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Air Quality Monitoring Using IoT Cloud Framework in Underground Mining

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Abstract

The quality of air is a major concern nowadays; this is due to its crucial impact on human beings. Maintaining a good and healthy environment in a closed area depends heavily on the atmosphere. The primary difficulty lies in upholding air quality within an enclosed workplace setting. The conventional way to measure the quality of air was to collect the air quality samples by the fixed instruments in fields and measure the index in laboratories but with advances of Micro electromechanical Systems (MEMS) and Internet of Things (IOT) devices, the purity of air can be monitored in real time. This can be possible for the IOT enabled devices to collect the important data from the site (UG mine) and send the information to the base station to take preventive measures to improve the air quality or may design a way and set standards by which we can make prior arrangements for safe exit of personnel. In this study, we propose an IOT based real time air quality monitoring system to the level air is pure and acceptable.

Keywords: Underground mining, IoT, cloud, framework, air quality

INTRODUCTION

Fossil fuel (coal) is of utmost demand because it plays an important role in all facets of life for fuel, in generation of thermal power, metallurgical process industry etc. However, of all industrial endeavors, underground mining is not only the most difficult, but also one of the riskiest ways to excavate.

The truth is that working in a very restricted environment like UG mining generate an extremely stressful environment to work with. In UG mining, many fatal accidents have occurred if we investigate the database of UG mining. The accidents have substantially reduced due the awareness created by mine safety and health awareness. Therefore, the safety of miners is of great concern in UG mining.

The normal mine air is comprised of around 78% nitrogen and 21% oxygen, along with carbon dioxide (CO_2) and other hazardous gases such as carbon monoxide (CO), methane (CH_4), nitrous oxides (NO_x), and hydrogen sulfide (H_2S) [1]. Today, air pollution is also a major threat to life, which is substantial challenge to researchers. The people are more concerned on health issues because of a high increase of particulate material as per WHO update on April s2022. People suffer from number of disease due to air pollution, difficulty in breathing, asthma, coughing, wheezing etc. Air pollution not only affects health, it affects every sphere of life, affecting the global environment, and global economy [2]. The impact of air pollution is tremendous. In a UG mine, it is a different environment, there is sudden change in the concentration of gases, and it is hazardous especially if poisonous gases are released. To detect

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the presence of poisonous gases earlier, before the invention of sensor technology, the miners used to take mice and canaries sensitive to specific gases such as colorless and fatal carbon monoxide [3]. Today, miners carry with them Gas Chromatographs and Mass spectrometers while going into a mine [4]. Detecting the poisonous gases inside a UG mine and alerting the mine personnel above a specific standard vale plays a vital role in underground mining.

So, for safe mining, gas wireless sensors need to be set up everywhere right through the UG mining environment and design an efficient monitoring system which can collect the real time data of toxic gases studying which we can give an alarm if the concentration of gas is beyond a threshold value. This can be done by building an efficient communication infrastructure. To prevent havoc, we need to continuously monitor the mining gases and ensure the atmosphere is free from poisonous gases and germs.

Today, with the advancement of Micro-Electromechanical System (MEMS) based sensors, cloud computing based techniques route towards the development of internet of things (IOT) and examine the status of UG mining environment. The IOT platform has proved to be a blessing in predicting the closed environment status by sending decisive information from remote site beyond the reach of humans.

In 1987, several devices were used in sensing the environment status, e.g., Pelistor was used, but due to false sensing and its heavy maintenance cost, was excluded from use, also, use of birds like canaries was also expelled by authorities. Later, Infrared (IR) based Gas sensors were used and this led to the use of gadgets inside UG mines.

In foreign countries, the mining sector has implemented latest technology gadgets in mining industry for safety purpose. Regardless of several modern gadgets like IOT, WSN, MEMS, etc., India has not adopted it inside UG mines. To support real time monitoring of ambient environment status inside a UG coal mine and to overcome the research gap of collecting gas samples manually by outdated instruments, we have a mission of exploring the scope and opportunities. This can be done with the help of latest tools and techniques, which will prevent miners against poisonous gases. Here it is important to deal with the issue how mining environment can be monitored in online mode by deploying WSN in IOT framework. It is seen in most of the researches that they use Zigbee based communication protocol for studying the status of the UG mines but none of the works have been implemented in industrial practices for successful and safe realization of IOT enabled devices in UG mines.

The objective of this study is to have a prerequisite in surveying and giving a best design to propose an IOT based real time remote monitoring of the UG environment status and giving a much early admonition for safety of miners. Here the proposed model addresses the issues by the following ways:

1. Design a network using MEMS sensor devices to capture ambient air and collect the gas and measure the concentration of it.
2. Propose a model using IOT enabled systems to supervise the UG mine environment.
3. Implement a cloud-based data analytic technique forecasting the UG mining environment.

The reaming part of this study is sequenced as per the following plan: It explains the purpose of motivation for the work; then it gives the literature survey behind the work; gives the key concepts like mine gas, air quality standard, air pollution monitoring equipment, gas sensors etc.; presents challenges in UG mining environment; mentions the proposed architecture of the underlying model for studying the environment; gives the proposed algorithm for air quality monitoring using IOT framework in UG mining; discusses the result and analysis made; and finally it presents the conclusion and discusses the potential for expanding the study for broader field applicability.

MOTIVATION

Today, there is high demand of mineral resources, which is an extremely profitable business in export and import. The mining industry has become a highly profitable business due to the need of mineral resources which results in unexpected increase of mining activities. Though UG mining is risky, the heavy demand for the mineral resource triggers the mining activity using modern tools and techniques.

LITERATURE REVIEW

UG mining activity is one of the risky activities and many contributions have been made by researchers all over the world. The researchers took the help of IOT and WSN devices to monitor the toxic gases and the concentration level of mining gases. Few underground mines, however, have used IoT-based wireless monitoring of ambient air quality in tunnels.

Kadir *et al*. proposed the design and development of a remote monitoring device and test bed based on the Internet of Things (IoT) to monitor indoor air quality (IAQ), Total Volatile Organic Compound (TVOC), temperature, and humidity [5].

Air quality sensors (BME680 and CCS811) were used in conjunction with an ESP32 microcontroller, which serves as the brain and sends data to the InfluxDB cloud database that is portrayed and monitored through the Amazon Web Server (AWS).

Osunmakinde investigated the presence of different types of hazardous gases, particulate matter suspension in the ambient air with the goal of generating knowledge and prevent diseases among the UG miners [6]. It developed some intelligent system of how the miners can boost their safety. He presented an autonomous remote monitoring framework based on WSN that brings together mobile sensing, Ohm's law, and ambient intelligence to guide and make decisions for miners. To address the humidity, precipitation and harmful carbon emissions in coal mines Hasan *et al*. suggested an IoT-driven Dynamic Sensor Information Control System (IoT-DSICS) [7]. To prevent serious and big accidents it integrates, Industrial Internet of Things (IIoT) with sensor networks and control systems. It used Industrial IOT Wi-Fi microcontroller system to monitor the prototypes and trigger an alarm upon dangerous situation. The outcome examines the potential of IIOT in UG mines their infrastructure and how they leverage the risk in a closed environment. Idrees *et al.* provides a comprehensive view of air pollution monitoring system (APMS) in which the work is divided into static and mobile air monitoring using different technologies monitoring devices, WSN and IoT devices [8]. They studied the different issues and provided the limitations that had to be dealt with in future. Cheng *et al.* presented the design, implementation and evaluation of the quality of air using a cloud based system [9]. In this paper, they used two methods to deal with air quality study. In one method, they used mechanical structures to monitor the particulate matter (PM2.5), in the second method, they used a cloud based study of the air quality monitoring by making an analytical study of data collected from the sensor data and found it to be better than using mechanical structures at low cost. Gonzalez *et al.* presented in their paper a description of long range sensor network (LoRa) for monitoring the air quality and leakage of gas [10]. They used commercial gas sensor along with a resistance measurement channel for grapheme chemo resistive sensors which helps in measuring the Air Quality Index (AQI) based on the concentration of air pollutants. The grapheme sensors used with LoRa can measure the pollution level of NO_2 in 5 min as well as can supervise the changes in the atmosphere if any. Wan and Khan [11] utilized this platform.

