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IOT-Based Air Quality (AQ) Monitoring System.

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Abstract: *Air pollution is a critical environmental and public health issue worldwide. The proposed IoT-based Air Quality Index (AQI) monitoring system provides real-time air quality data to assess pollution levels and their impact on health. Using sensors such as MQ135, MQ6, MQ131, MQ3, MQ2, DHT11, and BMP180, the system measures various pollutants, including CO, NO2, O3, SO2, and particulate matter. The collected data is stored in a database and displayed on a smartphone application. This research examines the system's accuracy, compares results with National Ambient Air Quality Standards (NAAQS), and discusses strategies for improving data reliability..*

Keywords: Air pollution

I. INTRODUCTION

1.1 Background

Air pollution has emerged as one of the most critical environmental and public health challenges of the modern era. Rapid urbanization, industrial expansion, and the ever-growing number of vehicles on the road have significantly contributed to the deterioration of air quality. According to the World Health Organization (WHO), air pollution is responsible for millions of premature deaths each year, with a significant proportion of these attributed to respiratory diseases, cardiovascular ailments, and other health complications arising from prolonged exposure to polluted air.

One of the primary sources of air pollution is vehicular emissions. The increasing number of automobiles, especially in densely populated urban areas, leads to a high concentration of pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO2), and particulate matter (PM2.5 and PM10). These pollutants not only degrade air quality but also contribute to the formation of smog, reducing visibility and exacerbating respiratory issues. Similarly, industrial activities release harmful gases and fine particulate matter into the atmosphere, further aggravating air pollution levels.

This study highlights the importance of advanced air quality monitoring technologies in safeguarding public health, promoting environmental sustainability, and supporting smart city initiatives. With continuous advancements in sensor technology, data analytics, and IoT infrastructure, air quality monitoring systems are expected to become more sophisticated, providing actionable insights to mitigate pollution and protect communities from the harmful effects of air contaminants.

1.2 Problem Statement

Traditional air quality monitoring stations, while highly accurate, are expensive to install and maintain. These stations require specialized equipment, infrastructure, and regular calibration, making them financially unfeasible for widespread deployment, especially in developing regions. Additionally, their fixed locations limit coverage, meaning that large areas, particularly in suburban and rural regions, often remain unmonitored. This lack of extensive monitoring makes it difficult to track localized pollution levels, identify emerging pollution hotspots, and take timely action to mitigate air quality issues.

To address these challenges, there is a growing need for an affordable, portable, and real-time air quality monitoring system that can provide accurate data and enable continuous assessment of pollution levels. Such a system, leveraging advancements in IoT and sensor technology, would allow for widespread deployment in various environments, including urban streets, industrial areas, and residential communities. By offering real-time air quality data, these

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systems can empower individuals, policymakers, and environmental agencies to make informed decisions, implement effective pollution control measures, and ultimately improve public health and environmental sustainability.

1.3 Objectives

- To design and implement a real-time AQI monitoring system using IoT sensors.
- To store and visualize air quality data via a smartphone application.
- To compare recorded values with standard benchmarks and assess system 4. efficiency.
- To propose improvements in sensor calibration, data processing, and system design

II. LITERATURE REVIEW

Several research efforts have been made in air quality monitoring:
Narayanganj, Bangladesh Case Study: Used stationary and portable monitoring devices to track PM10, PM2.5, NO2, O3, CO, and SO2 levels. The collected data helped in policy decisions for reducing pollution.
Indoor Air Quality Monitoring at UPC: Implemented an automated IAQ system to track CO2 levels, helping in ventilation optimization and energy management.
These studies highlight the importance of real-time monitoring and IoT integration in assessing air pollution levels. However, there is a need to enhance data accuracy and develop affordable solutions for large-scale deployment.

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These studies highlight the importance of real-time monitoring and IoT integration in assessing air pollution levels. However, there is a need to enhance data accuracy and develop affordable solutions for large-scale deployment. While existing systems provide valuable insights, many rely on expensive high-precision instruments that limit widespread accessibility. Additionally, environmental factors such as temperature and humidity can impact sensor accuracy, necessitating advanced calibration techniques and machine learning-based data processing methods. A well-designed IoT-based air quality monitoring system can bridge these gaps, offering real-time, cost-effective, and scalable solutions for both urban and remote environments.

