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IOT-BASED SOLUTION FOR DETECTION OF AIR QUALITY USING ESP32

Abstract. Air pollution, a growing public health crisis worldwide, has become one of the most imperative concerns challenging human health, the environment, and the economy. The detrimental effects of air pollution on individuals' well-being and the ecological system necessitate implementing advanced solutions to accurately monitor and manage air quality. In response to this global challenge, a comprehensive, real-time IoT-based air quality monitoring system is proposed using ESP32 and multiple pollutant sensors. This versatile system endeavors to measure and report various air quality parameters and pollutants, such as temperature, humidity, carbon dioxide (CO2), particulate matter (PM2.5 and PM10), volatile organic compounds (VOCs), and other noxious gases, including nitrogen dioxide (NO2), ozone (O3), and sulfur dioxide (SO2).

The innovative solution showcased in this proposal combines the functionalities of an ESP32 microcontroller, a highly integrated and low-power device, with diverse pollutant sensors chosen for their high sensitivity and ability to offer precise and reliable readings. The various sensors integrated into the system include the MQ135, CCS811, PMS5003, and BME280, each responsible for detecting specific pollutants and air quality parameters. As a leading component of the air quality monitoring system, the ESP32 microcontroller warrants seamless wireless data transmission to cloud servers for real-time monitoring, allowing for remote access and analysis of the air quality data through secure networks.

The modular design and ease of deployment of the IoT-based air quality monitoring systems make them installable in various scenarios, including residential, commercial, and industrial settings. Users can make informed decisions about their environment by analyzing extensive real-time data, promoting timely exposure warnings, proactive pollution management, and environmental sustainability. This portability and versatility of deployment ensure substantial coverage of areas that would benefit from real-time air quality monitoring.

The air quality monitoring system is further enhanced by incorporating a user-friendly mobile application or web interface, empowering users to access real-time sensor data directly, configure threshold-based alerts and notifications, and visualize trends in air quality parameters over time. This hands-on approach to accessing real-time air quality data encourages individuals to adopt environmentally conscious habits and fosters a better understanding of the impact of pollution on their health and surroundings.

To ensure the optimum performance and efficacy of the air quality monitoring system, regular maintenance and calibration services are advocated. By undertaking timely sensor calibration, replacing worn-out components, and updating software when required, the life span, accuracy, and reliability of the system are enhanced, promising continued effectiveness in the real-time monitoring and management of air quality.

Keywords: quality monitoring, IoT, pollutant sensors, deep learning, predictive analytics, machine learning.

Introduction

Air quality has become a critical concern globally due to the increasing levels of pollution that pose numerous threats to human health, the environment, and economic well-being. The urgent need to monitor, measure, and mitigate the effects of poor air quality has led to the development of advanced technological solutions. The proposed comprehensive, real-time IoT-based air quality monitoring system utilizing ESP32 microcontroller and multiple pollutant sensors seeks to address this pressing challenge with an efficient and user-friendly solution.

This advanced system integrates ESP32, a highly integrated and low-power microcontroller system, with various sensors capable of measuring significant air quality parameters, such as carbon dioxide (CO2), particulate matter (PM2.5, PM10), volatile organic compounds (VOCs), nitrogen dioxide (NO2), ozone (O3), and sulfur dioxide (SO2). With its real-time data monitoring capabilities, the system enables users to stay informed about the air quality in their immediate surroundings, allowing them to make informed decisions about their environment [1].

The modular design of the IoT-based air quality monitoring system ensures its simplicity and ease of deployment in various settings, including residential, commercial, and industrial locations. By monitoring extensive real-time data, users can take proactive measures to mitigate their exposure to potential health risks associated with polluted air. The system's portability allows for application in multiple scenarios, offering extensive coverage of areas that would benefit from real-time air quality monitoring.