The suggested platform integrates monitoring, analysis, and localization methodologies through the utilization of Internet of Things (IoT), cloud computing, a real-time operational database, application gateways, and application programming interfaces. At the active Hassan Kishore underground coalmine, the prototype was tested and verified. Sensors for air quality measures such as temperature, humidity, CH_4, CO_2, and CO performed brilliantly when compared to their commercial counterparts, with regression constants always more than 0.97 for each parameter [12].

This system enables the immediate monitoring, detection of abnormal occurrences (>90% accuracy), and determination of a miner's position (with an error margin of 1.8 m) within the challenging conditions of deep mine environments. The primary contribution of this study lies in creating a versatile, budget-friendly, open-source platform that effectively supports the advancement of underground coal operations.

BACKGROUND TECHNOLOGY AND TECHNIQUES

Air Quality Standards

Most often, pollutants are released by human activity and sometimes by natural resources. It has been seen that most dangerous contaminants are found in the atmosphere, as shown in Table 1. Some six varieties are extensively studied and investigated like carbon monoxide (CO), carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Ground level Ozone (O_3), Sulphur dioxide (SO_2), Particulate matter (PM), lead (Pb). The effect of these contaminants can be found in previous studies [13–18].

Air Pollution Monitoring Equipment

Air pollution can be monitored using state of the art instruments to guarantee the accuracy of the quality data. To maintain the accuracy and quality of data, several tools are used, which include humidity controller, temperature controller, Hepa-filter and an integrated calibrator. These instruments are typically expensive, with high power requirements, massive volumes, and large weights as shown in Figure 1. Owing to technological advancements, inexpensive, compact environmental sensors with quick response times (in the range of seconds or minutes) are now readily available. Unfortunately, no portable ambient sensor with a cheap cost can match the data quality and accuracy of traditional monitoring devices (Table 2) [19].

Gas Sensors

A lot of gas detection techniques are available today, each of them having their advantages and disadvantages. The five most popular methods used now are solid-state sensors, non-dispersive infrared radiation absorption (NIDR), photo-ionization detector (PID), and electrochemical gas sensors. All of these sensors are cheap, light in weight and the response time of these sensors is fast.

Table 1. Details of health effects of pollutants.

Pollutants	Concentration	Health Effects	Properties
Carbon Monoxide	0.005%	• Slight loss of concentration • Not allowed to exceed 0.005%	• It is highly toxic in nature. • It is colorless, odorless, and tasteless gas, it is not noticed easily. • The specific gravity is almost equal to the specific gravity of air, it exists at all the levels. Hence the chances of its inhalation are very high.
Carbon Dioxide	• 0.03% • 0.5% • 2.0% • 3.0% • 5-10%	Diffusion of gas is rapid in blood stream, it affects the rate and depth of breathing • No effect • Ventilation of lungs increased by 5% • Ventilation of lungs increased by 10%. • Heavy breathing, panting • Severe headache, rapid exhaustion and collapse	• It is colorless, odorless, and slightly acidic. • The specific gravity is 1.519 • It has liquidity at 5ºC under a pressure of 31.4 bar
Nitrogen Dioxide	• 60 ppm • 100 ppm • 150 ppm • 200 ppm	• Minor throat irritation • The person may cough • The person faces severe discomfort. Later the person may suffer from Pneumonia. • It may be fatal.	• It has a pungent smell. • NO_2 cools down and gets converted to N_2O_4 and is a colorless gas. • The specific gravity is 1.519. • It is highly soluble in water and are very poisonous • The TWA (Time weighted average) value is 50 ppm.
Particulate Matter [6]	• 0–50 AQI • 51–100 AQI • 101–150 AQI • 151–200 AQI • 201–300 AQI • 301–500 AQI	• No Health Problem • Sensitive people must be prevented • Unhealthy • Very unhealthy • Hazardous	• The wind speed and temperature are the fundamental parameters in movement of the particulate matter or contaminants.

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Table 2. List of Equipment used for air quality measurement.

Contaminant	Equipment Used (Example)	Measuring Methodology Used	Precision	Scope
$PM_{2.5}$	Met one instrument BAM-1020 Beta Attenuation Monitor	Beta Attenuation	±1 μg/m^3	0–1000 μg/m^3
	Alpha sense OPC-N2 Particle Monitor	Light Dispersion	Not given	Not given
	Sharp Microelectronics DN7C3CA006 PM2.5 Module	Light obscuration (Nephelometer)	Not given	25–500 μg/m^3
PM_{10}	Teledyne Model 602 BetaPLUS Particle Measurement System	Beta Attenuation	±1 μg/m^3	0–1500 μg/m^3
	Met One Instrument Aerocet 831 Aerosol Mass Monitor	Light Dispersion	±10% of reading	0–1000 μg/m^3
	Alphasense OPC-N2 Particle Monitor	Light Dispersion	Not given	Not provided
	Sharp GP2Y1010AU Air Quality Sensor	Light obscuration (Nephelometer)	Not given	0–500 μg/m^3
CO	Teledyne Model T300U Gas Filter Correlation Carbon Monoxide Analyzer	IR Absorption with Gas Filter Correlation Wheel	±5% of reading	0–100 ppb or 0–100 ppm
	Aeroqual Series 500 with CO Sensor Head	Electrochemical Sensor	±0.5 ppm at 0–5 ppm or ±10% at 5–25 ppm	0–25 ppm
	Alphasense B4 Series CO Sensor	Electrochemical Sensor	Not provided	0–1000 μg/m^3
	Hanwei MQ-7 CO Sensor	Solid-state Sensor	Not provided	20–2000 ppm
NO_2	Teledyne Model T500U Nitrogen Dioxide Analyzer	Cavity Attenuated Phase Shift Spectroscopy	±5% of reading	0–5 ppb or 0–1 ppm
	Aeroqual Series 500 with NO_2 Sensor Head	Electrochemical Sensor	±0.02 ppm or 0–0.2 ppm	0–1 ppm
	Alphasense B4 Series NO_2 Sensor	Electrochemical Sensor	Not provided	0–20 ppm
	SGXSensorTech MiCS-2714 NO_2 Sensor	Solid- State Sensor	Not provided	0.05–10 ppm
O_3	Teledyne Model 265E Chemiluminescence	Chemiluminescence Detection	±0.5% of reading	0–100 ppb or 0–2 ppm
	Aeroqual Series 500 with O3 Sensor Head	Solid-State Sensor	±5 ppb	0–150 ppb
	Alphasense B4 Series O_3 Sensor	Electrochemical Sensor	Not provided	0–5 ppm
	Hanwei MQ-131 O_3 Sensor	Solid-State Sensor	Not provided	10–1000 ppm
SO_2	Teledyne Model 6400T/6400E Sulfur Dioxide Analyzer	UV Fluorescence	±0.5% of reading	0–50 ppb or 0–20ppm
	Aeroqual Series 500 with SO_2 Sensor Head	Electrochemical Sensor	±0.05 ppm at 0–0.5 ppm or ±10% at 0–0.5 ppm	0–10 ppm
	Alphasense B4 Series SO_2 Sensor	Electrochemical Sensor	Not provided	0–100 ppm
	Hanwei MQ-136 SO_2 Sensor	Solid-State Sensor	Not provided	0–200 ppm

