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A Microcontroller-Based Wireless Sensor Network System for the Detection of Soot in Port Harcourt, Nigeria

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ABSTRACT
This paper is aimed at applying a wireless sensor network system for the detection of soot in Port Harcourt. The soot particle was collected by open-air trapping on white paper and was stored for characterization. The soot was characterized using Gas Chromatography – Flame Ionization Detector (GC – FID) and Fourier transform-infrared (FT-IR) spectroscopy methods. GC - FID provides the concentration of the compositions contained in a particular sample. The FT-IR analysis revealed the presence of the functional groups that identified the presence of NO_2, CO_2, NH_2, CO, SO_4, CH_4 and H_2S. From the research findings NO_2, CO_2, NH_2, CO, SO_4, CH_4 and H_2S were identified to be part of soot compositions. The FT-IR spectra showed the presence of some functional groups related to the presence of NO_2, CO_2, NH_2, CO, SO_4, CH_4 and H_2S. Based on the identified compositions a sensor-detecting system was designed and constructed for the monitoring and detection of soot. Each sensor module transmits the current levels of NO_2, CO, SO_4, CH_4, H_2S, CO_2, NH_2 through a GSM module. Also, findings from the study show that the detector system identified soot in different environments and was able to detect increases or decreases in soot concentration on a real-time basis. A GSM module was incorporated to store, monitor, process, and visualize the data received from the sensor network.

KEYWORDS: Fourier Transform Infra-Red (FT-IR), Gas Chromatography – Flame Ionization Detector (GC – FID), Micro-electro-mechanical systems (MEMS), Soot, Wireless Sensor Networks (WSNs)

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1. INTRODUCTION
In recent years, protecting the environment has risen to the top of every government priority. Although the degree of industrialization has been rising unchecked over the past few decades, the situation is shifting in favour of more ecologically friendly options, as air quality is crucial to keep the balance between human progress and a healthy ecosystem. There is tendency that air pollution monitoring systems are usually constructed in wireless mode due to the rapid growth of communication technology, network technology, and remote sensing technology (Swagarya *et al*., 2014). Recently, Wireless Sensor Networks (WSNs) have grown quickly, and this study will take advantage of them.

According to Ghorani-Azam *et al*. (2016), suspended particles of carbon monoxide, hydrocarbons, nitrogen oxides, sulphur oxides, ozone, and lead are among the common gaseous, liquid, and solid pollutants released into the atmosphere. The world's premature mortality rates are thought to be mostly caused by environmental pollution in poorer nations. These contaminants have been discovered as being

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mutagenic while others have been shown to be carcinogenic in biomass smoke, which also contains carbon dioxide (Oguntoke *et al*., 2010). These contaminants turn deadly when they settle on buildings, food, plants, and other agricultural products. Microorganisms in the air can enter the human respiratory system and harm the lungs and other important organs. Soot may also cause other health issues, such as chronic long-term health issues and irritation of the eyes, nose, ears, throat, and eyes.

Air pollution results when the amount of dangerous atmospheric gases present (whether indoors or outdoors), exceeds the tolerable or allowable limits. Environmental pollution, according to Abdulkareem (2005), is any disturbance of the environment: physical, biological, etc., that exposes the local population to different health risks or safety dangers. The ecosystem is contaminated by unlawful refining of crude oil in several ways, which has far-reaching effects on the environment (Ko & Day, 2004). Consequently, the level of atmospheric gases in the area is shown in Figure 1.

Figure 1: Illegal Refining Activity (Taylor, 2013).

The World Health Organization (WHO) reports that 6.5 million fatalities worldwide, or 11.6% of all deaths, were caused by outdoor air pollution in 2012. In low- and middle-income nations, non-communicable illnesses such as lung cancer, chronic obstructive pulmonary disease (COPD), and cardiovascular diseases (CVDs) account for 94 per cent of the roughly 90 per cent of air pollution-related deaths. Soot, a form of particle pollution that is linked to deep lung penetration, has particles that are around 2.5 microns in size (AICHAW, 2017; USEPA, 2017).

Studies of air quality in Nigeria, and notably in the city of Port Harcourt, are still in their infancy and face several obstacles. There aren't many independently conducted air pollution studies in Nigeria (Taiwo, 2005). The author also stated that the government is not engaged in regular and systematic air quality measurements programs like those run by the Environmental Protection Agency (EPA) in the United States or other regions of the world. The absence of necessary and sufficient skilled personnel to conduct comprehensive and complicated air quality investigations in the area is another issue that hinders most community-based air sampling programs due to geographical difficulties and security concerns.

