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Air pollution monitoring system using wireless sensor networks and cloud computing

[1*]OBIRA O J., [3]LYMO M F., [3]HENRY S

[1]School of Computational and Communication Sciences and Engineering, The Nelson Mandela African Institution of Science and Technology (NM-AIST), P.O. Box 447, Arusha, Tanzania
[2]Faculty of Engineering, International Business Science and Technology University (ISBAT), Kampala, Uganda
[3]School of Computational and Communication Sciences and Engineering, The Nelson Mandela African Institution of Science and Technology (NM-AIST), P.O. Box 447, Arusha, Tanzania

***Corresponding Author**: okelloj@nm-aist.ac.tz

Abstract

Air pollution is the availability of pollutants and other particles in the air which affect its quality. The common sources of air pollution include vehicle and industrial emissions, bushfire and volatile organic compounds. Over 80% of the urban dwellers are exposed to air pollution especially in low and middle-income countries. With most African countries embracing industrialization coupled with rapid urbanization, air pollution is swiftly becoming a serious concern due to the associated health risks. Globally, about 4.2 million people die annually from diseases attributed to air pollution. This paper presents a mechanism of using sensors to remotely monitor air pollution. The monitored data are then sent to the cloud database in real time using an internet connection. The materials used include an Arduino Uno, ESP8266 module, carbon monoxide and smoke sensors. The approach involves connecting an ESP8266 wireless module, smoke and carbon monoxide sensors to the Arduino board using jumpers. Results revealed that data is collected by the sensors, processed by Arduino and sent to the cloud for storage and analysis. The cloud service visualizes the received data in a graphical format for easy analysis whereas a spreadsheet document can also be extracted for offline analysis. In conclusion, a system capable of monitoring smoke and carbon monoxide pollutants has been proposed. This system is effective in sending the monitored data to a cloud database in real time. Policy makers, governments, and different stakeholders such as environment authorities should embrace such systems and also sensitize the citizens on the dangers of air pollution.

Keywords: *Arduino; sensors; air pollution; ESP8266 module*

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Introduction

Air pollution is the availability of pollutant substances and other particles in the air which affect the air quality. Air pollutants are a combination of substances which are either toxic gases or particulate matter (PM) (Okoko, 2019). The most common toxic gases include carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), oxides of nitrates (NOx), oxides of Sulphur (SOx), and ozone (O_3) (Okoko, 2019). Outdoor air pollution is becoming a huge danger to the environment due to the increasing industrial emissions from the industrial advancement in the world (Sagar and Bhanarkar, 2016).

The effects of these pollutants depend mainly on the level of concentration and the duration of exposure. However, a less concentration of the pollutants for a longer duration can still be dangerous to human beings. Smokes from wildfires, burning bushes are common sources of gases such as CO. Smaller concentration of CO like 100 percentages per minute (ppm) can result into dizziness and headache after a longer period of exposure. While higher concentrations for instance 3200 ppm can lead to death when there is longer duration of exposure. However, longer exposure to very high concentrations for instance 12800 ppm can lead to unconsciousness and eventually deaths. More than 80% of individuals in cities especially those of low and middle-income countries are at risk of the effects of poor air quality due to the high concentration levels of air pollutants in the atmosphere (WHO, 2013). The World Health Organization (WHO) puts the figure of individuals who die annually due to exposure to air pollution to about 4.2 million. In 2016, ambient air pollution was reported to have caused 4.2 million premature deaths, with almost thirty thousand being under the age of five (TW, 2004). Therefore, air pollution monitoring systems especially using sensor networks and cloud computing is quickly being adopted to curb the associated dangers of air pollution exposure to human beings and the environment. Wireless sensor networks (WSNs) are a group of sensor nodes communicating to one another wirelessly. WSN was initially mostly used in the military for battlefield surveillance however, today they have gained popularity in many industrial process monitoring, consumer applications, health monitoring, and industrial automation (Rajeswari and Pratheeba, 2014). For instance, cloud computing and WSNs have been used successfully to monitor heartbeat rate and body temperature readings for chronic patients in remote areas (Okello and Sinde, 2021). The benefits of WSNs in terms of low cost, low power consumption, reliability and less maintainability efforts, makes it a better option for environmental monitoring (Duzce, 2017). These WSNs use different communication protocols which include among others ZigBee, Bluetooth and Wireless Fidelity (Okokpujie *et al.,* 2018).

Many research works have been done in this area of wireless sensor networks especially in the fields of military and industrial automation. However, little attention has been put on utilizing low cost wireless sensors in air pollution detection and cloud computing for visualization, analysis and data storage. This work brings in the element of using WSNs and cloud computing services to store, visualize and analyze data on the cloud. The developed system monitors CO, and smoke pollutants sending the processed data to the cloud database in real time.