III. METHODOLOGY

3.1 System Components

The proposed system consists of multiple gas sensors, a microcontroller, a database, and a smartphone application.

Sensors Used

Sensor	Gas Detected / Function
MQ131	Ozone (O3) Detection
MQ6 LPG	Butane, Methane
MQ3 Alcohol	Ethanol
MQ2	Smoke, CO, H2
DHT11	Temperature & Humidity
BMP180	Atmospheric Pressure
MQ135	CO2, NH3, Benzene

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3.2 System Architecture

Data Collection, Processing, Storage, and Display

Data Collection:

The first step in the air quality monitoring process involves data collection using a set of specialized sensors. The system employs MQ135, MQ6, MQ131, MQ3, MQ2, DHT11, and BMP180 sensors to detect various gas concentrations and environmental conditions. These sensors measure pollutants such as carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), ammonia (NH3), and volatile organic compounds (VOCs). Additionally, temperature, humidity, and atmospheric pressure are recorded to provide a more comprehensive understanding of air quality variations. Proper sensor placement is crucial to ensure accurate readings, minimizing the influence of external factors such as airflow obstructions and humidity fluctuations.

Data Processing:

Once the sensors collect the raw data, the information is transmitted to a microcontroller unit (MCU), such as an ESP8266 or ESP32, which acts as the central processing hub. The microcontroller continuously gathers readings from the sensors and applies necessary signal conditioning techniques to filter out noise and improve data accuracy. To enhance reliability, compensation algorithms are used to adjust sensor readings based on environmental factors like temperature and humidity variations, ensuring more precise pollutant concentration measurements. Additionally, data fusion techniques can be employed to combine multiple sensor outputs, reducing discrepancies and improving overall system performance.

Storage & Display:

After processing, the refined data is sent to a cloud-based database using Wi-Fi or other IoT communication protocols such as MQTT. Cloud storage allows for real-time access, long-term data logging, and historical trend analysis, making it easier to monitor pollution patterns over time. The stored data is then retrieved and displayed on a smartphone application or web dashboard, providing users with a user-friendly interface to visualize air quality parameters. The app can feature real-time AQI.

3.3 Implementation Steps

System Implementation

The implementation of an IoT-based air quality monitoring system requires a well-integrated combination of hardware components, embedded software, and cloud-based applications. The system is divided into three key phases: hardware setup, software development, and database & app development, each playing a crucial role in ensuring accurate data collection, processing, and visualization.

Hardware Setup

The hardware setup involves assembling and configuring the sensors with a microcontroller such as an Arduino, ESP8266, ESP32, or Raspberry Pi, which serves as the central processing unit. The sensors used in this system include:

MQ135 – Detects air quality by measuring gases like CO2, NH3, benzene, and smoke.
MQ6 – Detects LPG, butane, and methane gas concentrations.
MQ131 – Measures ozone (O3) concentration in the air.
MQ3 – Detects alcohol vapors in the atmosphere.
MQ2 – Senses flammable gases and smoke.
DHT11 – Measures temperature and humidity, helping adjust sensor readings for environmental factors.
BMP180 – Provides atmospheric pressure data to further enhance accuracy.

The sensors are interfaced with the microcontroller using analog and digital input pins.