To ensure that users have access to the information they need to make informed decisions, the proposed air quality monitoring system incorporates a user-friendly mobile application or web interface, allowing them to view real-time air quality data, configure threshold-based alerts, and visualize trends in air quality parameters over time. This empowering approach to accessing real-time air quality information promotes environmentally conscious behavior and fosters a better understanding of the impacts of pollution on human health and well-being.

We will explore the components and implementation of the IoT-based air quality monitoring system, focusing on the integration of ESP32 microcontroller and the sensor technologies. We will also discuss the data management aspect, including cloud-based storage and analytics solutions, as well as the vital role of predictive analytics and machine learning techniques in anticipating adverse air quality events. Additionally, we will address the maintenance and calibration of the system to ensure continued effectiveness in the real-time monitoring and management of air quality.

System Overview and Components

The IoT-based air quality monitoring system comprises several essential components working together to collect air quality data, analyze it, and provide insights for users. The following sections detail the critical components and their roles in the system.

1. ESP32 Microcontroller: The ESP32 microcontroller acts as the core of the system, providing processing of sensor data and wireless communication capabilities. It features built-in Wi-Fi and Bluetooth Low Energy (BLE) modules, enabling seamless connectivity to the internet and data transfer to cloud servers. Its low energy consumption ensures that battery-powered devices remain functional for extended periods.
2. Pollution Sensors: The system includes a variety of sensors that measure different air quality parameters with high accuracy and precision. The key sensors used in this system are:

   a. MQ135: A gas sensor that can detect various harmful gases, including CO2, ammonia (NH3), benzene, and alcohol.

   b. CCS811: An integrated sensor that measures equivalent CO2 and total volatile organic compounds (TVOC) concentrations in the ambient air.

   c. PMS5003: A laser-based particulate matter sensor that measures PM2.5 and PM10 levels.

   d. BME280: An environmental sensor that measures temperature, humidity, and barometric pressure.
3. Power Supply: The system requires a reliable power source, such as a rechargeable battery or USB power bank, to function independently and maintain portability.
4. Cloud Services: Platforms like ThingSpeak, Adafruit IO, or Google Cloud IoT Core are used to store and analyze collected air quality data, ensuring accessibility, real-time tracking, and visualization [4].
5. User Interface: A mobile application or web-based platform allows users to interact with the system, retrieve data, set threshold alerts, and monitor air quality trends across time and space. Fig. 1 shows the block of the air quality monitoring system. ESP32 serves as the main controlling unit in the system.

Implementation

To successfully implement the IoT-based air quality monitoring system, the following steps are essential:

1. Assemble the hardware components: Connect the pollutant sensors to the ESP32 microcontroller using appropriate analog or digital pins. Ensure that the connections are secure and follow best practices for managing wiring and layout.
2. Configure and program the ESP32: Set up the required settings for wireless connectivity, cloud services API keys, and other relevant configurations. Develop appropriate firmware to acquire data from the sensors, preprocess the data if necessary, and transmit it to the cloud

platform in a format compatible with the chosen cloud service.

3. Cloud server setup: Create an account and configure the chosen cloud platform to receive, store, and analyze air quality data from the ESP32 microcontroller, enabling data visualization, tracking, and alerting.

4. Develop a user interface: Create a mobile application or web-based platform that allows users to interact with the system,access real-time air quality data, set up threshold-based alerts, and visualize trends in air quality parameters.

5. Calibration and maintenance: Regularly calibrate the sensors, update firmware, and perform other necessary maintenance tasks to ensure the system's continued accurate functioning and reliability [2].