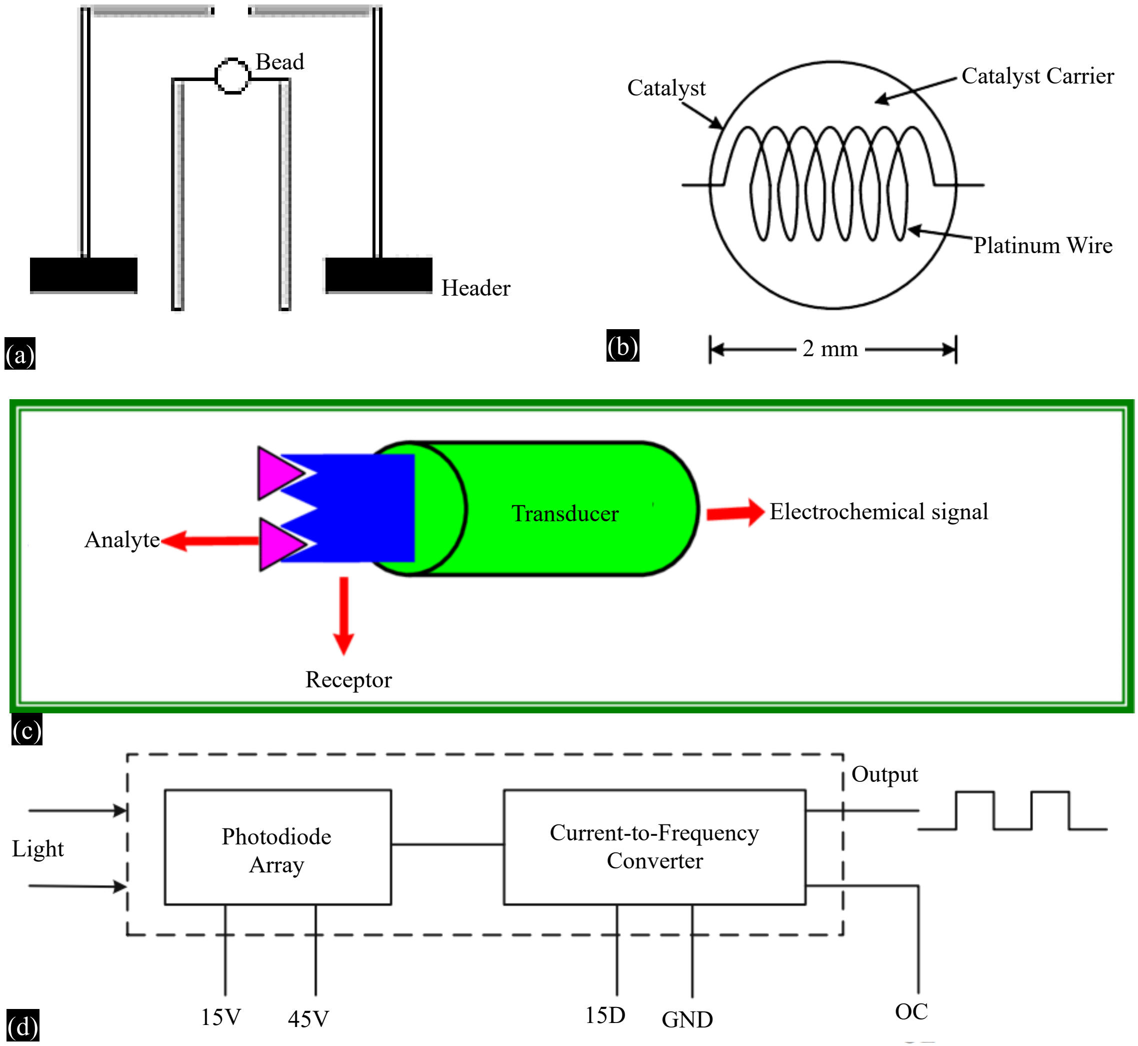

Figure 1. Sensors used for air quality monitoring.

As we know, there is no single type of sensor, which can measure all of the hazardous gases at a time. Therefore, we calibrate the sensors as per our need and type of gas (Calibration means exposing a sensor to a specific type of gas). Details of the calibration process can be found in the paper by Chiang *et al*. [20].

In this setting, we observe and track four distinct gas varieties, specifically Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), and Ozone (O_3). The need for calibration and calibration process can be found from the study by Moridi *et al*. [21]. Comparing with respect to sensor detectable gases [22, 23], its linearity, energy consumption, sensitivity with other gases, comparing the response times and the life expectancy, two best sensors are determined for the study of the above characteristics of gases, as shown in Table 3.

- *CO:* The gas can be detected effectively using the Solid-state and electrochemical sensors.
- *NO_2:* This gas can be effectively detected by the use of Solid-state and electrochemical sensors.
- *O_3:* Ozone can be detected by using Solid-state and electrochemical sensors effectively. The interfering gas O_3 must be taken into account and appropriate techniques must be used to minimize the interference.
- *SO_2:* Only electrochemical and solid-state sensors can effectively detect SO_2. The sulphur dioxide gas contaminates the catalytic sensors. NDIR sensors do not have enough sensitivity.

The solid-state and electrochemical sensors are often the best types of sensors to monitor these four different categories of hazardous gases while building the TNGAPMS scenario. In fact, these two categories of sensors serve as the primary building blocks for the majority of the existing works as displayed earlier in this study. The following part introduces the two types of sensors' operating principles:

Solid State Gas Sensor

It has been seen that solid-state gas sensors sense the environmental gases effectively following the principle of p-n junction. A heating element plus one or more metal oxides, such as tin oxide or aluminium oxide, makes up a solid-state sensor (The type of metal oxide used inside a solid-state gas sensor depends on the type of ambient gas used). Here a paste is made up of metal oxides known as bead type sensors. In a process similar to that used to build semiconductors, metal oxides can also be deposited onto a silica chip to generate a chip-type sensor. When the metal oxides come into contact with the surrounding gases, they cause the gases to divide into charged ions or complexes, which can be detected by monitoring changes in conductivity.

Electrochemical Gas Sensor

The electrochemical gas sensors have a specific mechanism for sensing the gases. The sensors react with the gaseous environment when they are exposed to it, and this response generates an electrical signal (current) that is in proportion to the gas concentration. The two electrodes that make up the electro-chemical sensors (CE) are the Working Electrode (WE) and Counter Electrode. A Reference Electrode (RE) is required for sensors that need an outside driving voltage. Separately placed into the sensor's electrolyte are these two or three electrodes.

It is known to us that sensors use various forms of selective membranes, electrolytes, and electrodes to identify various gases. In order to prevent electrolyte leakage, the ambient gas is directed to flow through a hydrophobic barrier and a capillary-type hole. This allows the ambient gas to interact with the sensors and prevent electrolyte leakage. When the ambient gas comes into contact with the active electrode, the oxidation-reduction reaction begins. These reactions are catalyzed by the specially designed electrode for a specific ambient gas.

Table 3. Comparison of Different type of gas sensors.

Sensor Category	Gases that are detectable	Linearity	Sensitivity to other gases	Energy Consumption	Maintenance	Time to Respond	Average Life expectancy
Electro-Chemical Sensor [24]	Gases with electro-chemical activity	At room temperature it is linear	Can be eliminated using chemical filter	A minimal amount of power needed.	little	Less than 50 %	1–2 years
Catalytic sensor [25]	Can detect combustible gases	At temperature of 400–600˚C, it is linear	It is of no use when it is used with different gases mixed together	More power is needed from 400 to 600˚C.	Needed in due time as sensitivity decreases with Poisonous gases.	Less than 15%	More than 3 years
Solid state Sensor [26]	It can detect more than 150 gases	Linear	Using filter, we can minimize the sensitivity to other gases.	Needed, require an equipment for heating.	Little.	20–30 sec	More than a decade.
Non dispersive Infrared sensor [26]	Detects those of hydrocarbons and CO_2	It is non-linear	Each and every hydrocarbon has a similar hydrocarbon band which makes it cross sensitive.	Very less	least	Less than 20 sec	3–5 year

By observing the electrical current between the Working Electrode (WE) and the Counter Electrode (CE), it becomes possible to ascertain the concentration of the targeted ambient gas. In sensors with reference electrodes (RE), the oxidation and reduction reactions are controlled by the reference electrode.

