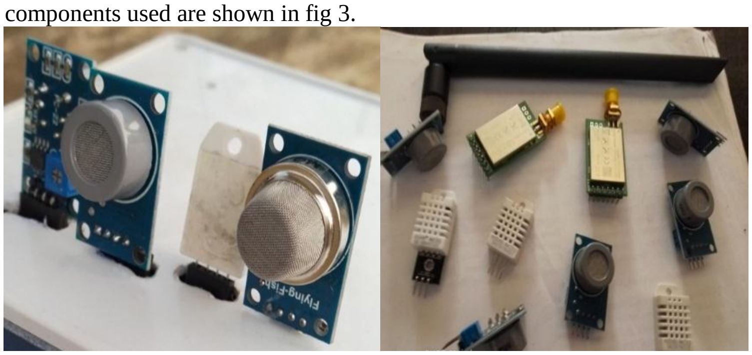

Fig 3 Gas sensors, temperature for air pollution monitoring

The pollution gas sensor used and its summarized specification and properties is presented in table 1

TABLE 1 PROPERTIES OF GAS POLLUTION SENSOR USED

S/N	Sensor Typ	Sensor Detectable pollutant	Sensor range (ppm)
1	MQ-7	Carbon monoxide, CO	20 - 2000

WSN Gas pollution Sensor Node implementation

The sensor node consists of the signal conditioning stages, microcontroller for the processing stages and a LoRa module for wireless transmission of data. This phase of the implementation involves designing the printed circuit board layout on a PCB software called PCB Wizard 3.0 was used to design the PCB. The sensor node circuit was divided into two (2) units. One was for the processor and wireless module and the other for the signal conditioner stages. This is depicted in figure 4. The signal conditioner outputs were connected to the ATMEGA328 processor. The ATMEGA328 processor was connected to the E32-868T20D module and 16x2 LCD display. All stages were carefully linked and soldered with the power supply and both boards were looped together and placed on-top of each other to reduce space and make it more compact and portable.

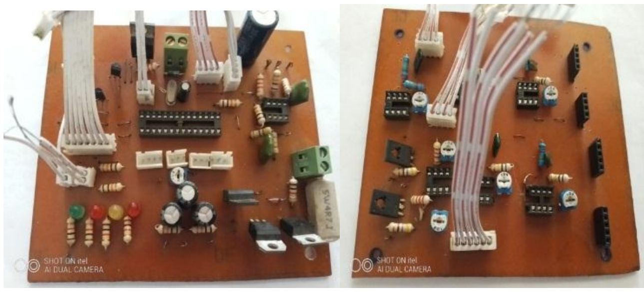

Fig 4 Processor and transmission and signal conditioner open board section of the WSN sensor node

The pollution gas sensor modules used for the targeted pollution gas is outlined in table 1 The sensors used gives corresponding electrical quantities change for changes in environmental factors which are the pollution gas concentration levels. The performance of the gas concentration levels monitoring, and air quality monitoring is greatly influenced and improved with good calibration, speed of response, accuracy, resolution and linearity. For this reason, decoupling capacitors were used at the sensing stages with the signal conditioning circuits and processor stages to remove errors due to noise, apply filter circuits to remove noise within and outside sources. Proper grounding was applied where necessary to enhance sensor results. Comparison was carried out between the wanted output as obtainable from standard equipments and that obtained output from this monitoring device was used to determine appropriate correction factors for proper calibration and scaling which immensely helped in applying proper compensation when needed. The gas sensors have analog outputs and so it was necessary to apply pre-conditioning of their electrical output before processing stage.

Fig 5 PCB with mounted components for the WSN node stage

Fig 5 shows the final board with mounted components, including the LoRa module board and the power supply stage. The output from the sensor was connected to its sockets which was also connected to the signal conditioners. The output of the conditioners were connected to the six (6) analog to digital converter (ADC) pins of the ATMEGA328.