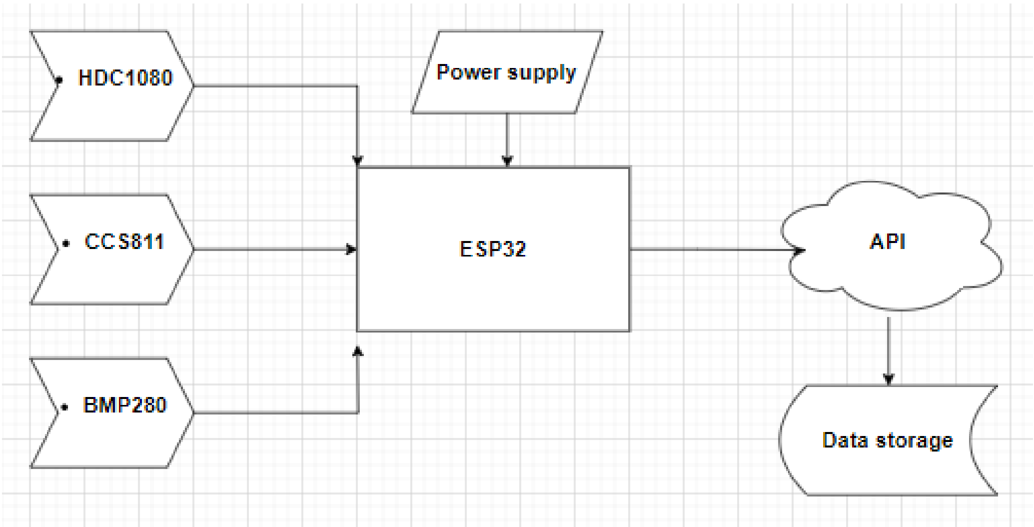

Fig. 1. IoT System Architecture Setup

By implementing the above steps, the IoT-based air quality monitoring system can effectively collect, analyze, and present air quality data for various contexts, empowering users to make informed decisions about their environment, and thereby promoting environmentally conscious behavior and proactive pollution management. Fig. 2 shows the block of the air quality monitoring code using Arduino IDE.

Predictive Analytics, Machine Learning, and Future Enhancements

The proposed air quality monitoring system leverages the power of IoT and real-time data to provide users with accurate and up-to-date information about their immediate environment. However, advancements in computational technology and data science offer promising avenues for future enhancement and elevated air quality management.

1. Predictive Analytics: By incorporating predictive analytics techniques, the monitoring system can anticipate potential air quality events, allowing users and stakeholders to take preemptive measures. Using historical data and advanced algorithms, it is possible to predict spikes in air pollution levels, enabling users to make informed decisions and adapt their behavior accordingly. Predictive analytics can also aid in devising intervention strategies, helping authorities to control future emissions and improve overall air quality.

2. Machine Learning: Integrating machine learning algorithms into the air quality monitoring system further augments its capabilities. From automatic sensor calibration to anomaly detection, machine learning models can continually improve the predictive accuracy of the system based on new data and insights, ensuring the highest possible effectiveness. In addition, unsupervised learning techniques can be employed to detect hidden patterns or correlations among air quality parameters, which can assist in identifying potential sources of pollution.

```
#include "Adafruit_CCS811.h"

Adafruit_CCS811 ccs;

void setup() {
  Serial.begin(9600);

  Serial.println("CCS811 test");

  if(!ccs.begin()){
    Serial.println("Error");
    while(1);
  }

  // Wait for the sensor to be ready
  while(!ccs.available());
}

void loop() {
  if(ccs.available()){
    if(!ccs.readData()){
      Serial.print("CO2: ");
      Serial.print(ccs.geteCO2());
      Serial.print("ppm, TVOC: ");
      Serial.println(ccs.getTVOC());
    }
    else{
      Serial.println("ERROR!");
      while(1);
    }
  }
  delay(500);
}
```

Fig. 2. Working code in Arduino IDE

3. Improved Sensor Technologies: As sensor technology continues to advance, new and improved sensing mechanisms can be incorporated into the system, ensuring more accurate and reliable measurements. Some emerging sensor technologies include electrochemical sensors, metal oxide semiconductor sensors, and photoionization detectors, which can provide extended pollutant coverage and increased detection precision.