As a result, the effects of soot dispersion from illicit oil activities and other sources are most noticeable in Port Harcourt city. According to O'connor (2000), air pollution is one of the exacerbating factors in many cases of respiratory disorders, which are among the primary causes of death and mobility in many emerging nations. Maintaining excellent ambient air quality becomes a major challenge as Port Harcourt becomes a more industrialized, urbanized, and densely populated city. Figure 2 shows the Ground level haze and smog within Port Harcourt Metropolis during the soot invasion.

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Figure 2: Ground level haze and smog within Port Harcourt Metropolis during the soot invasion (Taylor, 2013).

It is acknowledged that Port Harcourt's black soot problem requires urgent attention. Systematic monitoring of soot around the city has been extremely challenging due to the lack of air quality monitoring stations. Furthermore, tracking the progress of soot in several sites at once is currently not possible due to the lack of a well-built network. Soot detection and monitoring system design and construction is the goal of this research. In light of this, it is still a priority to develop a dependable, small, and affordable system for the detection and management of soot that causes environmental issues in Rivers State.

The aim of the study is to apply a wireless sensor network system for the detection of soot in Port Harcourt and the specific objectives of the study are as follows: to collect soot particles, to characterize soot, to simulate a wireless sensor network for soot monitoring and finally to design and construct a soot detector. The construction of a detection system for target soot composites at various concentrations and environmental circumstances is the major objective of this research. In order to maximize the detection of soot, the detectors were networked and processed depending on the soot's characterization and to deploy and monitor the soot presence in Port Harcourt, the wireless sensor networks (based on sensor nodes motes and smart devices) were employed.

2. MATERIALS AND METHODS

2.1 Wireless Sensor Networks

In recent years, wireless sensor networks (WSNs) have drawn interest from all around the world (Yick *et al*., 2008). The advancement of Micro-Electro-Mechanical Systems (MEMS) technology has aided in the creation of intelligent sensors. These sensors are less costly and smaller than conventional sensors and have less processing and computing power. They have the ability to observe, quantify, and gather data from their surroundings. Based on certain local decision-making procedures, they may relay that data to the user. The low-power smart sensor nodes have a radio, an actuator, a power source, a digital CPU, one or more sensors, some memory, and a memory.

The sensor node can be equipped with a range of mechanical, thermal, biological, chemical, optical, and magnetic sensors to monitor environmental characteristics.

A radio wave is an electromagnetic wave which emanates from a radiating source. The radio wave assumes all the properties of a plane wave; the wavefront is the plane which contains the Electric (E) and Magnetic (H) vectors and is at a right angle to the direction of propagation and power flow. Usually, it is convenient to carry out studies in terms of the electric component, E of the wave which is known as the electric field strength of the radio wave (Bakare *et al*., 2019).

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2.2 Applications of Wireless Sensor Networks (WSNs)

Applications for WSNs include industrial monitoring, medical telemetry, environmental monitoring, and military surveillance. These applications frequently use various WSN designs since they have various operating needs. The most crucial criteria for military surveillance are high bandwidth, strong security, and enough coverage. Secure, dependable, strong, and real-time WSN solutions are needed for industrial monitoring applications. Environmental monitoring often calls for reliable, energy-efficient, and autonomous nodes, whereas medical applications frequently place a greater focus on security and network dependability (Bhende *et al*., 2014; Zhao, 2011).

2.2.1 Environmental Monitoring

The growth of human society has had a significant influence on the environment, and attempts have been made in a relentless pursuit of bettering its preservation. One such important endeavour that has enabled numerous physical characteristics to be monitored in order to manage or restrict the future advancement of environmental deterioration is environmental monitoring. Traditional monitoring methods required the manual gathering of environmental data but were eventually deemed ineffective due to their labour-intensive nature and the absence of an early warning system for environmental pollution problems.

Digital data loggers were first developed a few years ago to aid in increasing the geographical and temporal resolution of environmental monitoring, but they did not yet have real-time data analytics. Micro-electro-mechanical systems (MEMS) enabled the development of low-power WSN technologies and enabled real-time, remote environmental monitoring (Oliveira & Rodrigues, 2011). Since then, this strategy has encouraged taking preventive action against environmental pollution.