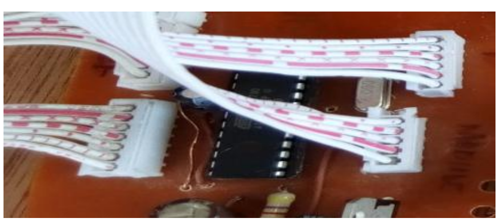

Fig 6 Atmega328p representing Arduino uno

Arduino IDE software was used to develop the program code. The code instructs the processor to initialize at start, sample each sensor signal conditioner output to get the values of the pollution gas level of interest, process the information and apply correction factors developed during calibration and sends the data by initializing the wireless module to transmit the data to the coordinators. The sensor data also includes location and sensor node identification number.

Gas Sensor and Signal conditioner Pre-test

Pre-testing was conducted to ensure that the sensor node will work to specification and in accordance with design. The test involves setting different analog voltage levels to represent signal change at the inputs of the signal conditioners and to ensure the appropriate voltage range and limits were scaled so that the proper amplification, scaling and calibration on the signal conditioner end is well set so that minimal or no adjustment is required when the actual gas pollution sensors are introduced. Proteus design suite circuit simulator was used to simulate the signal conditioner circuits as part of the pre-test phase. This was done for the gas sensor signal conditioner stages during pretesting phase, and this gave insight to needed component values adjustment needed for good performance. The pretesting phase also enable the actual determination of the pre-heat time for the gas sensors before their outputs can be accessed to get accurate sensor data as stipulated by the manufacturer. From the pretest, it was discovered that their pre-heat vary from 20 seconds to one minute.

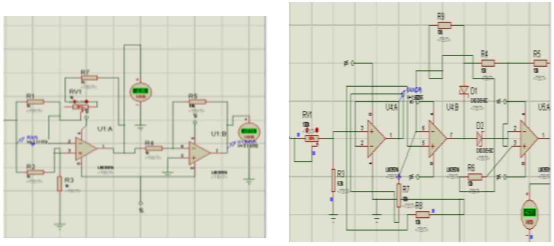

Fig 7 Proteus simulation circuit for signal conditioner pretest

Pre-test of WSN Node Wireless Transmitter

This pretest was done to show the possibility of establishing communication between the node and the gateway and to the base station, experiment on it to get all features and understand the bandwidth, distance, spread factor and other necessary several tests were carried for throughput and distance including experimentation with all possible command codes to aid in efficient use of the LoRa wireless modules and the gateway for WSN application.

The test involves connection to a PC with hyperterminal program using Arduino board and sending data generated for test purposes and using another LoRa module for receiver also connected to another PC to check for the inter-relationship between throughput, bandwidth, spread factor and how they affect distance covered. The communication test LoRa module to LoRa module (Node to Node) and LoRa module to gateway (Node to Coordinator/Gateway). Each unit was powered, and communication commands were issued from the hyperterminal program to the LoRa E32 module and to the gateway. Several tests carried out shows the

possibility of establishing communication over reasonable distance and several tests were carried for throughput and distance including experimentation with all possible command codes to aid in efficient use of these wireless modules for the wireless sensor network. This helped with obtaining practical average distance that was obtainable with the LoRa modules. Fig 7 shows the LoRa module connected to the processor board.

The LoRa module used for data transmission at the node end is the E32-868T20D shown in figure 4.8. Five pins out of the 7pins it has are needed for communication with two for UART/serial communication with Arduino ATMega328P. The information inputted into the code program includes the frequency for communication, bandwidth, spread factor, the address of the zone and gateway. It has M0 and M1 pins for configuration setting and was set with M0=0, M1=0 called mode0 for normal and continuous LoRa wireless communication. Mode 3 is setting of M0=1, M1=1 called the sleep mode used for parameter setting. Settings like baudrate, bandwidth spread factor, communication channel are set, and also whether communication is going to be transparent transmission or fixed transmission modes. In this work, the mode2 was used for sleep and communication. It is woken by received data, and then goes into mode0 for continuous communication. When there is no data after 1hour, it goes into sleep mode.