Particulate Matter Sensor

As it is difficult to measure the concentration of PM, we use different techniques [27]. Some of the techniques use conventional monitoring technique in which we use a heating element to remove the humidity. Sometimes the heating element causes semi volatile elements to evaporate and disturbing the result, so we sometimes use unique dryer to remove the humidity (Nafion dryer).

There are two types of procedures used to measure the concentration of Particulate Matter (PM):

1. Direct reading instrument, and
2. Filter based gravimetric sampler.

The first instrument measures the concentration of PM continuously (for a sample period). The second instrument collects the particulate matter and measures the samples weight in a laboratory, but this process is time consuming and may cause a long delay in days, so this process is not generally used, but in government organizations, the filter based gravimetric methods is used as a reference method.

The following are the frequently used measurement methods for Particulate matter in ambient air:

a. TEOM Analyzers [28];
b. Black Smoke Method [29];
c. β-Attenuation Analyzers [30]; and
d. Optical Analyzers.

Tapered Element Oscillating Microbalance (TEOM) Analyzers

The traditional approaches to measure the air pollution are using TEOM analyzers. TEOM is used to continually measure the size of air particles. The operating principle is that particulate matter are allowed to be deposited on the surface of the glass tube and this will change the frequency of oscillation of the glass tube; on measuring the oscillating pitch of the tube, we can deduce the mass concentration of the particulate matter of ambient air. Here, the air is sampled using a selective intake, which allows particles with a diameter of 2.5 µm or less while rejecting 50% of the particles with a diameter greater than 2.5 µm (no design can reject 100% of the particles with diameter higher than 2.5 m). For removing humidity, we use a special dryer.

Black smoke method

In this technique, we use a size selective method by selecting a specific size for particulate matter, we collect the particulate matter over a period of 24 h on a piece of paper filter, and after measuring the darkness of the paper filter, using the principle of reflectometry, find out the PM's concentration.

β-Attenuation Analyzers

To measure the size of particulate matter, we use β-Attenuation analyzers by selecting a size of PM_{10} or $PM_{2.5}$ or appropriate size. Then the ambient air is left through a paper filter, and then it is exposed to β-attenuation source, after that, the radiation intensity is measured and the mass of the particulate matter is found out.

Optical Analyzers

The interaction between ambient air, particle matter, laser, and infrared light is used by optical analyzers. Three categories of optical analyzers are based on the optical principle, including direct imaging analyzers for light scattering and light obscuration (nephalometers):

Light Scattering

This category of analyzers uses LASER light as the input source. When the light is sent through the detection chamber, a photo detector measures the diffraction of the light source. Measuring the intensity of light and the diffraction, we can find the size of the particle. Applying this method, we can also count the number of particles, also it can be used to find the size of particles of different sizes ($PM_{2.5}$, PM_5, and PM_{10}).

Direct Imaging

In this method, a halogen beam light illuminates the particles; the shadow is projected onto a high definition camera; and the diffraction is decided by examining the physical properties of the particulate matter. We can count the number of particles also the size and color the particulate matter.

Light obscuration (Nephelometer)

A nephelometer can be used to determine the size and mass of ambient air. A nephelometer is a device that determines both the density and size of particulate matter. Here, we take a silicon detector an infrared LED as the light source and measure the particulate matter's diffraction. Examining both the magnitude of the scattered light and the pattern of scattering facilitates rapid computation of the size distribution and mass concentration. The Table 4 below shows the comparison between different types of procedures followed to find the size, dimension, and color of particulate matter.

CHALLENGES IN UG MINING ENVIRONMENT

Implementing IoT and cloud computing in underground mining faces several challenges due to the unique and challenging nature of the underground mining environment. Some of these challenges include:

1. *Limited communication infrastructure:* Communication infrastructure is sometimes lacking in underground mining locations, making it challenging to send IoT data from the mine to the cloud. Specialized communication networks and protocols are required to ensure reliable and secure data transmission.
2. *Harsh environmental conditions:* The underground mining environment can be harsh, with high temperatures, humidity, dust, and vibration. IoT sensors and equipment must be designed to withstand these conditions and continue to function reliably.
3. *Power supply:* Underground mining operations are typically located in remote areas with limited access to reliable power. IoT sensors and devices must be designed to operate on low power to ensure they do not deplete the limited power supply available.
4. *Data security and privacy:* Mining companies must ensure that the data collected from IoT sensors and transmitted to the cloud is secure and protected from unauthorized access. Sensitive information, such as worker locations and equipment performance, must be carefully safeguarded.

Table 4. Comparison between Different Types of measurement techniques.

Measurement Technique	Advantages	Shortcoming	Accuracy
Tapered Element Oscillating Micro-Balance (TEOM) Analyzers	Data is of high precession	Always a heater is needed for which some of the semi-volatile material is lost. Usually is of high cost, is of large size and heavy weight.	±0.5 μg/m^3
Black Smoke Method	Sample time is short (min), robust, inexpensive and is easy to maintain	Darkness-mass factor may change from time to time and location to location.	±2.0 μg/m^3, or higher
β-Attenuation Analyzers	Provide real time data with high precision	Need to replace the paper filter periodically. Usually with large size, heavy weight and high cost.	±1.0 μg/m^3
Optical Analyzers	Can measure different sizes of particles simultaneously.	These assumptions may be different from time to time and location to location.	Depends on the analyzer type and usually not specifically declared by the manufacture.

5. *Cost:* Implementing IoT and cloud computing in underground mining can be expensive, requiring specialized equipment and infrastructure. Mining companies must carefully evaluate the costs and benefits of implementing these technologies to ensure they are cost-effective.

Overall, while IoT and cloud computing offer significant benefits for underground mining, addressing these challenges is critical to ensure successful implementation and realization of these benefits.

The Smart-Air and the web server are the two main components of the Internet of Things-based indoor air quality-monitoring platform as shown in Figure 2. A laser dust sensor, a CO, CO_2, a VOC, a temperature and humidity sensor, and a series of other sensing devices were all required to gather the data needed to analyze the air quality. For assessing air quality and showcasing the outcomes, each device transmitted data to the web server through the LTE module. In addition, cloud computing and a web server were merged. The improved accessibility, flexibility, and speed of the cloud computing-based web server are its main benefits. The web server's capacity to examine massive volumes of data rapidly and more flexibly is essential for a monitoring platform. The majority of browsers have quick access to the cloud computing-powered web server, making thorough monitoring possible. To analyze, visualize, and present the data gathered by Smart-Air in this study, a web server called Amazon Web Services (AWS) was used. The web server additionally offers a database for storing that data in the cloud. Additionally, a mobile application for the system was created to view air quality in real time "anywhere, anytime" with the online server. The platform's architecture is built on the IoT platform, which primarily consists of three layers: a perception layer, a network layer, and a presentation layer. The perception layer serves as the sensing element for gathering data with sensors or other measuring tools. The network layer is in charge of employing a wireless network module to send the detected data. Finally, data visualization and storage are made possible by the presentation layer for efficient measurement [31, 32, 24].