2.2.2 Air Quality Monitoring

Zhi-gang and Cai-hui (2009) examined the use of ZigBee-based WSN in air pollution monitoring. The suggested system used sensor nodes with GPS capabilities to track air quality metrics and send the data to a sink node connected to a computer network. Simulating the geographical and temporal distribution of air pollution in a specific location has been suggested using GIS analysis. The proposed scheme, however, was only designed for a limited region, suggesting that when thinking about a somewhat wide area, extra networking needs will have to be taken into account.

2.3 Sensor Cloud:

The creation of several applications that gather and interpret data from the real environment is made possible by wireless sensor networks. Similar to this, the utilization of data clouds enables the potential of sharing dispersed resources. The phrase "cloud computing" is used to refer to both a platform and a class of applications. As opposed to having local servers, a platform for cloud computing services may be configured or changed as needed. On the other hand, a cloud may be used to represent a web-based program. Internet-based cloud computing servers are in charge of always responding to queries. Figure 3 shows the cloud sensor network scheme.

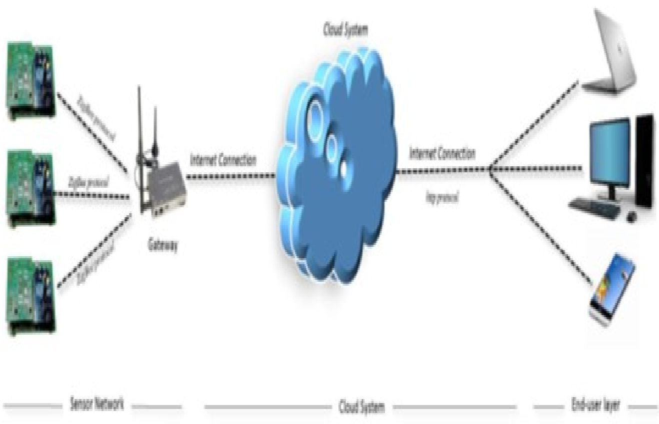

Figure 3: Cloud sensor network scheme

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With this strategy, services are accessible from any mobile or fixed device, wherever it may be, via an Internet connection. "Sensor Cloud," a promising concept, uses cloud data to communicate information from sensors on WSNs. The MQ7 multi-carbon sensor is a member of the MQ family of carbon sensors, which also includes the MQ 2, MQ 4, MQ 3, MQ 8, MQ 135, and others. It is a Metal Oxide Semiconductor (MOS) type gas sensor. Carbon monoxide, methane, sulphide, and nitride oxide are the principal gases that it is used to detect.

This sensor has a detecting element made mostly of ceramic with an aluminium oxide base that has been coated in tin dioxide (SnO_2) and is housed in a stainless steel mesh. The resistivity of the detecting element changes each time CO gas comes into contact with it. The concentration of the gases present is then determined by measuring the change. A tiny heating element is contained in the MQ7 Sensor and is used to pre-heat the sensor before inserting it into the working window.

2.4 Collection and Characterization of Soot

The soot particles were collected by open-air trapping on white paper and stored for characterization. Infrared spectroscopy was used to analyse and characterize the collected soot. For the analysis, a Buck Scientific M530 USA FTIR was employed. This device had a deuterated triglycine sulphate detector and a potassium bromide beam splitter. The spectra were obtained and altered using Gram A1's software. About 0.1g of samples and 0.5 ml of Nujol were added, thoroughly mixed, and then put on a salt pellet. FTIR spectra were acquired throughout the measurement in frequency ranges of 4,000 - 600 cm-1 and co-added at 32 scans and 4 cm-1 resolution.
Transmitter values were used to display FTIR spectra. The molecules in the soot sample were characterized using a Buck 530 gas chromatograph outfitted with an on-column, automated injector, mass spectroscopy, and an HP 88 capillary column (100m x 0.25m film thickness).

2.5 Design Components

Components used for the design are an Atmega328p Microcontroller, Flame sensor module, Crystal oscillator, Voltage regulators, Capacitors, Resistors, I.C socket, Light emitting diode (LED), 16*2 mm Liquid Crystal Display, GSM Module SIM 800, Battery, and a plastic box of 10cm long by 10cm width and 5cm high.