The field test performed was to check out LoRa transmission reliability. Several experiments were carried out to test the performances of LoRa communication like power consumption, distance. Different information on voltage levels were generated from the processor stage and fed to the LoRa module for transmission. The experiments for testing communication and monitoring performances were done within study. The LoRa device operational frequency was set at 868 MHz and during experiments the Nodes were placed at height of 1 meter and above because of environmental limitation of obstruction caused by buildings and other structures. The experiment performed was to check data reception for different distances away from the sensor node from the starting point of 0.1km to 3 km away from the node since the maximum for the LoRa module is 3km. The device was programmed to mode0 to continuously send data every 10 seconds from the transmission end while checking out the reception from the receiving mode also set at mode0. Figure 7 shows the test path covered during test.

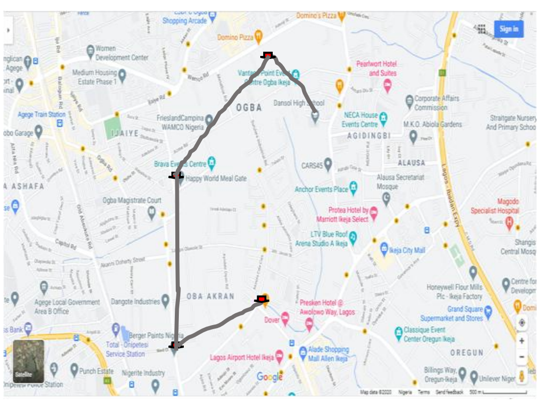

Fig 8 Preliminary lora device test path

WSN sensor Node Communication performance Test

The WSN endnotes performance test was focused on the Received Signal Strength Indicator (RSSI) and Signal-Noise Ratio (SNR) with respect to power of transmission. This was done in order to test communication performance of the node's LoRa device under different conditions. RSSI and SNR readings were obtained with respect to the power in dBm against different Spreading Factor (SF) range of SF7 to SF12 and to check the effect of different transmission power on RSSI and SNR and data rate of SF7 to SF12 for module to module and module to gateways.

Gateway implementation and Pre-test

This device used for gateway was the LG01 LoRa gateway device. It was also used as the coordinator. It was chosen because it has USB host port that can be used to connect to different cellular modules making it very flexible to bridge LoRa Network to different kinds of network to fit user's requirement. It has the capabilities of bridging LoRa wireless networks to an IP network base on Wi-Fi, Ethernet, 3G or 4G cellular including full Ethernet and 802.11 b/g/n WiFi capabilities. In this work it was used to set up a private ad hoc network was set up between the E32T modules at the nodes to the gateway and coordinators and to the receiver gateway at the server side computer at the base station.

Fig 9 LG01 dragino lora gateway device

After this setup, it was necessary to test the gateway with the endnote E32T module and the gateway device LG01 and a coordinator (client) and gateway (gateway/Master).

WSN node E32T module and LG01 Communication Test

An Arduino sketch was developed to run this test and uploaded into the processor ATMEGA328. The DHT22 sensor was used also with the E32T module connected and powered. The code sketch was programmed for the processor to transmit data every 10 seconds. The gateway device was at varying distances to receive the data and resend it to the computer. The setup of the gateway and end-node is shown in fig 9.

Coordinator and the Gateway device Preliminary Test

This test requires that the previous set up remains intact, but instead of connecting to the gateway, a connection link was established between the end device and coordinator (client) and the coordinator was linked to the gateway and gateway to computer representing base station. For this test temperature sensor DHT22 was used to measure the temperature and humidity from the node board environment and the processor was programmed to send data through with the E32T module and the end device was programmed to send data every 10seconds. The gateway device was to receive the data from the coordinator as the coordinator receives data from the end device and then send it to the laptop screen. Figure 10 shows the communication hierarchy between the gateway, coordinator and sensor node.