Technologies and Applications

IoT

Indeed, air pollution monitoring systems based on IoT utilize a range of technologies and applications, including cloud computing, smart cities, and IoT itself. Essentially, IoT functions as a conduit for information via the internet and traditional telecommunications networks, enabling physical objects to be independently addressed and interconnected. It comprises intelligent devices capable of sensing their environment and interacting with users or other systems. Therefore, IoT is characterized by its intelligence, with only addressable objects or sensors relying on its communication protocol. Generally, the hardware consists of sensor nodes, interface circuits, and embedded communication, while middleware handles data storage and processing, and a representation layer comprises efficient visualization tools, forming a complete IoT architecture.

The IoT model comprises three designated layers: the application layer, the network layer, and the sensor layer. In the sensor layer, data is gathered utilizing IP cameras, readers, and pollution sensors. Information is conveyed at the network layer, which serves as a middleware between the sensor layer and the application layer, employing cellular, remote, and broadcast networks. IoT has been heralded as the third revolution in the advancement of the world's information industry, thus bringing numerous societal benefits. It has spurred the creation of intelligent, interconnected products and machinery, offering significant potential for transitioning industry from an electrified, mechanized manufacturing paradigm to one governed and managed by networks. Addressing issues such as excessive resource consumption, severe environmental degradation, and substantial urban-rural development disparities, IoT leverages radio frequency signals for contactless information transmission and identification, effectively amalgamating resources. Integrating into larger systems enhances operational efficiency and reduces expenses. Facilitating swifter communication between electronic devices, IoT applications primarily target sectors including transportation, agriculture, industry, logistics, furniture, healthcare, electricity, and the environment, catalyzing shifts in productivity, production methodologies, and lifestyles.

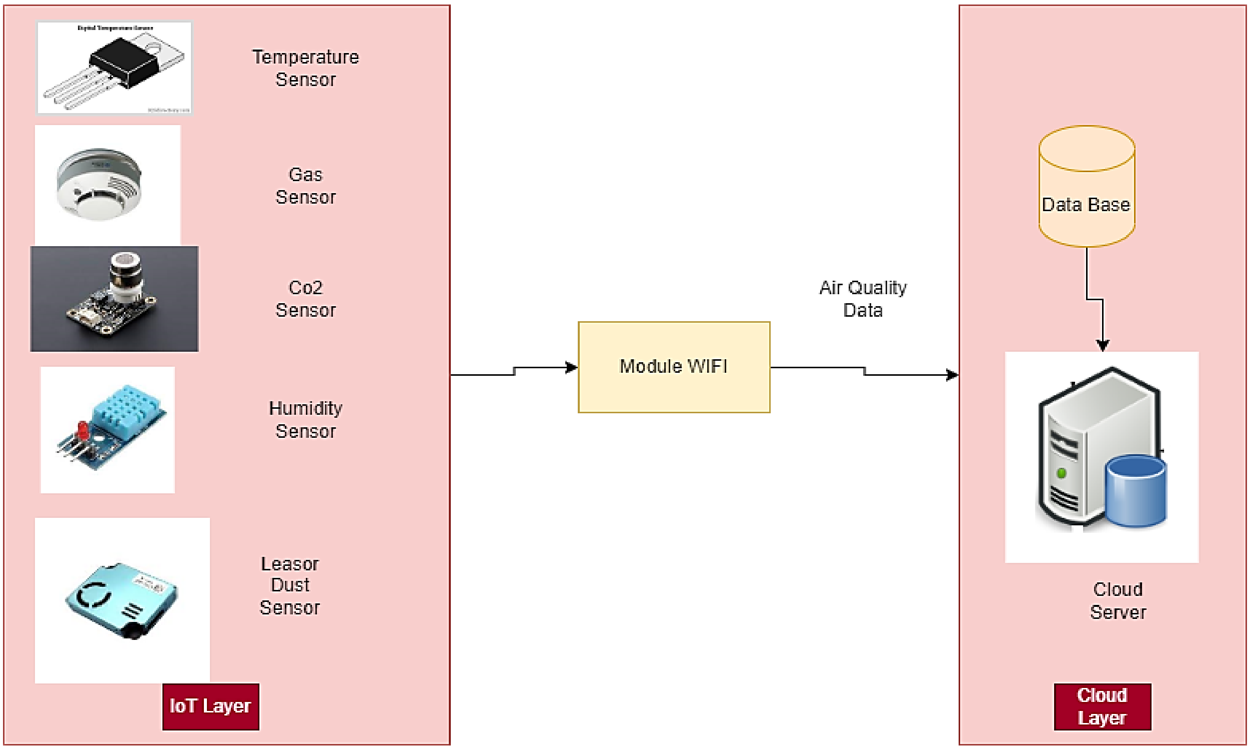

Figure 2. Proposed system model.

IoT drives economic development and technological progress between industries, as well as improving management efficiency. As an illustration, within environmental monitoring, an IoT system that integrates sensing devices and advanced communication technologies enables the analysis of data and the transfer of information. IoT will provide real-time bidirectional communication through the combination of information and communication technologies between users and monitoring systems. IoT offers the potential to model fire detection and effectively manage forest fires in real time, thereby mitigating forest damage. Additionally, IoT technology can be applied to regularly assess the levels of toxic or flammable gases and concentrations of pollutants, addressing air pollution stemming from industrialization and urbanization. Specifically, IoT-based air pollution monitoring systems utilize sensor networks to enable intelligent monitoring of air quality. Currently, IoT technology stands as the leading approach to air monitoring, playing a significant role in societal progress. Essentially, IoT facilitates the acquisition, transmission, storage, and analysis of air quality data, thus fostering ongoing advancements in environmental management.

Underground Mining

IoT (Internet of Things) and cloud computing can boost underground mining operations' productivity, efficiency, and security. IoT sensors can be used to gather information on a number of mining-related topics, such as worker safety, environmental conditions, and equipment performance. Subsequently, this data can be sent to a cloud computing platform for analysis and decision-making purposes.

Some potential benefits of using IoT and cloud computing in underground mining include:

1. *Predictive maintenance:* IoT sensors are able to track the functioning of mining equipment in real-time and identify any irregularities or problems. In order to prevent equipment failure and plan repair before it happens, this data can be examined in the cloud, which will save downtime and boost productivity.
2. *Enhanced worker safety:* IoT sensors can monitor conditions such as temperature, humidity, air quality, and gas concentrations within the mine. To identify potential dangers and notify workers in real-time, this data can be analyzed in the cloud, lowering the possibility of accidents and injuries.

3. *Increased productivity:* IoT sensors can follow the movement of supplies and machinery inside the mine, giving real-time updates on how things are going there. This data can be analyzed in the cloud to optimize workflows, reduce bottlenecks, and improve productivity.
4. *Cost efficiencies:* Utilizing cloud computing offers a cost-efficient solution for storing and analyzing vast quantities of data, empowering mining enterprises to enhance decision-making, minimize wastage, and improve operational efficiency.

However, implementing IoT and cloud computing in underground mining can be challenging due to the harsh and remote nature of mining environments. Specialized IoT sensors and communication networks are required, and data security and privacy must be carefully considered.

Overall, the potential benefits of using IoT and cloud computing in underground mining make it a promising technology for improving the efficiency, safety, and productivity of mining operations.

Cloud: Cloud computing plays a crucial role in IoT-based air pollution monitoring systems, as the data received regarding air quality by the gateway necessitates storage and processing in the cloud. With the expansion of IoT services, the heightened demand for data storage and computational capacity has spurred the emergence of cloud computing. Derived from distributed computing, parallel computing, and grid computing, cloud computing can execute numerous calculations swiftly, resulting in robust web services. Essentially, cloud computing involves aggregating various computer resources and automating their management, enabling users to access unlimited resources via the internet without spatial or temporal constraints. Compared to traditional network application models, cloud computing offers notable advantages in terms of security, adaptability, and data management. Specifically, cloud computing provides the most secure and reliable data storage centers, alleviating concerns regarding virus intrusion, data loss, and other potential issues. Furthermore, it is extremely easy to operate, since it has minimal device requirements on the user side. Lastly, cloud computing improves management efficiency by easily sharing data and applications between different devices. Thus, cloud computing is an essential technology in air pollution monitoring systems.

