LAUTECH Journal of Engineering and Technology 18 (2) 2024: 122-127
10.36108/laujet/4202.81.0211

Implementation of a sustainable real-time air quality monitoring system using the Internet of Things (IoT) for Kaduna metropolis, Nigeria.

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Article Info

Article history:

Received: May 4, 2024
Revised: June 9, 2024
Accepted: June 12, 2024

Keywords:

Air Quality Monitoring System, (AQMS) Carbon Monoxide (CO), Internet of Things (IoT).

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ABSTRACT

The environment is sustainable if it is free of air, water, and soil pollution. This agrees with the United Nations Sustainable Development Goal Three (SDG3). However, urbanization and industrialization have aggravated the rise in air pollution which are hazardous to both human health and society. The ingestion of large quantities of air pollution gases is one of the greatest health risks in the environment which often leads to brain damage, loss of consciousness at high doses, or death. Some common sources of carbon monoxide (CO), the most severe of these gases, can be traced to the incomplete combustion of cars' fuel, malfunctioning equipment, clogged chimneys and vents, and interior use of portable generators. Traditional ways of monitoring pollution are laborious and involve inefficient processes. To address this challenge, this paper implemented a real-time Air Quality Monitoring System using the Internet of Things (IoT) to measure the concentration of CO. The IoT devices were used to collate data within specific areas. The data collected, by the sensor, were processed using an application written in C/C++. The system also includes a user interface that allows users to view real-time air pollution data and receive alerts when pollution levels exceed the safe threshold. The system was tested in different environments, Air Force Institute of Technology and Kawo; densely populated areas of Kaduna State, Nigeria. The result obtained within the selected location in AFIT, the Parts per million (PPM) of CO ranges from 0.4 ppm to 0.7 ppm with Boy's Hostel being the worst area to stay. In the Kawo area, the threshold ranges between 0.4 and 0.8 with Kawo Bridge being the worst among the locations. This was done to demonstrate the high level of accuracy and reliability of the system. The correct implementation of the developed system has the potential to be used as a tool for researchers, and for the general public to better understand the problem of air pollution.

INTRODUCTION

One of the most essential components of man's environment is air. The Earth's atmosphere is full of air containing gases such as Nitrogen, Oxygen, Carbon Monoxide (CO), and traces of rare elements (Okokpujie *et al.*, 2018). An atmosphere free of pollutants is necessary for human survival. Air pollution is a major environmental problem that affects people across the globe. It can cause a variety of health problems, including respiratory diseases, cancer, and heart disease (Mani *et al*., 2021). Climate change is also largely caused by air pollution. Traditional air pollution monitoring systems are typically based on fixed sensors in specific areas (Al-Ali *et al*., 2010). Changes in the natural composition of air may cause grave harm to the body system (Petrica *et al*, 2023). When pollutants, such as CO, are present in the atmosphere, in large amounts, harm people, animals, or plants (Dhingra and Bhalla 2019; Mani, Viswanadhapalli, and Sriramalakshmi, 2021).

Air pollution is a significant environmental problem that affects the health and well-being of people globally. In a year, about seven million premature deaths have been linked to air pollution (WHO, 2023). In Nigeria, air pollution is a significant environmental problem that affects the health of the people in urban areas. The rise in air pollutants can be linked to industrialization, urbanization, and increased vehicular emissions which then pose a serious threat to public health. Conventional methods of monitoring air pollution often involve manual data collection, which can be time-consuming and limited in accuracy (Senthilkumar, Velayutham, and Balaji, 2020). However, with the advancement in Internet of Things (IoT) technology, one can develop a real-time IoT-based Air Quality Monitoring System (AQMS). This will help in addressing the challenges associated with air pollution. This article focuses on how to address a major component of the United Nations Sustainable Development Goals (SDG), the environment.

In the work of Kularatna and Sudantha (2008), a concept of developing an IoT-based air pollution monitoring system involving the use of sensors to detect and measure the concentration of pollutants in the air was proposed. The data collected by the sensors is processed into a format suitable for performing Artificial Intelligence functions thus, allowing the system to perform a relatively accurate analysis on the data set. The system was designed to be cost-effective, reliable, and easy to use. However, these features were not adequately achieved. Ayele and Mehta (2018) probed the application of an Artificial Intelligence pollution monitoring system that used a combination of sensors and machine learning algorithms. The system was tested in a real-world environment however the circuitry is complex. Ha, Metia, and Phung, 2020), investigated an air pollution monitoring system that uses a combination of sensor and machine learning algorithms to provide real-time data on air quality. The system was tested in a controlled environment and was found to be reliable and accurate. The system was expensive and it is not user-friendly. Jo *et al* (2020) presented a real-time air pollution monitoring system that uses sensors, microcontrollers, and machine learning to provide data on air quality. The system was tested and was found to be slightly stable. Tooki, Olukolade, and Odaba (2022) proposed an energy harvesting system that can be used in powering systems such as AQMS.