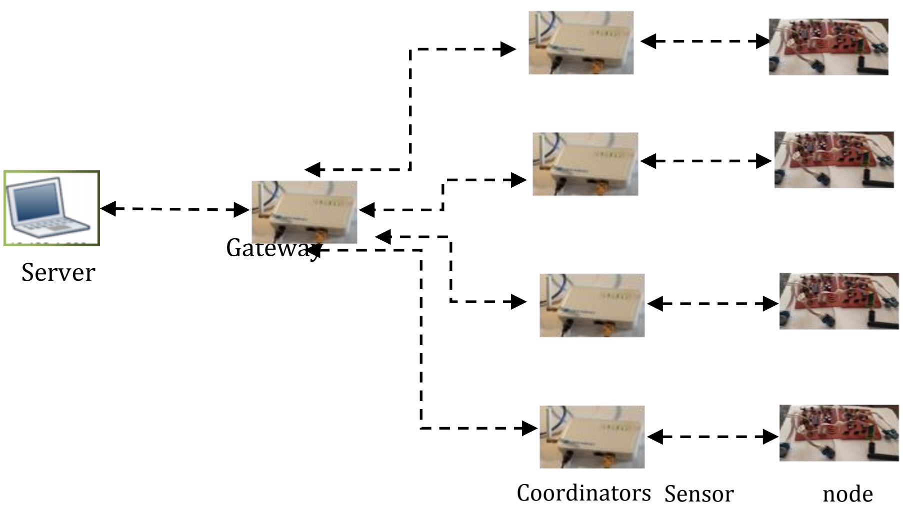

Fig 10 Mesh networks of WSN end device, coordinator and gateway connections

The tests performed includes signal strength RSSI, throughput based on spread factor, delay between transmission and reception and the effect of range/distance to data received and data integrity. The outdoor test was done likewise between the nodes to coordinator and gateway to base station with the same objectives of obtaining field test results to help in selecting appropriate locations for good signal strength. The gateway was configured with Lora WAN protocol for the field test. The WSN nodes were configured to transmit data packet every 10 seconds interval with payload of 40 bytes. Appended to the data packets were identification numbers to aid in identifying the data packets in order to calculate data packet losses.

The tests shows the transmission power when programmed to 14 dBm, SF12, BW of 250 kHz, using the two channels of 868.175 and 868.575 MHz gave the best results. From the tests data packets that were transmitted and signal strength, it was observed that power levels and signal strength of −20dbm to −141dBm was achievable depending on the bandwidth/channel (BW) and spread factor (SF) and channel four and SF12 had the best sensitivity and range.

The measurement setup parameters are listed in Table 5.8. During all the measurements, the position of the gateway sink was fixed, while the sensor node was moved to different location.

TABLE 2 LORA LG01 TEST SETUP PARAMETERS

Parameter	Value
Sensor Node	Custom made design
Sink	LG01 Dragino Gatewa
Tx power	-14dBm
Frequency (F)	868MHz
Bandwidth (BW)	250kHz
Antenna	3 dBi omnidirectional
Spread factor (SF)	12
Coding rate	4/5
Payload Length	40 bytes
Time interval	10seconds
Sensor Node antenna heig	0.1m
Sink antenna height	0.05m

Energy Consumption

A sensor node is equipped with a limited energy source and hence has a lifetime that is dependent on that source. In a WSN, each node can originate data and also has to route data. When few nodes deplete their energy resources, topology changes occur which may require rerouting of data packets. A sensor node's task is to sense data, perform some processing and then transmit the data. Energy consumption in a node can therefore be divided into three areas, communication, processing and sensing. A node traditionally expends most of its energy during communication. The transceiver unit consumes energy during both start-up for warming the heater coils and active states. As the size of the packets become smaller the energy consumed during transmission decreases. The power consumed during transmission was calculated using expression 1.0.

$$P_C = N_T\,[P_T\,(T_{on} + T_{st}) + P_{out}(T_{on})] + N_R[P_R(R_{on} + R_{st})] \quad (1.0)$$

where, N_T is the number of times the transmitter is turned on per unit time.