In many countries, researchers and organizations have been doing research and publishing several papers about air pollution. Several systems have been proposed for monitoring of air pollution using several concepts and mechanisms. However, most of the systems use complex and expensive hardware and software, ignoring the cheap alternative of free cloud services. Some of the previously proposed air monitoring systems include those discussed below.

An Environmental Air Pollution Monitoring System (EAPMS) that monitors the amount of some air pollutant such as gases has been developed which uses the IEEE 1451.2 standard (Kularatna and Sudantha, 2008). The EAPMS system detect quantity of air pollutants like CO, NO_2, SO_2, and O_3 by means of semiconductor sensors. Here a smart transducer interface module (STIM) using ADuC812 micro converter chip is used. The smart transducer interface module is connected to a Network Capable Application Processor (NCAP) by means of a personal computer. Three gas sensors are used and the level of gas concentration is shown on a graphical user interface of the NCAP. The EAPMS can also be used to alarm when the amount of pollutants exceeds the allowable levels (Kularatna and Sudantha, 2008).

In Doha a wireless sensor system that monitor and analyze air quality has been proposed. The system uses a back-end server that relay data in real time. The data stored on the back-end servers are later processed and analyzed to come up with different formats that suits different purposes. The system focus on computation mechanism of air quality index to allow easier data dissemination to the general public. Furthermore, they described different ways of data presentation using various software modules for friendly use by environmental authorities. Here some of the software systems suggested include R software system and Open-Air package for assessment and analysis of the real time data received (Yaacoub *et al.*, 2013).

The important element that has been included in the proposed system is the idea of using software as a service, embracing the use of free cloud analytic tool and service.

Materials and methods

Developed Air Pollution Monitoring System

The developed system uses Arduino, ESP8266 wireless module, MQ7 and MQ135 air quality monitoring sensors, and Thingspeak cloud service. WSNs are made of sensors which collect data from the targeted area and transmit it to the cloud via an internet connection. The Arduino board is the main device in this WSN node. The Air quality will be monitored by smoke, and carbon monoxide gas sensors. The sensed data is then sent to the cloud database for visualization, analysis and storage using the ESP8266 wireless module. The MQ135 sensor is connected to analog pin A3 of the Arduino board while the MQ7 sensor is connected to the analog pin A2. The general system set up is illustrated in Figure 1.

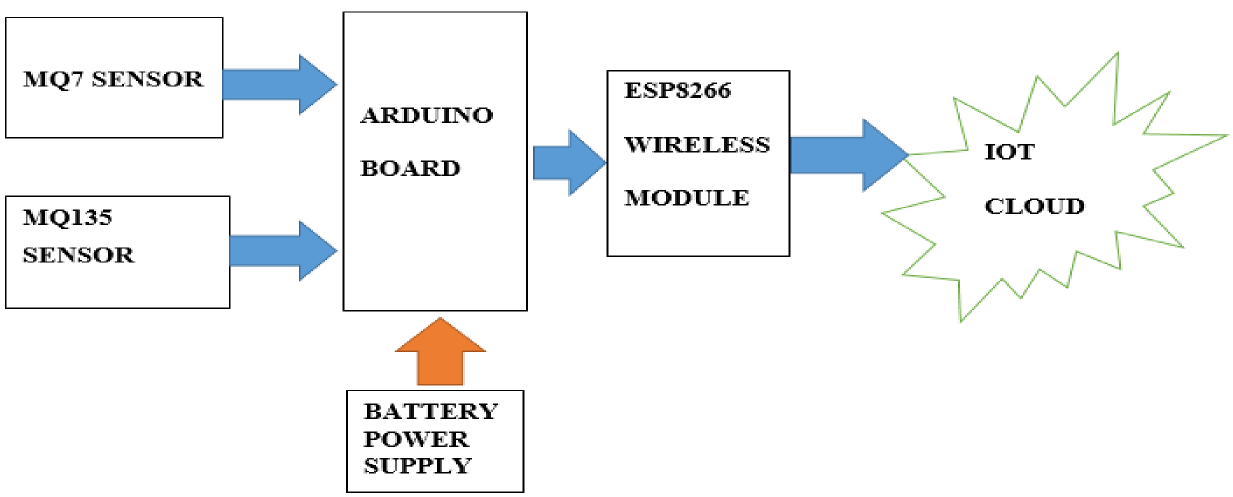

Figure 1: General Setup of the System Hardware

Hardware Requirements

The hardware materials used for making the proposed system is summarized in Table 1.