The implementation of an IoT-based air pollution monitoring system involves the use of sensors to detect and measure the concentration of pollutants in the air. Studies have been conducted on the implementation of air pollution monitoring systems, and the results have shown that the systems are either not reliable or cost-effective. The proposed system aims at implementing an air monitoring system that is reliable, durable, and cost-effective.

METHODOLOGY

The setup includes IoT devices, an MQ-7 sensor, and microcontrollers capable of measuring dangerous gases, temperature, and humidity. In the implementation, a buck converter was used to step down the voltage of the input to achieve the required output. Two 5V Batteries were connected to power the electric current. The ESP32 DEV Board was used as a host MCU to reduce communication stack overhead on the main application processor. The wi-fi was configured to collect data at regular intervals and establish a communication protocol for data collection and transmission. The data collection mechanism is done to gather real-time readings from the IoT devices and sensors and transmit the collected data, securely, to a central database/cloud platform for storage and processing. This system utilizes an IoT sensor, MQ-7, to collect data on air pollutants, such as carbon dioxide (CO). The collected data is then stored for further analysis. The processed data is then displayed on a user-friendly interface, allowing users to access and understand the current air quality conditions.

Another approach is real-time data analysis and visualization. This was used to implement real-time data processing to analyze incoming data from the sensors, calculate air quality indices, and display the analyzed data on the user interface through dynamic and informative visualizations. The System was integrated with the IoT devices, sensors, microcontrollers, and data visualization components to work together seamlessly; and ensure proper synchronization of data streams and real-time updates on the user interface.

Performance evaluation was conducted through comprehensive testing of the entire system, including sensor accuracy, data transmission reliability, IoT model predictions, and user interface functionality. A comparison of the IoT model's predictions with actual air quality measurements to assess its accuracy was carried out; and feedback, potential users were invited to test the web/mobile interface and provide feedback on its usability and effectiveness. Necessary adjustments were made based on user feedback to enhance the user experience. The implementation Flowchart is shown in Figure 1. The Figure gives the sequential procedure followed in the implementation of the system.

These include; the system setup, the integration of IoT devices, performance analysis, and the comparative analysis. The server uses IoT to analyze the data and provide real-time information on air quality.