P_T is the power consumed by the transmitter. T_{on} is the transmitter on time.

Tst is the transmitter startup time.

P_{out} is the output power of the transmitter.

N_R is the number of times the receiver is turned on per unit time.

P_R is the power consumed by the receiver. Ron is the receiver on time.

Rst is the receiver startup time.

WSN node Power Supply

For continuous operation, the system was designed to run on solar-battery supply arrangement. This was necessary due to the limitation of using external power source that may limit location of the WSN node placement. The solar PV panel and battery were designed to furnish power for 24hours service. Figure 11 shows the casing and battery

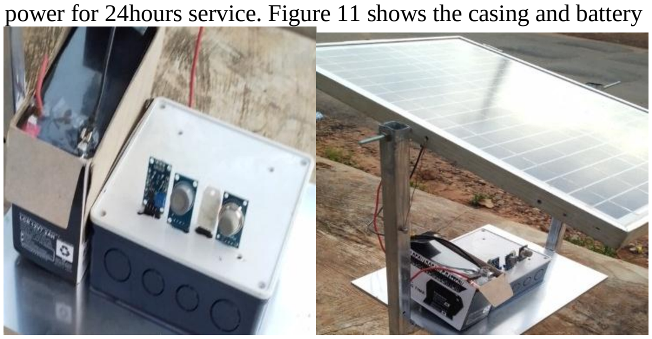

Fig 11 Power supply set up for WSN endnote device

Gateway/Coordinator Hardware Installation

For the coverage area three coordinators and two gateways were needed to cover the area with good signal strength for data packet transmission integrity and aid in zero losses. The components were encased in white adaptable plastic case. The coordinator and gateway were mounted at a minimum height of 5meters (low residential buildings rooftop and as much as 10meters for storey buildings height levels. This height is to aid in distance and range improvement in that there would be less obstruction.

Fig 12 Completed and installed WSN nodes on site; sidewalk and roof top

WSN based Air Pollution Monitoring and Reporting System Architecture

The block diagram of figure 3 depicts the wireless sensor network (WSN) application in air pollution monitoring and reporting architecture with concept as embarked on this study. It shows three nodes and a gateway and each node consists of several gas sensors. The sensor nodes or end devices send their sensor data to the gateway they are tuned to through necessary configuration settings. The gateway eventually collates all sensor node data after receiving data from the nodes and sends it to the base station.

The remote base station also referred to the computer systems that serves as the server or data hub. The server has installed software with developed applications to handle database and data presentation through graphic user interface (GUI) for human machine interaction (HMI). The applications in the server stores information of the network sensor nodes, sensor locations, time, and date of transmissions for data reception. The major functional blocks of the system are listed as:

1. Sensor Nodes
2. Gateway
3. Remote Base Station (Server)

Test Results and Discussion

This section presents the test result obtained for the period of 12 months (One year). The data was collected for the four zones and from the eight clusters. The gas sensor was calibrated using known concentrations of CO from gas stations and laboratories. The WSN nodes pollutants readings were validated against known concentrations from standard laboratory samples to confirm the accuracy level of the system. The test result data was obtained from the GUI and spreadsheet database in real-time and analyzed accordingly. The test analysis was done for 24hours/daily, weekly, monthly for the duration of six months. Table 3 presents a typical data for a warm day with average temperature of 28^{o}C of July 8, 2019.