It has the capability to summarize and analyze vast volumes of historical monitoring data, providing reports on air quality for further processing. Additionally, it can store raw data in real-time and generate indices. This addresses not only the needs of contemporary IoT applications but also resolves issues related to data storage and management inherent in traditional computing methods.

PROPOSED ALGORITHM

Inputs

- Air quality sensors (temperature, humidity, gas levels).
- IoT communication network.
- Cloud computing platform.
- Data analytics tools.

Outputs

- Real-time alerts for potential hazards.
- Long-term monitoring data for analysis and decision-making.

Steps

1. Set up air quality sensors in the underground mining environment to monitor temperature, humidity, and gas levels.
2. Establish a connection to an IoT communication network to broadcast data from the sensors to the cloud computing platform.
3. Continuously collect air quality data from the sensors and pass on it to the cloud computing platform.

4. Process the data in the cloud computing platform to identify potential hazards, such as high gas levels or extreme temperature and humidity levels.
5. If a potential hazard is detected, send real-time alerts to workers and the safety team.
6. Store the air quality data in a cloud-based database for long-term monitoring and analysis.
7. Use data analytics tools to analyze the air quality data over time, identify trends, and make informed decisions on air quality management strategies.
8. Integrate the air quality data with other data sources, such as equipment performance data and worker location data, to gain a comprehensive understanding of the mining environment and improve safety and productivity.

Install IoT sensors for monitoring air quality metrics like temperature, humidity, and gas concentrations. Capture sensor readings and transmit them to a cloud computing infrastructure. Utilize cloud-based analysis to identify any irregularities or variations from acceptable air quality standards. If hazardous conditions are detected, promptly alert both employees and the safety team. Store the collected data in a cloud-hosted database for ongoing analysis and prolonged monitoring purposes. Use data analytics tools to analyze the data over time, identify trends, and make informed decisions on air quality management strategies. Integrate the air quality data with other data sources, such as equipment performance data and worker location data, to gain a comprehensive understanding of the mining environment and improve safety and productivity.

COMPARATIVE ANALYSIS

Types of Air Quality Monitoring Sensor

There are various types of air quality monitoring sensors available, each designed to measure different pollutants and parameters. Here are some common types of air quality monitoring sensors:

1. *Particulate Matter (PM) Sensors:* These sensors measure the concentration of particulate matter in the air, typically classified as $PM_{2.5}$ (fine particles with a diameter of 2.5 µm or less) and PM_{10} (coarser particles with a diameter of 10 µm or less).
2. *Gas Sensors:* Gas sensors detect and measure the concentration of specific gases in the air. Some commonly monitored gases include:
   a. *Carbon Monoxide (CO) Sensors:* CO sensors detect the presence and level of carbon monoxide, a colorless and odorless gas produced by incomplete combustion of fossil fuels.
   b. *Nitrogen Dioxide (NO_2) Sensors:* NO_2 sensors measure the concentration of nitrogen dioxide, a gas primarily emitted from vehicle exhaust and industrial processes.
   c. *Ozone (O_3) Sensors:* Ozone sensors monitor the concentration of ozone, a gas formed by the reaction of sunlight with pollutants like nitrogen oxides and volatile organic compounds.
   d. *Sulphur Dioxide (SO_2) Sensors:* SO_2 sensors detect the presence and level of sulphur dioxide, a gas primarily emitted by burning fossil fuels, especially in power plants and industrial processes.
   e. Volatile Organic Compound (VOC) Sensors: VOC sensors measure the concentration of volatile organic compounds, which are emitted by various sources such as paints, cleaning products, and fuels.
3. *Carbon Dioxide (CO_2) Sensors:* CO_2 sensors monitor the level of carbon dioxide in the air. These sensors are commonly used to assess indoor air quality and ensure adequate ventilation.
4. *Temperature and Humidity Sensors:* These sensors measure temperature and humidity levels, which are essential factors for assessing overall air quality and comfort.
5. *Weather Sensors:* Weather sensors can provide additional information such as wind speed, wind direction, rainfall, and atmospheric pressure, which can help in understanding the impact of weather conditions on air quality.
6. *Radiation Sensors:* Radiation sensors detect and measure the levels of ionizing radiation in the environment. These sensors are used in specific cases to monitor radiation levels resulting from nuclear accidents or industrial processes.

It is important to note that different air quality monitoring systems may utilize a combination of these sensors to provide a comprehensive assessment of the air quality in a particular area.

Comparative Analysis of the air Quality-Monitoring Sensor

To provide a comparative analysis of air quality monitoring sensors, let us consider some key factors:

1. *Measurement Capabilities:* Different sensors specialize in measuring specific pollutants or parameters. For example, particulate matter (PM) sensors are designed to measure the concentration of fine particles in the air, while gas sensors focus on detecting gases like carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and volatile organic compounds (VOCs). Consider the pollutants of interest and ensure that the sensors you choose can measure those pollutants accurately.
2. *Accuracy and Precision:* The accuracy and precision of a sensor are crucial for reliable air quality monitoring. Seek out sensors that have undergone rigorous testing and validation by reputable organizations or regulatory bodies. Accuracy and precision can vary among different sensor models and manufacturers, so it is essential to review technical specifications and performance data.
3. *Sensitivity and Detection Limits:* Sensitivity pertains to the capability of a sensor to identify slight variations in pollutant concentrations. A lower detection limit signifies greater sensitivity. For example, a PM sensor with a low detection limit can detect very small particles, enhancing its effectiveness in monitoring air quality. Consider the required sensitivity level for your monitoring objectives.
4. *Reaction Time:* The reaction time of a sensor refers to the duration it takes to detect and communicate alterations in pollutant levels. Certain sensors offer instantaneous measurements, whereas others might exhibit a lag. Assess the necessary reaction time based on your particular application. Real-time monitoring is crucial for immediate action, such as triggering alerts or adjusting ventilation systems.
5. *Maintenance and Calibration:* Sensors may necessitate periodic upkeep, calibration, and part replacement. Evaluate the convenience of maintenance and the accessibility of calibration standards or services. Some sensors may have a shorter lifespan or may need more frequent calibration, which can affect long-term monitoring costs.
6. *Cost:* The cost of air quality monitoring sensors can vary significantly depending on the type, brand, features, and accuracy. Take into account your budget and assess the cost-effectiveness of various sensors according to their performance and appropriateness for your monitoring requirements.
7. *Connectivity and Data Output:* Consider how the sensor communicates and outputs data. Some sensors may have built-in wireless capabilities, allowing for remote data collection and integration with monitoring networks or smart systems. Others may provide analog or digital output that requires manual data collection. Determine the connectivity options that align with your monitoring requirements.
8. *Regulatory Compliance:* If you are conducting air quality monitoring for compliance purposes, ensure that the sensors you choose meet relevant regulatory standards and requirements. Look for sensors that are certified or approved by regulatory bodies or have been validated through independent testing.

Thorough research, expert consultation, and careful consideration of your particular monitoring goals and environmental circumstances are essential when choosing sensors for air quality monitoring. Different sensors may excel in different areas, so, it is essential to prioritize the factors that are most critical for your application.

As depicted in Figure 3, Volatile Organic Compounds (VOCs) are organic substances emitted from diverse sources such as building materials, furniture, cleaning agents, and personal care products. Advanced air quality sensors for VOCs offer real-time detection and measurement of these compounds, furnishing significant insights into Indoor Air Quality (IAQ). Through continuous monitoring of VOC

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concentrations, occupants can undertake suitable measures to mitigate exposure and enhance indoor air conditions.