Table 1: System Requirements

S/N	Component Required	Quantity
1	Arduino Uno	1
2	MQ7 CO Sensor	1
3	MQ135 smoke Sensor	1
4	ESP8266 wireless module	1
5	Battery	2
6	Jumper wires	1 packet

Arduino UNO

Arduino Uno is an embedded development board with different pins for analog, digital signal and pulse width modulation (PWM) interfacing. Arduino include an integrated development environment (IDE) for programing. The Arduino development board in Figure 2 is used to interface sensors which is use to collect data from the environment.

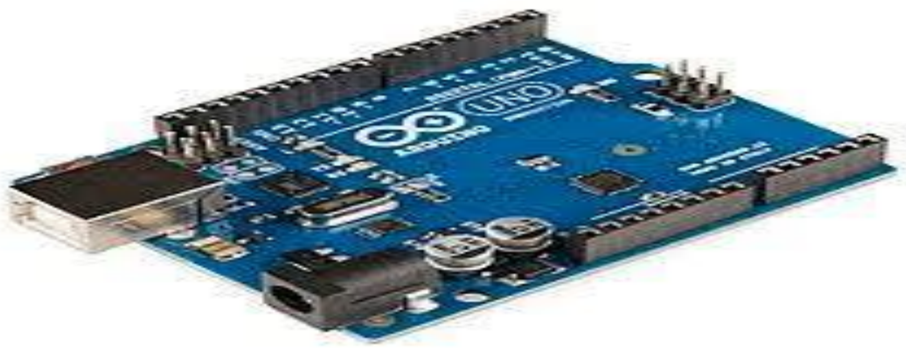

Figure 2. Arduino Uno

MQ7 Sensor

MQ7 gas sensor is used to detect the presence of carbon monoxide in the environment. It is effective when the carbon monoxide concentrations are between 10 to 10000 ppm. The threshold of CO is 200 ppm and beyond that it becomes harmful and dangerous to humans leading to various health risks and diseases. The MQ7 illustrated in Figure 3 has four pins namely; power pin, ground pin, digital pin and analog pin. The Analog out pin is used in order to measure the gases in ppm, while VCC and Ground pins are connected to 5V power and ground respectively.

Figure 3. MQ7 Sensor

MQ135 Sensor

The MQ-135 sensor shown in Figure 4 is used for air quality management since it is capable of sensing a wide range of gases which include; Ammonia (NH_3), Nitrogen dioxide (NO_2), Alcohol, Smoke, Benzene and Carbon dioxide (CO_2). In this system, we have used MQ135 to sense smoke. It can also detect CO_2 concentration from 10 to 1000 ppm, Alcohol concentration from 10 ppm to 300 ppm and Benzene concentration from 10ppm to 1000 ppm. The threshold of CO_2 is 400 ppm and beyond that it becomes dangerous to humans leading to various health risks and diseases. The MQ135 analog pin is used in order to measure the gases in ppm, while power pin and ground pins are connected to 5V power and ground respectively.

Figure 4. MQ135 Sensor

ESP8266 Wireless Module

The ESP8266 wireless module provides a complete wiFi internetworking alternative either as a standalone host receiving internet connection from a router or as a master giving internet connection to other hosts.

For this system the ESP8266 module pin connections were as follows: Tx pin to pin 2 of Arduino, Rx to pin 3 of Arduino, VCC and CH_EN pins were connected to 3.3V and Reset respectively while the ground pins to GND of Arduino.

Results

Air pollution monitoring system was designed and developed. The system revealed that the air pollution from CO and smoke were detected, processed and sent to the cloud for storage, visualization and analysis. The developed system aids in creating awareness of the air quality and polluted air conditions.

The sensor data were analyzed and organized in graphical format in different channels. The channel receives real time data from the sensor nodes corresponding to different air quality. Figure 5 shows the collected data from CO and smoke sensors which were visualized by cloud analytic tool. A total of 3000 entries were collected and sent to the cloud analytic tool from the different sensors. The result indicated that CO values collected by the sensor were mostly below 307ppm and the smoke values were mostly below 385ppm. The threshold value for CO concentration is about 200ppm therefore, the system was able to detect CO pollution effectively. Longer exposure to smoke with concentration beyond 150ppm is considered harmful to human beings.