TABLE 3 RESULTS FOR ZONE1FOR A TYPICAL WARM DAY WITH AVERAGE TEMPERATURE OF 28^{O}C AND HUMIDITY OF 65%

Time	CO	CO_2	Temperature	Humidity
7.09	6.9	478	26	71
8.10	9.9	503	27	69
9.09	10.7	553	27	70
10.09	10.5	562	28	67
11.10	9.9	645	29	63
12.09	9.7	642	30	62
13.09	9.3	648	31	60
14.09	9.2	658	32	59
15.10	9.5	665	33	57
16.09	11.2	666	33	54
17.10	11.8	651	30	58
18.09	11.2	678	29	62
19.09	10.8	622	27	64
20.10	9.2	563	27	66
21.09	8.9	532	27	67
22.09	7.8	496	27	70
23.09	6.3	443	26	73
0.09	5.2	438	26	73
1.10	4.1	436	26	74
2.09	3.7	434	25	76
3.09	3.1	432	25	77
4.09	3.4	428	25	78
5.09	5.4	426	25	76
6.10	6.7	424	26	72
Average	8.1	542.625	27	65

Basically, real-time ambient air pollutant concentrations during measurements always have random spatial behavior that affects interpretation of data hence the data presented were for every one hour as programmed. The extra 9 to 10 seconds were for the gas sensor pre-heating time as the main code starts the process on the hour. The table and the graph show the variation of all gas pollutants for a 24 hour/daily readings. These readings indicate that the average emissions of CO. This is mainly due to the fact that itsr main emission sources are of vehicular origin. The readings show that the late evenings (night time) to early mornings have low readings obviously due to lesser vehicular movements and activities and this time range falls between 11pm to 5am. The higher concentrations are more in the mornings through afternoon to early evenings when students and workers are on the move to work and school thus increasing density vehicular activities and movement. It is slightly lower at about 12noon to 2pm owing to the less presence of workers and students from school and work. But the general economic activities that are high in these zones still results in high pollution levels as shown by the readings. The following charts shows a typical daily reading for a warm day that is not very sunny.

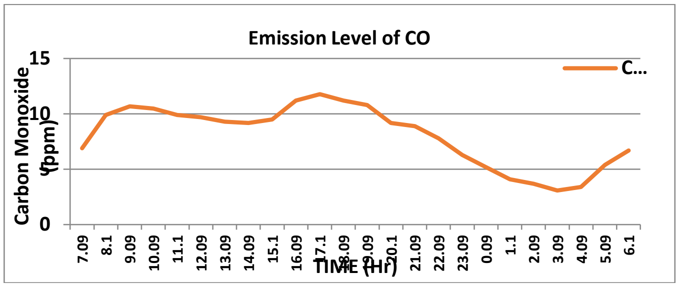

Fig 12 Chart of typical daily variation of carbon monoxide

The daily variations of carbon monoxide as seen from the chart shows a similar pattern as observed daily throughout the year. It shows that in the morning to early evening hours the CO levels are high and above WHO and FEPA levels of 10ppm and the high peaks always fall in the morning hours of 8 - 10am and about 4 – 6pm in the evening hours.

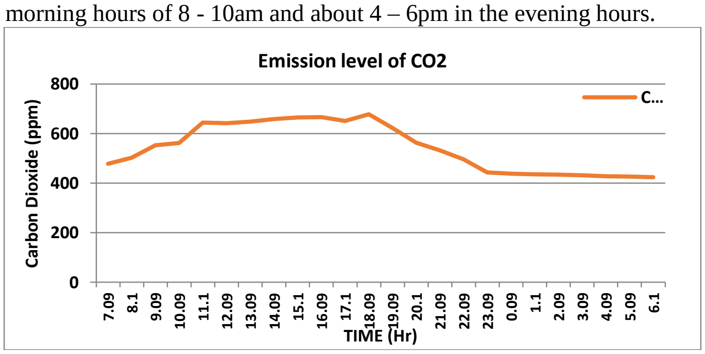

Fig 13 Chart of typical daily variation of Carbon dioxide

The carbon dioxide level is always high right from the morning rush hours to the evenings, with slight variations over the day depending on the weather conditions of the day in question. The CO2 level exceeds WHO and FEPA levels of 350ppm.

The chart shows the temperature and humidity levels. The average of 28ºC shows that it is a warm and almost cool day as higher temperatures up to 36ºC have been noticed during high sunny days.