4. Integration with Smart Cities and Building Management Systems: The air quality monitoring system can be integrated with existing or future smart city initiatives and building management systems, providing an added layer of environmental monitoring and intelligent decision-making. By leveraging connected infrastructure and sophisticated data analysis, urban planners and building owners can take targeted action to ensure cleaner air and healthier environments for inhabitants [5, 6].

5. Public-Awareness Campaigns: Harnessing the power of real-time air quality data, governments, NGOs, and communities can develop public-awareness campaigns to inform and educate individuals about the impacts of air pollution on their health and well-being. With increased understanding of the importance of air quality, citizens can make environmentally conscious choices and advocate for responsible pollution-control policies, ultimately contributing to the sustainability of urban environments.

Through these enhancements and the integration of predictive analytics and machine learning, the IoT-based air quality monitoring system marks a significant leap forward in combating the global challenge of air pollution. Not only does it provide real-time data for informed decision-making, but it also offers a multi-layered approach to mitigate pollution's detrimental effects on health and the environment, fostering a healthier and more sustainable society. Fig. 3 shows the table of the air quality monitoring data with current time and location-based by latitude and longitude. This data can be used to perform various analyses, such as calculating daily or hourly averages, identifying trends, and determining correlations between different air quality parameters.

Latitude	Longitude	CurrentTime	Humidity	Pm10	Pm25	Pressure	Temperature	AirQualityIndex
48.5011	34.990169	7/20/2023 11:37:05 AM +03:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 12:02:22 PM +03:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 9:21:59 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 10:01:45 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 11:01:35 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 12:01:46 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 1:02:31 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 2:01:28 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 3:01:27 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 4:01:36 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 5:01:32 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 6:02:04 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 7:01:57 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 8:01:17 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 9:01:44 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 10:01:22 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/20/2023 11:01:40 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 12:02:06 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 1:02:00 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 2:01:20 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 3:01:45 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 4:01:58 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
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48.5011	34.990169	7/21/2023 10:01:42 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 11:01:55 AM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 12:01:34 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 1:01:41 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 2:01:56 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 3:02:08 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 4:01:56 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 5:01:30 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42
48.5011	34.990169	7/21/2023 6:01:44 PM +00:00	16.44	9.55	3.1	1010.76	45.46	42

Fig. 3. Saved data from ESP32

Maintenance, Calibration, and Reliability

To ensure optimal performance, accuracy, and longevity of the IoT-based air quality monitoring system, proper maintenance and calibration are crucial. The following recommendations outline essential practices for maintaining the functionality and reliability of the system:

1. Regular Sensor Calibration: Over time, sensors may experience drift, causing discrepancies in the accuracy of pollutant measurements. Regular calibration ensures sensor accuracy and optimal performance. Depending on the type and manufacturer of the sensors, calibration can be performed using standardized reference gases, calibration kits, or specific calibration procedures recommended by the manufacturer.

2. Firmware Updates: To maintain security and functionality, updating the firmware of the ESP32 microcontroller is vital. Regular updates can introduce performance improvements, bug fixes, or compatibility enhancements, ensuring

the monitoring system's continued effectiveness and stability.

3. Hardware Maintenance: Periodic inspection and maintenance of hardware components, such as sensor housings, wiring, and connectors, help prolong the system's life. Neglect or damage to any hardware component can impair the system's functioning, leading to inaccurate pollutant measurements or system failure.

4. System Diagnostics: Implementing self-diagnostic features at both hardware and software levels can assist in detecting potential sensor malfunctions, communication issues, or power irregularities. By identifying issuesearly, preemptive measures can be taken to resolve problems and maintain system reliability.