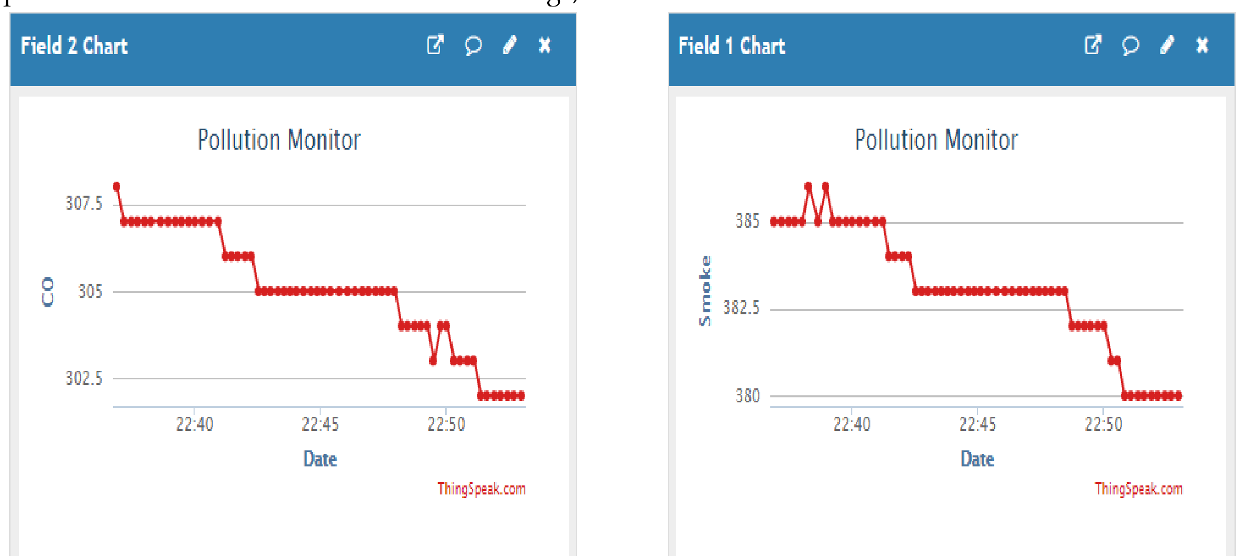

Figure 5: ThingSpeak Capture of Sensed Data

Discussion

This work utilized the concept of cloud computing and wireless sensor networks to develop the system. The wireless communication using ESP8266 module was used to send sensor data to the cloud. A total of 3000 sensor values were captured and visualized using ThingSpeak cloud analytics for both smoke and CO pollutants.

In Doha, for instance, an air pollution monitor using wireless sensors and R software for analysis has proved to be effective (Yaacoub *et al.*, 2013). An Environmental Air Pollution Monitoring System (EAPMS) that uses a semiconductor sensor and Network Capable Application Processor (NCAP) software installed on a personal computer for visualization and analysis has been proposed (Kularatna and Sudantha, 2008). From the above, it can be concluded that wireless sensor networks are a reliable mechanism for detecting air pollution.

From the findings of this study, it can be concluded that the cloud analytics is an effective alternative to R and NCAP analysis software. Additionally, the proposed system stores the data in the cloud which brings in the element of safety as opposed to the previously developed systems that stores the data in the local machine.

The system did not incorporate the global positioning system (GPS) coordinate system in order to reduce on the cost however, this makes it a bit difficult to pin-point the exact location where the harmful levels are coming from. In this work the challenge is resolved by considering each channel to indicate sensor values coming from one particular location for easy identification. It is recommended for the system to provide very precise locations a compromise of cost can be made and a GPS module added in the system.

Conclusion

A system for monitoring and relaying air pollution data to the ThingSpeak cloud database was designed and developed. The MQ135 and MQ7 sensors were used to build the wireless sensor network to sense smoke and CO pollutants respectively. The Arduino board was used to process the data from different sensors and forwarded to the cloud database via an ESP8266 wireless module. ThinkSpeak cloud service was configured, and tested to display sensor data in real time. The proposed system utilizes an ESP8266 wireless module for sending sensor data to the cloud for storage, visualization and analysis. This proposed system once fully deployed will be capable of providing real time air pollution data to environmental authorities. This proposed system has a number of benefits which include monitoring and displaying real time air pollution data to the cloud database. The system can be used in harsh environments and risky areas where human involvement may be dangerous. This system, when implemented, will aid decision-making processes of environmental authorities when handling and dealing with air pollution challenges and associated health and environment threats.

Recommendations

This system can be further improved by incorporating a mobile application so that pollution levels can be displayed on a mobile interface in real time. Governments, policy makers, and stakeholders like environment authorities should embrace such systems and also sensitize the citizens on the benefits of a clean environment while pointing out the dangers of air pollution.

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