The tests carried out for all the zones shows that the zone 2, 3 and zone4 have slightly higher variations on some days than zone1, with zone3 and zone4 being the highest two.

The charts for the four zones are presented accordingly.

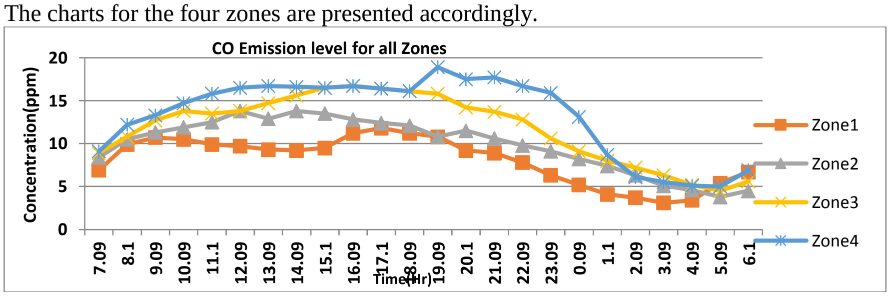

Fig 14 Chart of the four zones showing CO emission level

TABLE 4: INTERNATIONAL COMPARISON OF AMBIENT AIR QUALITY STANDARDS AND GUIDELINES AS COMPARED WITH RECOMMENDATIONS OF THE WORLD HEALTH ORGANIZATION (WHO)

Pollutant	World health Organizatio	European Unio	United State
Carbon monoxide (CO	9	9	9

TABLE 5: AQI VALUE, DESCRIPTION AND THEIR CORRESPONDING CONCENTRATION VALUE IN MG/M³

Value	Grad	Description	CO
0-50	I	Good	2,000
51-10	II	Moderate	4,000
101-15	III	Unhealthy for sensitive people	14,000
151-20	IV	Unhealthy	24,000
201-30	V	Very unhealthy	36000
301-50	VI	Hazardous	60000

$$AQI = \frac{data\ measured\ for\ each\ pollutant}{standard}\ x\ 100 \qquad (2.0)$$

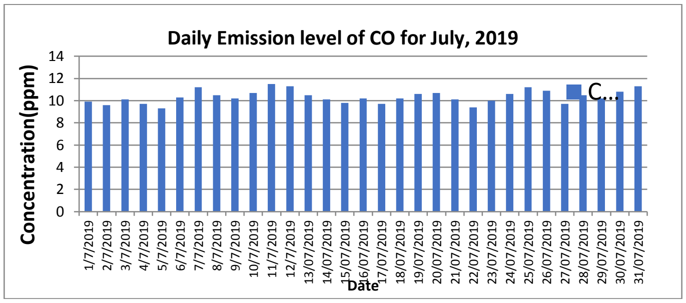

Fig 14 Daily CO emission level

The daily average for CO exceeds 10ppm as recommended by FEPA and WHO and this means there is limited supply of oxygen. This can cause high temperatures, and higher generation of other gases such as ozone and CO2 exceeding such levels means the air quality is poor and there is tendency for sensitive individuals to suffer from good, oxygenated blood as CO causes drowsiness and other related illnesses.

Conclusion

In this paper, a wireless gas sensor network focusing on monitoring the concentration of carbon monoxide in the environment was presented. This was carried out to observe the changes in temperature and humidity as a result of the pollutant profile in the environment.

The aim was to implement a system to measure air pollutant using specialized sensors for this pollutants and data-log all data received for analysis and get the concentration profile of CO at the end of the work for the specified period.

The system was equipped with RF communication link for remote site monitoring and measurement with a remote base station with database for datalogging function with time and date.

The data collated over time would be used for modeling of the environmental pollution pattern of CO pollutant at different at chosen locations and develop relationships between gases and human activities in those locations. This would be of great public health significance to the people of Lagos state as it would help to know when the carbon monoxide gets to a hazardous level that eventually leads to abnormal changes in temperature and humidity. This would help to know the necessary mitigating measures to introduce.

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