5. Data Quality Assurance: Regularly assess the quality of the collected data to ensure accuracy and consistency. Implementing data validation and outlier detection techniques can help identify sensor malfunctions, incorrect calibration, or other issues that affect data quality. Fig. 4 shows the date of the air quality monitoring data by current time. At 49.01, 8/6/2023 7:01:42 AM +00:00 had the highest Average of Temperature and was 400.10% higher than 9/10/2023 2:01:59 AM + 00:00, which had the lowest Average of Temperature at 9.80. Average of Temperature and total Average of AirQualityIndex are negatively correlated with each other. Across all 1,185 CurrentTime, Average of Temperature ranged from 9.80 to 49.01, Average of AirQualityIndex ranged from 3.00 to 109.00, and Average of Pm10 ranged from 0.55 to 273.07.

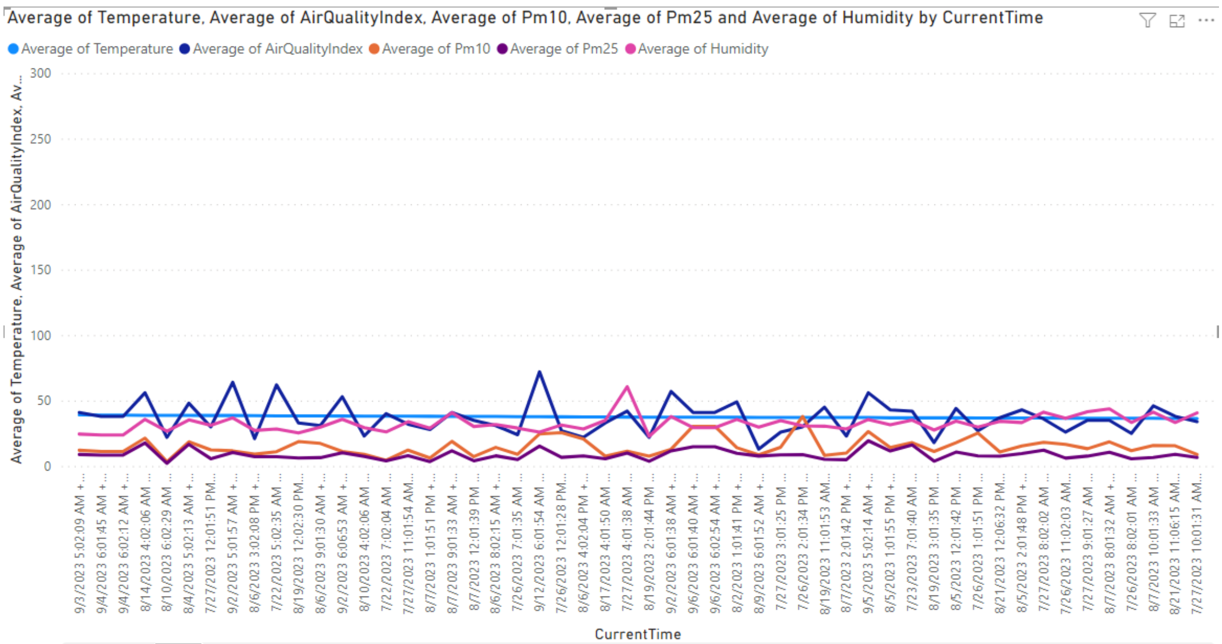

Fig. 4. Historical of air quality data by the time

By adhering to these recommendations and routinely performing calibration and maintenance tasks, the IoT-based air quality monitoring system can operate effectively, delivering accurate and reliable air quality data that informs and empowers individuals and communities to make proactive decisions about their environment [2]. Fig. 5 shows the average of the air quality monitoring data for a specific day. The average of Pm10 and the total Average of Pm25 are negatively correlated with each other.