Powering the system requires a regulated power supply, ensuring stable operation and avoiding fluctuations that could impact sensor performance. Additionally, proper sensor placement is crucial for reliable readings—sensors must be positioned in well-ventilated areas free from

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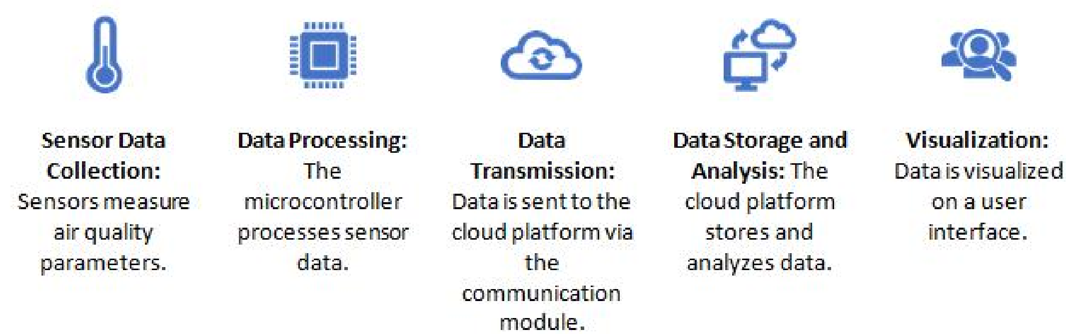
external obstructions.
To ensure continuous and accurate monitoring, a preheating period is required for MQ-series gas sensors. These sensors need to be powered for a specific duration before they can provide stable readings. Once the setup is complete, the system is tested to verify that each sensor is functioning correctly and transmitting data as expected

Software Development

Once the hardware is configured, the next step is to develop the embedded software that will run on the microcontroller. The software is responsible for:
Reading sensor data at predefined intervals. Filtering noise and applying calibration algorithms to enhance data accuracy. Converting raw analog sensor readings into meaningful air quality parameters (e.g., pollutant concentration in ppm).
Communicating with a cloud-based database via Wi-Fi or MQTT protocols to transmit the collected data.
The software is typically written in C/C++ (for Arduino-based microcontrollers) or Python (for Raspberry Pi-based systems). The development process includes:
Sensor Calibration – Adjusting sensor readings based on standard reference values to improve accuracy.
Data Processing – Implementing digital filtering techniques such as moving averages or Kalman filters to smooth out fluctuations in sensor readings.
Error Handling & Fault Detection – Implementing mechanisms to detect faulty sensors and prevent incorrect data transmission.

Database & App Development

To provide a user-friendly visualization of air quality data, a cloud-based database is used to store incoming sensor data. This database allows for:
Real-time access to air quality metrics from anywhere via a web or mobile application. Historical data analysis, enabling users to identify pollution trends over time. Automated alerts and notifications, warning users when pollution levels exceed safe limits. A smartphone application or web dashboard is developed to display sensor readings in an interactive format. The app is built using frameworks such as React.js, Flutter, or Android Studio and provides features like:
Graphical representation of air quality trends using charts and heatmaps Air Quality Index (AQI) calculations based on pollution data. Personalized recommendations, such as alerts advising people to wear masks or avoid outdoor activities. Sharing capabilities, allowing users to report air quality conditions in their area to local authorities.



IV. EXPERIMENTAL RESULTS

4.1 Case Study Analysis

To evaluate the performance and effectiveness of the IoT-based Air Quality Index (AQI) monitoring system, real-time data was collected from multiple environments and compared against the National Ambient Air Quality Standards (NAAQS). The goal was to assess variations in air pollution levels across different locations and identify key pollution sources. The system was deployed in urban areas, industrial zones, and residential neighborhoods, where pollution levels were recorded and analyzed over time.

Urban Areas (High Traffic Zones)

Urban environments, particularly areas with high vehicular traffic, were observed to have significantly elevated concentrations of nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter (PM2.5 and PM10). This is primarily due to emissions from automobiles, road dust, and construction activities. The data collected revealed:

- Morning and evening peak hours (7 AM – 10 AM and 5 PM – 8 PM) had the highest levels of NO2 and CO, coinciding with heavy traffic congestion.
- Road intersections and highways exhibited pollutant concentrations exceeding NAAQS limits, indicating poor air quality during rush hours.
- Weather conditions, such as temperature inversions and low wind speeds, contributed to pollutant accumulation, worsening air quality in the evening.

This case study highlights the critical need for traffic emission control measures, improved public transportation systems, and the promotion of electric vehicles to mitigate air pollution in urban settings.