2.6 Design Method

Before live implementation, testing of the developed technique is required. Most of the time, testing and evaluating the protocols or theories proposed is not practically feasible through real experiments as it would be more complex, time-consuming, and even costly. So, to overcome this problem, “SIMULATORS and TESTBEDS are effective tools to test and analyze the performance of protocols and algorithms proposed (Bakare & Enoch, 2018).
The microcontroller is an improved RISC (Reduced Instruction Set Computer) architecture-based low-power CMOS (Complementary Metal Oxide Semiconductor) 8-bit microcontroller. The attainment of 1 MIPS per MHz throughput is made possible by the effective execution of instructions in a single clock cycle, which enables the designer to balance power use and processing performance.
Figure 4 depicts the microcontroller's internal architecture. The microcontroller's brain, or Central Processing Unit (CPU), directs how the program is run. The MCU (Microcontroller unit) is made up of 512/1K/2K bytes of SRAM, 256/412/1K bytes of EEPROM, and 4K/8K bytes of in-system programmable flash with read-write capabilities.

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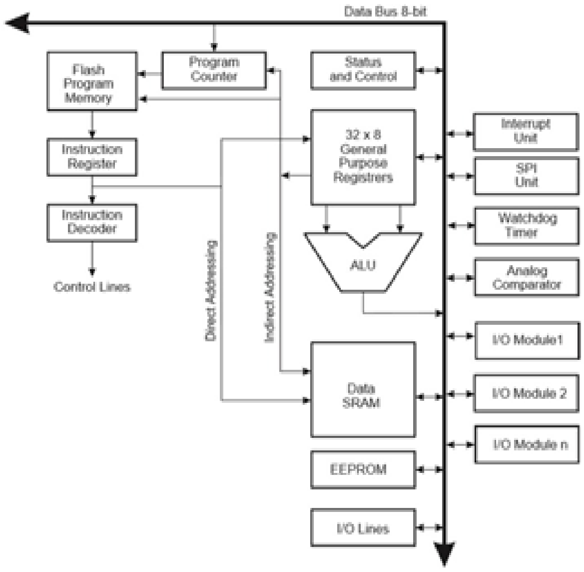

Figure 4: Microcontroller architecture

A microcontroller (Atmega 328p) and additional digital and analogue sensors and modules, such as the MQ7 multi-carbon sensor and GSM module, are used in the design process. Within the first two minutes of operation, the MQ7 multi-carbon sensor picks up and calibrates. It detects the components of black soot (C, SO_4, and NH_4) and provides a unique value for each of the components specified. Additionally, the microcontroller does the logical function by summing the values of each individual element and providing the black soot value in ppm. The 16x2 mm LCD screen, which is linked to the microcontroller through a serial connection module, shows the microcontroller's active processes in a comprehensible manner. Figure 5 shows the block diagram of the soot detector system.

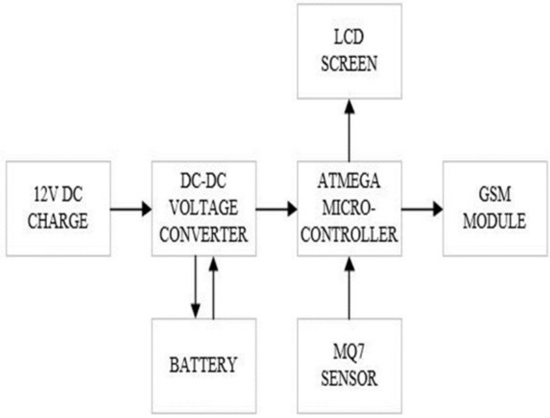

Figure 5: System block diagram

The developed nodes, which were in charge of wirelessly sensing and transferring the data, were displayed. The central node of the network, a gateway, received this data. The user was then able to control the network, prepare the data, and establish a connection to the SMS. Additionally, the entire procedure was necessary and applied to the data-processing jobs. Finally, utilizing a GSM module, the SMS system's services for data saving and classification sent a real-time signal to the end user.

2.7 Computation for Design Specifications

We need a voltage regulator; hence an LM7805 is required for the design.

LM7805 IC Rating:

i. Output voltage range V_{Max}=5.2V, V_{Min}=4.8V
ii. Input voltage range 7V-35V
iii. Current rating Ic = 1A

Finally, to make the device wireless, we used a SIM 800L GSM module; as a result, a registered user's mobile number is embedded in the code. The device reads black soot values every two minutes, and the GSM module reads those values from the microcontroller and writes them by sending an SMS through a registered sim card inserted into the GSM module (GLO network preferably). The soot detector system was designed and constructed based on the characterization of the soot as shown in Figure 6.