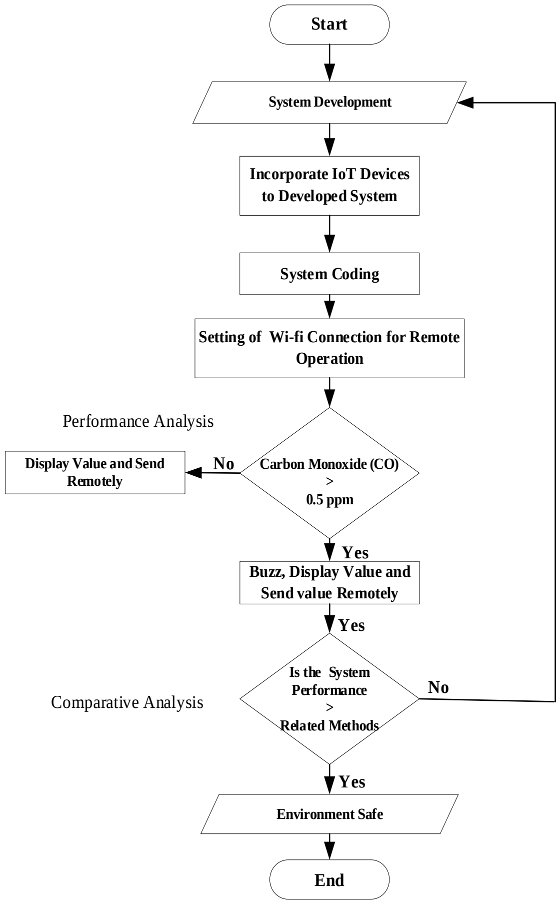

Figure 1: Implementation Flowchart

RESULTS AND DISCUSSION

Results

The system has been successfully implemented and constructed and is currently collecting real-time data on air quality levels. The data collected by the system has been analysed to identify trends and patterns in air quality levels. The results of the analysis have shown that air quality levels vary significantly throughout the day and night. The system has also been able to identify the level of air pollution. The system has successfully collected and transmitted real-time data on air quality levels. The system has the potential to provide valuable insights into air quality trends and patterns, enabling users to make informed decisions about their health and well-being. In addition, the system can be used to identify and address air pollution hotspots, contributing to improved air quality overall. Tables 1 and 2 summarize data obtained from the two locations in Kaduna, Nigeria. The locations are the Air Force Institute of Technology (a hybrid institution with a blend of military and civilian students) and Kawo one of the densely populated areas of the Kaduna metropolis. Also, Kawo is an industrial and commercial centre. The justification for these locations is the assess the air quality status of these densely populated areas.

3.2 Discussion and Findings

Based on the collected data, several key findings emerged. Firstly, the system detected higher levels of CO in Kawo areas and AFIT, Kaduna. This highlights the impact of human activities and industrialization on air quality. Additionally, the system identified peak pollution hours of 13:00hrs in AFIT and 18:00hrs in the Kawo area; suggesting specific times when pollution levels were higher and requiring targeted interventions. The study also indicates that the IoT-based air quality monitoring system is a valuable tool for providing real-time data on air quality levels. The system has the potential to provide valuable insight into air quality trends and patterns, enabling users about their health and policymakers to make informed decisions about the well-being of the citizenry. These findings emphasize the importance of considering meteorological factors when analysing air quality data. Secondly, the graphs also enunciate the level of concentration of CO at a certain time; and give insights on how to take preventive measures.

The system is capable of revealing the concentration of CO per ppm (parts per million) which is from 0.1ppm – 0.8ppm, between 0.1ppm - 0.4ppm is good air, from 0.4ppm – 0.6ppm is moderate air while from 0.6ppm – 0.8ppm is bad air. In good air, the concentration of CO is low and considered safe, in moderate air, the concentration may be slightly higher but still within acceptable limits.

Table 1: Air Quality Metrics of AFIT and Environs

S/N	Location	Date	Time (hrs)	CO (ppm)	Remarks
1	AFIT Headquarters	2023-11-13	15:00	0.4	Good air
2	200 Level Classes	2023-11-13	18:00	0.5	Moderate air
3	Boy’s Hostel	2023-11-14	15:00	0.7	Bad air
4	Girl’s Hostel	2023-11-14	18:00	0.5	Moderate air
5	L-R Classes	2023-11-15	15:00	0.5	Moderate air
6	Ibrahim Alfa Hall	2023-11-15	18:00	0.4	Good air

Table 2: Air Quality Metrics of Kawo Area and Environs, Kaduna

S/N	Location	Date	Time (hrs)	CO (ppm)	REMARKS
1	Abuja Street	2023-11-17	15:00	0.6	Moderate
2	Kawo Bridge	2023-11-17	18:00	0.8	Bad
3	Sabon Birni Road	2023-11-18	15:00	0.5	Moderate
4	Adama Close	2023-11-18	18:00	0.7	Bad
5	Lere Street	2023-11-19	15:00	0.5	Moderate
6	Yoruba Street	2023-11-19	18:00	0.4	Good

However, in bad air, the concentration is high and can be harmful to breathe, it is important to be aware of air quality and take necessary precautions. This system enables real-time monitoring and data analysis, helping us make informed decisions to create a healthier environment.

CONCLUSIONS

The creation of an IoT-based air quality monitoring system was a major endeavour to give real-time data on air quality levels in the surrounding area. This system collects data on CO, using a sensor. The data obtained is subsequently sent to a central server for processing and analysis. The processed data is then displayed on a user-friendly interface, allowing users to access and comprehend the current state of air quality. The IoT-based AQMS alerts citizens on the danger posed by excessive concentration of CO and prompts them to take appropriate actions. It is a robust system capable of real-time data collecting and analysis using cutting-edge sensor technology and seamless connection. The system can give accurate and fast air quality information in critical areas, allowing users to easily obtain crucial data. In summary, the IoT-based AQMS contributes to knowledge both through its technological innovation and the abundance of data it provides, which allows for a deeper comprehension of air quality dynamics.

The developed system is a useful tool for academics, policymakers, and environmentalists to make homes healthier and cleaner and to make informed decisions about the health risks associated with air pollution. This work further enhances monitoring and tracking health indicators towards achieving a substantial reduction in illnesses from air pollution which thus aligns with Sustainable Development Goals 3.9.1 and 11.6.2 that target improving air quality around our environment.

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