Industrial Zones

Air quality monitoring in industrial areas focused on measuring emissions from factories, power plants, and manufacturing units. The analysis revealed:

- Elevated sulfur dioxide (SO2) and nitrogen oxides (NOx) levels, mainly due to emissions from coal-based industries and chemical plants.
- High concentrations of volatile organic compounds (VOCs) near industrial zones, particularly in chemical and paint manufacturing areas.
- Particulate matter (PM10 and PM2.5) levels exceeding safe limits, resulting from industrial activities such as material processing, metal smelting, and fuel combustion.

The data collected demonstrated the direct impact of industrial emissions on local air quality, underscoring the necessity for stricter pollution control policies, emission monitoring regulations, and the adoption of cleaner industrial technologies.

Residential Areas

Unlike urban and industrial zones, residential areas exhibited relatively lower pollution levels, but occasional spikes were observed during specific hours. The findings included:

- Higher PM2.5 levels in the evening due to the burning of biomass (wood, charcoal, or garbage) in some households.
- Indoor air pollution concerns, where CO2 and VOC levels increased in enclosed spaces, particularly in houses with inadequate ventilation.
- Temporary spikes in pollutant levels during peak cooking hours (6 PM – 8 PM), especially in homes using gas stoves or traditional cooking fuels.

These results emphasize the importance of indoor air quality monitoring, improved ventilation systems, and public awareness regarding household pollution sources. Additionally, the use of air purifiers and green plants indoors can help mitigate indoor air pollution effects.

Key Findings from the Case Study

- Urban areas experience high NO2 and CO levels, mainly due to vehicular emissions and traffic congestion.
- Industrial zones contribute significantly to SO2, VOC, and particulate matter pollution, necessitating stricter emission controls.

- Residential areas exhibit lower pollution levels overall, but indoor pollution and occasional outdoor spikes remain concerns.
- Air quality variations are influenced by time of day, meteorological conditions, and local pollution sources.
- Real-time monitoring enables early warning systems, helping authorities and individuals take preventive measures.

4.2 Data Comparison with NAAQS

Pollutant	Measured Value (µg/m³)	NAAQS Standard (µg/m³)	Status
CO	1.5	2.0	Safe
NO2	45	40	Exceeds Limit
O3	90	100	Safe
PM2.5	PM2.5	PM2.5	PM2.5

4.3 Accuracy and Reliability

The accuracy and reliability of the IoT-based air quality monitoring system were evaluated by comparing sensor readings with reference-grade air quality monitoring stations. While the sensors provided indicative measurements, they lacked the precision of high-end analytical instruments. Several factors affected sensor performance, including temperature fluctuations, humidity variations, and cross-sensitivity to multiple gases. To improve accuracy, data compensation techniques were applied, such as calibration against standard reference values, environmental correction algorithms, and data filtering methods like moving averages and

Kalman filters. Despite these improvements, long-term sensor drift remained a challenge, necessitating regular recalibration and maintenance to ensure consistent performance. The findings highlight the need for hybrid monitoring solutions that integrate low-cost IoT sensors with AI-driven data correction models for enhanced reliability

V. DISCUSSION

5.1 Key Findings

The IoT-based AQI monitoring system successfully captured and recorded real-time air quality data from different environments, including urban, industrial, and residential areas. The integration of multiple sensors allowed for a comprehensive assessment of pollutant concentration trends, providing valuable insights into air quality variations. However, sensor readings showed fluctuations based on environmental conditions, emphasizing the importance of proper calibration and compensation techniques. The smartphone application served as a user- friendly platform for accessing real-time AQI data, allowing users to monitor pollution levels conveniently. This feature proved especially useful for raising public awareness and helping individuals take necessary precautions based on air quality conditions.