Figure 6: Soot detector system

3. RESULTS AND DISCUSSION

The soot sample was characterized using FT-IR to determine the functional groups that are present. The FT-IR spectrum in Figure 7 shows FT-IR bands that were present in the soot sample.

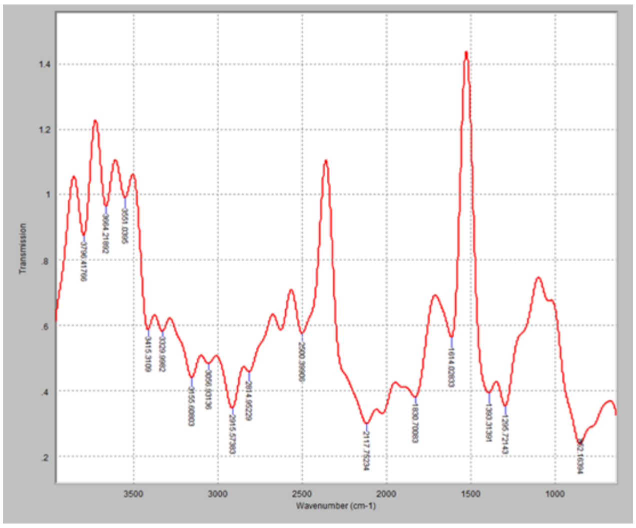

Figure 7: FT-IR characterization of the soot sample

For the soot characterization, the functional groups present in the spectrum identify the presence of NO_2, CO, SO_4, CH_4, H_2S, CO_2 and NH_2.The results of the GC – FID analysis of the soot sample showed that it contains varying amounts of NO_2, CO, SO_4, CH_4, H_2S, CO_2 and NH_2. These are the gaseous composition of soot. The types and amounts of the different soot compositions are listed in Figure 8.

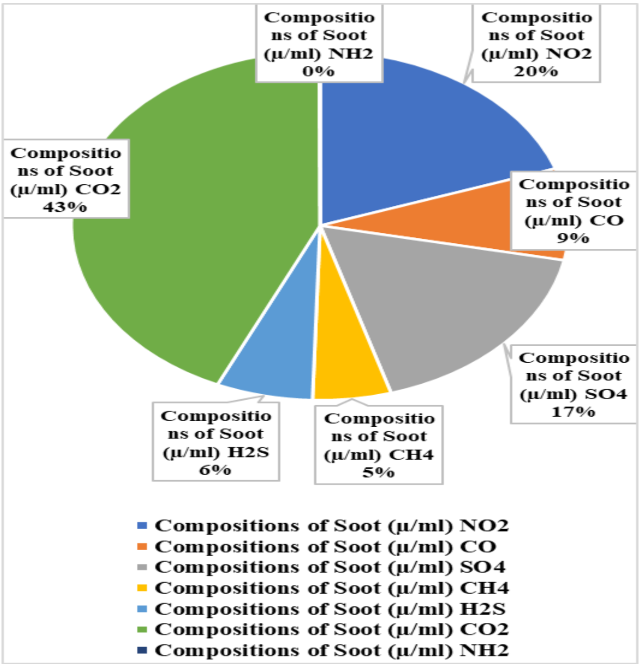

Figure 8: GC – FID analysis of the soot sample

Different concentrations have been performed to test the operation of the system. First, the conditions and configuration of the measurements are described. Then, the processing procedure and the results obtained are presented. Figures 9 and 10 show the output data from the measurement of soot with the constructed detector system.

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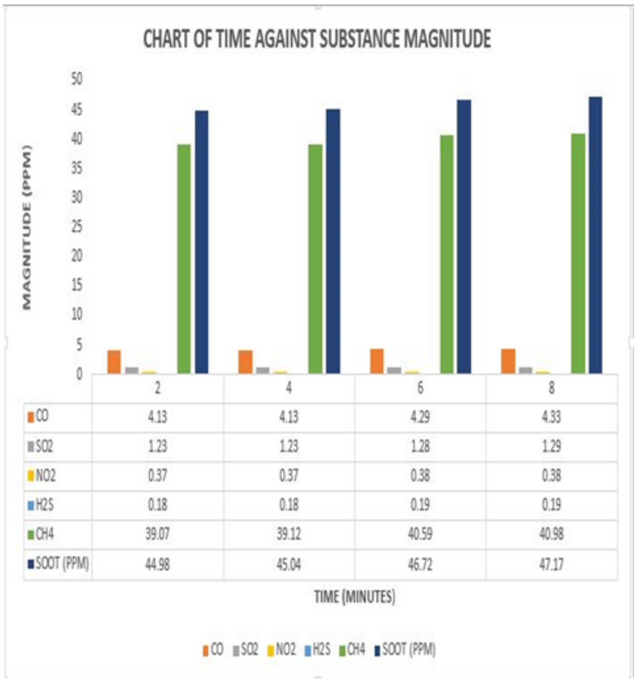