Figure 4 shows that by employing CO sensors for air quality monitoring, individuals, households, and building management systems can proactively detect and address potential carbon monoxide hazards, minimize health risks, and create safer and healthier indoor environments.

Figure 5 shows that CO_2 sensors play a crucial role in air quality monitoring by providing real-time feedback on indoor air conditions. They contribute to occupant comfort, productivity, energy efficiency, and health and safety. By using CO_2 sensors to optimize ventilation, occupants can enjoy improved indoor air quality and well-being.

Figure 6 shows that a temperature sensor can play a significant role in an air quality monitoring system by providing important information about the thermal conditions of the environment. While its direct impact on measuring air quality may be limited, temperature measurement can be valuable for several reasons.

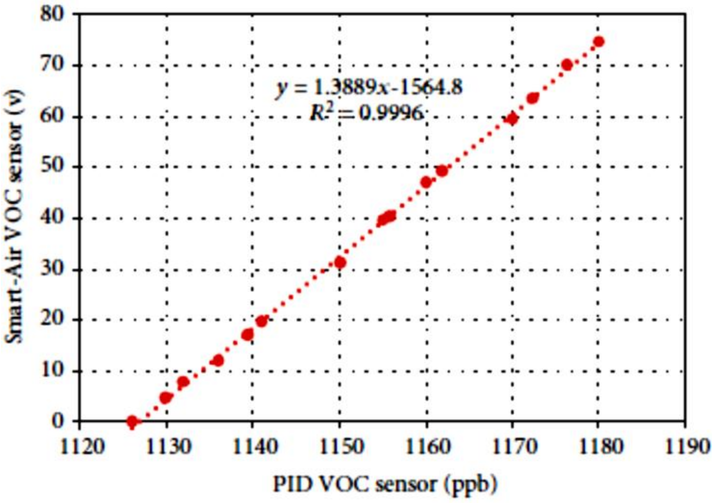

Figure 3. Effect of Sensor in air quality monitoring.

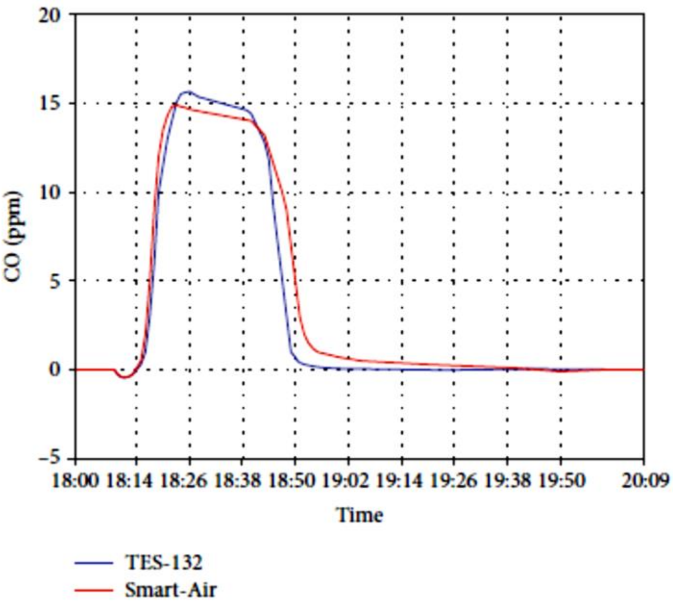

Figure 4. Effect of CO sensor over manual air quality monitoring.

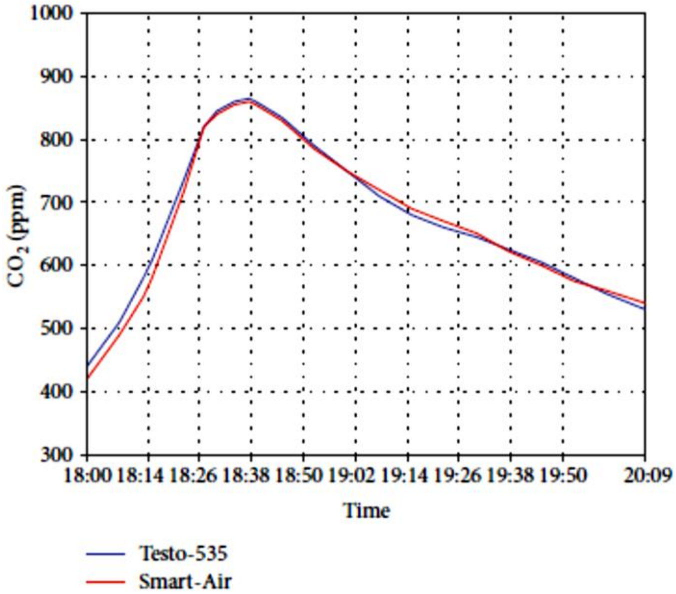

Figure 5. Effect of CO_2 sensor over manual air quality monitoring.

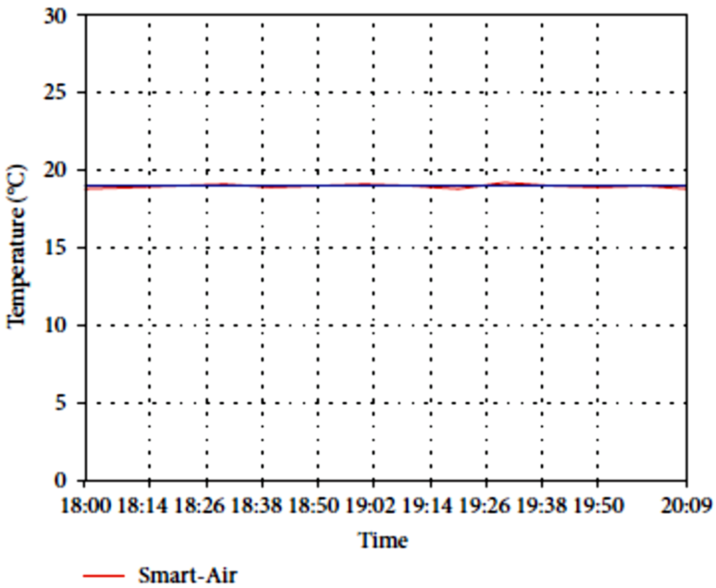

Figure 6. Effect of Temperature sensor over manual air quality monitoring.

Figure 7 represents, by incorporating humidity measurements into an air quality monitoring system, it becomes possible to account for its influence on mold prevention, occupant comfort, particulate matter behavior, chemical reactions, and sensor calibration. This comprehensive understanding of humidity's impact on air quality allows for better management and control of indoor environments and the implementation of effective strategies to maintain optimal air quality conditions.

IoT Cloud Based Air Quality Monitoring System

An IoT cloud-based air quality monitoring system utilizes sensors to collect air quality data, which is then transmitted to a cloud-based platform for storage, analysis, and visualization. Here is an overview of how such a system typically works:

1. *Sensor Deployment:* Air quality sensors are strategically deployed in various locations to monitor pollutant levels and environmental conditions. These sensors can include particulate matter (PM) sensors, gas sensors (for gases like CO, NO_2, O_3, etc.), temperature and humidity sensors, and other relevant sensors depending on the specific monitoring requirements.

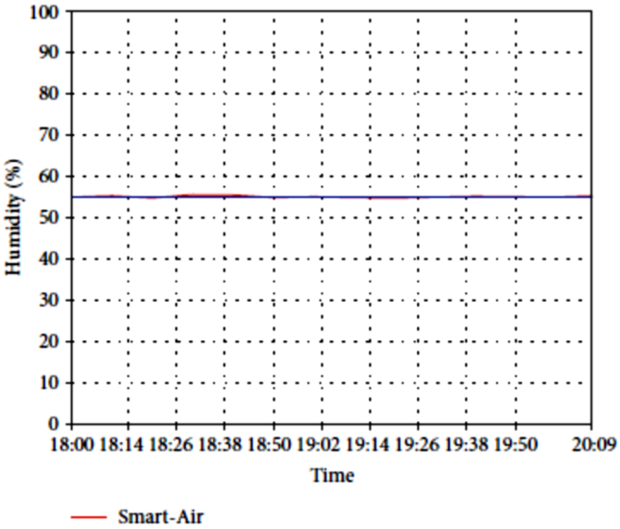

Figure 7. Effect of Humidity sensor over manual air quality monitoring system.