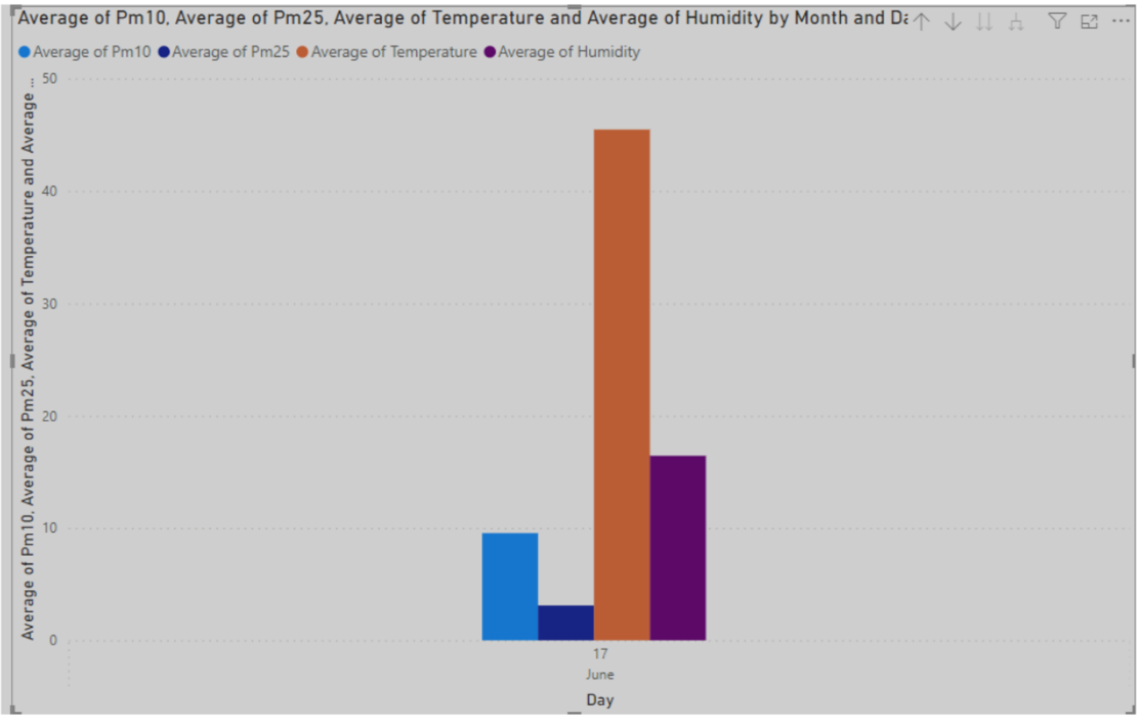

Fig. 5. Average of air quality data for one day

Conclusion

The comprehensive, real-time IoT-based air quality monitoring system successfully combines state-of-the-art sensor technology, ESP32 microcontroller, and robust data analytics to effectively address the pressing global concerns of air pollution, public health, and environmental sustainability. This sophisticated monitoring system provides users with valuable insights into their immediate environment and facilitates data-driven decision-making, thus promoting public engagement and environmentally conscious behaviors.

By leveraging advanced sensor technology and cloud-based data management, the system yields highly accurate real-time measurements of critical air quality parameters. When coupled with predictive analytics and machine learning algorithms, the system demonstrates the potential to revolutionize air quality management and pollution mitigation strategies. As technology advances and innovation continues to shape the future, the integration of smart city initiatives, advanced analytics, and efficient communication systems can further enhance the capabilities of the air quality monitoring system.

In the realm of environmental science and public health, the proposed system's ability to generate and analyze high-quality air pollution data can significantly contribute to the understanding of pollution dynamics and its widespread effects on both local and global scales. Furthermore, the system enables researchers, policymakers, and stakeholders to develop targeted mitigation measures, implement data-driven policies, and evaluate the effectiveness of implemented strategies.

In conclusion, the IoT-based air quality monitoring system presents a scientifically sound, technologically advanced, and versatile solution for addressing critical environmental challenges faced by contemporary societies. By empowering individuals and communities with real-time, accurate, and actionable air quality information, the system fosters proactive pollution management, prudent urban planning, and environmentally responsible choices. As a result, the air quality monitoring system serves as an instrumental tool in the continuous pursuit of improved public health outcomes and a sustainable future.

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