Figure 9: Output from the measurement of soot from an artificial burned area

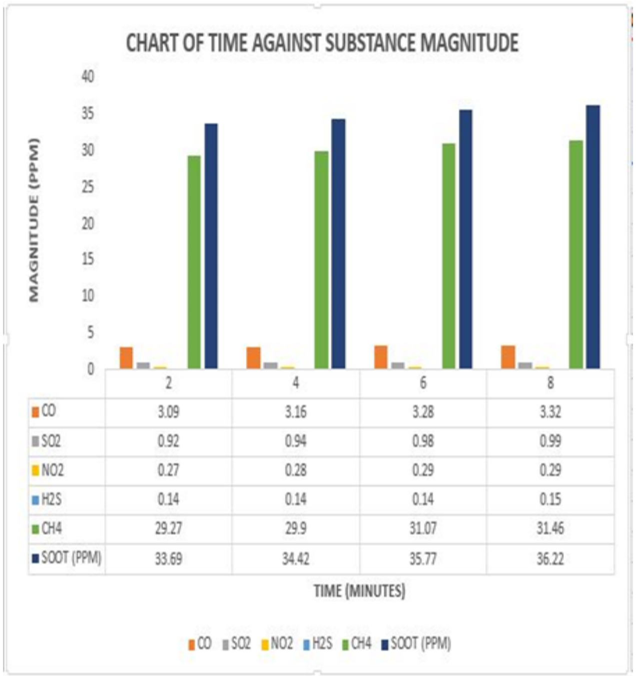

Figure 10: Output from the measurement of soot from a control room.

Figure 5, FT-IR spectrum depicts the FT-IR bands that were found in the soot sample. The functional groups in the spectrum may be used to characterize the soot by pointing out the presence of NO_2, CO, SO_4, CH_4, H_2S, CO_2, and NH_2. A modern technique called Gas Chromatography - Flame Ionization Detector (GC - FID) provides trustworthy proof of the kinds and concentrations of compositions contained in a particular sample. The soot characterization GC-FID research findings revealed that it includes various concentrations of gases. NO_2 3.2833 /ml, CO 1.4167 /ml, SO_4 2.8712 /ml, CH_4 0.849 /ml, H_2S 1.0472 /ml, CO_2 7.2015 /ml, and NH_2 0.0076 /ml were the values for the various compositions.

The existence of these components in soot is confirmed by the FT-IR and GC-FID analyses. At the designated time, each sensor module sends to the GSM module the current NO_2, CO, SO_4, CH_4, H_2S, CO_2, and NH_2 levels. The monitoring of outside circumstances for the presence of soot sends data to a GSM module is shown in figure 7 and Figure 8.
The results of the current investigation further demonstrate that the detector system could detect changes in soot concentration in real time and identify soot in various conditions.

4. CONCLUSION

The study provided a description of soot and designed and built a wireless system to track soot. According to current studies, the soot compositions contain NO_2, CO_2, NH_2, CO, SO_4, CH_4, and H_2S. Some functional groups associated with the presence of NO_2, CO_2, NH_2, CO, SO_4, CH_4, and H_2S were seen in the FT-IR spectra. A sensor-detecting system was created and built for the monitoring and detection of soot based on the indicated compositions. By detecting and announcing its presence via a wireless SMS communication network, the soot discovered was effectively measured.
According to the results, wireless sensor networks are an effective method to deliver data

on multiple temporal and geographical scales in this respect. It was demonstrated here that low-cost, dependable, and selective gas sensing nodes are in fact possible. The cost of each individual sensing node is the limiting issue. Future study will involve the installation of several nodes in the monitoring region, testing under actual conditions, and sensor field calibration.

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