2. *Data Collection:* The deployed sensors continuously measure air quality parameters and generate data. This data is collected by the sensors and transmitted wirelessly using communication protocols like Wi-Fi, Bluetooth, LoRaWAN, or cellular networks (e.g., 3G, 4G, or 5G) to the cloud-based platform.
3. *Cloud-Based Platform:* The gathered data is transmitted to a cloud-hosted platform, where it is securely stored in a database. This platform serves as a centralized storage hub for all data collected from various sensor nodes.
4. *Data Processing and Analysis:* The cloud-based platform processes and analyzes the collected data using algorithms and analytics tools. This can involve data cleaning, normalization, statistical analysis, and pattern recognition techniques. Machine learning and artificial intelligence algorithms can also be utilized to recognize patterns, associations, and irregularities within the data.
5. *Visualization and Reporting:* The processed data is presented through interactive dashboards, charts, and maps on a web-based or mobile application. This allows users to easily visualize air quality parameters, track trends, and assess the current and historical air quality conditions. Reports and notifications can be automatically generated according to predefined thresholds or criteria set by the user.
6. *Alerting and Notifications:* The system can be configured to send alerts and notifications to relevant stakeholders when air quality exceeds predefined thresholds or when certain events occur. Such notifications can be delivered through SMS, email, or push notifications on mobile devices.
7. *Historical Data and Trends:* The cloud-based platform stores historical data, allowing users to analyze long-term trends, compare data across different times, and generate reports for regulatory compliance or research purposes.
8. *Integration and APIs:* The cloud-based platform may provide APIs (Application Programming Interfaces) to enable integration with other systems or applications. This allows the air quality data to be integrated into smart city platforms, building management systems, or other IoT-enabled solutions.
9. *Scalability and Flexibility:* Cloud-based architectures offer scalability, allowing the system to handle large-scale deployments with thousands of sensors. Additionally, the cloud-based platform can be easily updated and expanded to accommodate new sensors, parameters, or functionalities as needed.

By leveraging IoT and cloud technologies, a cloud-based air quality monitoring system enables real-time monitoring, data analysis, and remote access to air quality information, facilitating better decision-making, pollution management, and public awareness about air quality conditions.

CONCLUSION

In conclusion, IoT cloud-based air quality monitoring systems offer numerous advantages for monitoring and managing air quality in a wide range of applications. By integrating sensors, cloud-based platforms, and data analysis capabilities, these systems provide real-time monitoring, data storage, analysis, visualization, and remote access to air quality information. Here are some key takeaways:

1. *Real-time Monitoring:* IoT cloud-based systems enable continuous and real-time monitoring of air quality parameters, allowing for prompt identification of pollution events and the ability to take immediate action to mitigate risks.
2. *Data Accessibility:* The cloud-based platform stores and organizes air quality data, making it easily accessible from anywhere with an internet connection. This accessibility enables decision-making based on data, fosters collaboration among stakeholders, and enhances public awareness.
3. *Scalability and Flexibility:* Cloud-based architectures provide scalability, allowing for the expansion of the monitoring system to accommodate a larger number of sensors and locations. The system can also be easily upgraded or modified to incorporate new sensors, parameters, or functionalities.
4. *Data Analysis and Visualization:* Cloud-based platforms offer powerful data processing and analysis capabilities, including statistical analysis, trend identification, and correlation studies. Interactive visualizations and dashboards allow users to understand and interpret air quality data effectively.
5. *Alerting and Notifications:* IoT cloud-based systems can generate alerts and notifications when air quality conditions exceed predefined thresholds or when specific events occur. This enables timely responses and interventions to mitigate health risks and environmental impacts.
6. *Integration and Interoperability:* Cloud-based platforms often provide APIs for seamless integration with other systems, enabling the sharing of air quality data with smart city platforms, building management systems, or other IoT-enabled solutions. This integration enhances the potential for comprehensive data analysis and decision-making.
7. *Accuracy and Calibration:* Ensuring the accuracy of air quality monitoring sensors through regular calibration and validation is critical for reliable data. High-quality sensors, proper maintenance, and adherence to calibration protocols contribute to accurate measurements.

IoT cloud-based air quality monitoring systems have the potential to enhance environmental monitoring, public health management, and policy development. However, it is important to consider the specific requirements of the monitoring application, the quality of sensors, and the reliability of the cloud-based platform when implementing such a system. Regular monitoring system evaluations, sensor maintenance, and data quality control are essential to maintain accurate and reliable air quality data for effective decision-making and action.

FUTURE SCOPE

The future of IoT cloud-based air quality monitoring holds great potential for advancements and enhancements. Here are some possible future enhancements for such systems:

1. *Integration with Smart Devices:* IoT air quality monitoring systems can integrate with smart devices, such as smartphones, wearable devices, and smart home assistants. This integration can enable personalized air quality information and alerts, providing individuals with real-time updates and recommendations to protect their health.
2. *Advanced Data Analytics:* Progress in data analytics methodologies, such as machine learning and artificial intelligence, can bolster the functionalities of cloud-based platforms. These techniques can improve data processing, anomaly detection, and predictive modeling, enabling more accurate forecasting of air quality trends and proactive decision-making.
3. *Sensor Miniaturization and Wireless Connectivity:* Miniaturization of air quality sensors and advancements in wireless communication technologies can lead to smaller, more portable, and cost-effective sensor nodes. This allows for increased deployment density and flexibility in monitoring networks, enabling finer-grained spatial coverage and localized air quality assessment.

4. *Multi-Pollutant Monitoring:* Future enhancements can focus on developing sensors and algorithms capable of measuring multiple pollutants simultaneously. This would enable a more comprehensive understanding of air quality conditions and their interdependencies, supporting more effective pollution control strategies and health risk assessments.
5. *Improved Sensor Calibration and Maintenance:* Efforts can be directed towards developing self-calibrating sensors and automated maintenance routines within the IoT system. This would reduce the reliance on manual calibration and maintenance, ensuring more consistent and accurate measurements over extended periods.
6. *Community Engagement and Citizen Science:* Future enhancements can focus on incorporating citizen science initiatives, enabling individuals to actively participate in air quality monitoring and data collection. Crowd sourced data can supplement traditional monitoring networks, increase spatial coverage, and engage communities in environmental awareness and action.
7. *Integration with Urban Planning and Infrastructure:* IoT cloud-based air quality monitoring systems can be integrated with urban planning and infrastructure systems. This integration can help optimize city layouts, transportation networks, and building designs to minimize air pollution exposure and improve overall air quality.
8. *Real-time Air Quality Index (AQI) Calculation:* The integration of data analytics and real-time monitoring can enable the calculation of accurate and localized Air Quality Index (AQI) values. This information can be used to provide users with simplified and easily understandable air quality assessments, aiding in making informed decisions and taking appropriate actions.
9. *Collaboration and Data Sharing:* Enhancements can focus on promoting collaboration among different monitoring systems, research institutions, and regulatory agencies. Sharing standardized data formats, protocols, and methodologies can lead to more comprehensive and interoperable air quality data across regions, facilitating broader research, policy-making, and international comparisons.

These future enhancements can contribute to improved air quality monitoring, public awareness, and effective pollution management, ultimately leading to healthier and more sustainable environments.

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