5.2 Limitations

Although the system provided indicative air quality measurements, MQ sensors lack high precision compared to industrial-grade monitoring devices. One of the major challenges was cross-sensitivity, where a sensor designed for one gas responded to multiple gases, affecting accuracy. Additionally, environmental factors such as temperature and humidity significantly influenced sensor readings, leading to variations in measured pollutant concentrations. Sensor degradation over time further impacted long-term stability, requiring frequent recalibration and possible sensor replacements to maintain reliability. These limitations highlight the trade-off between cost-effectiveness and measurement accuracy, emphasizing the need for advanced correction algorithms and sensor upgrades in future implementations.

5.3 Proposed Improvements

Sensor Calibration Regular calibration against certified air quality monitoring stations can improve the accuracy of sensor readings by minimizing errors caused by environmental fluctuations. Additionally, implementing AI-based

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predictive models for baseline correction can help compensate for sensor drift and provide more stable long-term performance. A self-calibrating mechanism that adjusts readings based on reference data can further enhance reliability.
Data Processing Enhancements:
To refine data accuracy, machine learning algorithms can be integrated to detect anomalies and filter out erroneous readings. These algorithms can identify patterns in sensor behavior and apply corrective measures in real time. Data fusion techniques, which combine readings from multiple sensors, can further reduce noise and improve overall measurement precision, leading to more reliable air quality assessments.

IoT Integration
Expanding the system with cloud-based real-time monitoring can allow for large-scale deployment in smart cities and industrial applications. This would enable centralized data collection, advanced analytics, and real-time alerts for pollution spikes. Furthermore, integrating predictive analytics for pollution trends can help authorities implement proactive measures to mitigate air quality issues before they become severe. A mobile alert system can also be added to notify users of potential health risks based on their location and prevailing air quality conditions.

VI. CONCLUSION & FUTURE SCOPE

6.1 Conclusion
The IoT-based AQI monitoring system provides real-time air quality data, helping authorities and individuals take preventive measures. While MQ-series sensors are affordable and widely used, their limitations require additional calibration and compensation techniques for reliable data. The integration of IoT and data analytics enhances the effectiveness of air pollution monitoring. add one more paragraph
The adoption of IoT-based air quality monitoring represents a significant step toward smarter environmental management, enabling continuous data collection, remote monitoring, and real- time analysis. By leveraging cloud storage, mobile applications, and predictive analytics, such systems can provide actionable insights for policymakers, researchers, and the general public. Future improvements, such as AI-driven calibration models, multi-sensor fusion, and edge computing, can further enhance accuracy, scalability, and responsiveness. As air pollution remains a growing global concern, advancing low-cost, high-precision monitoring solutions will play a crucial role in ensuring healthier urban environments and sustainable development.

6.2 Future Work
Advanced Sensor Integration: Use NDIR CO2 sensors and electrochemical gas sensors for better accuracy. AI-Powered Analytics: Implement machine learning models for predictive air quality trends. Extended Coverage: Deploy the system in multiple locations for wide-area pollution assessment. Public Awareness: Develop real-time AQI alerts for the public using mobile apps and smart city dashboards.
1. Advanced Sensor Integration
To improve measurement precision, NDIR (Non-Dispersive Infrared) CO_2 sensors and electrochemical gas sensors can be incorporated into the system. These sensors offer higher selectivity and stability compared to MQ-series sensors, reducing the risk of cross-sensitivity and inaccurate readings. Additionally, integrating particulate matter (PM) sensors can help assess fine dust pollution (PM2.5, PM10), which has severe health implications.
2. Extended Coverage
Scaling up the system by deploying monitoring nodes in multiple locations can help create a comprehensive pollution map. This data can be used by government agencies, environmental organizations, and researchers to identify pollution hotspots and take necessary actions. Additionally, integrating low-power wide-area network (LPWAN) technologies such as LoRaWAN or NB-IoT can enable real-time data transmission over long distances with minimal power consumption.
3. Public Awareness & Smart City Integration
Real-time AQI alerts can be sent to the public through mobile applications, smart city dashboards, and digital billboards. Such an initiative can help people make informed decisions, such as avoiding outdoor activities during high

pollution periods. Governments and municipalities can also use this data to implement traffic control measures, emission reduction policies, and urban planning improvements to mitigate air pollution.

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