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Review On Technologies and Sensors Used for Air Quality Index Monitoring

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Abstract: Recent research work on air quality checker technology highlight significant advancements driven by Internet of Things (IoT) and Artificial Intelligence (AI), the proliferation of low-cost sensors, and the exploration of hybrid monitoring approaches. Air pollution is a most unavoidable serious issue which risks to human health and ecosystems. Continuous monitoring of air quality is essential for assessing pollution levels and for taking timely preventive measures. The standard indicator use for air quality measurement is Air Quality Index (AQI). It includes concentration of major pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). This paper reviews various air quality monitoring approaches, including conventional monitoring stations, Internet of Things (IoT)-based systems, and data-driven techniques. Traditional monitoring methods provide high accuracy but suffer from high cost and limited coverage. Recent advancements in low-cost sensors, wireless communication, and cloud platforms have enabled real-time and scalable AQI monitoring. Furthermore, machine learning techniques have improved AQI prediction and pollution trend analysis. The review highlights existing challenges such as sensor calibration, data reliability, and environmental interference, and discusses future research directions for smart and sustainable air quality monitoring systems.

Keywords: Air Quality Index (AQI), Air Pollution Monitoring, IoT, Low-Cost Sensors, Machine Learning, Environmental Monitoring, Smart Cities

I. INTRODUCTION

This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website. Air pollution has become one of the most critical environmental and public health challenges worldwide. Rapid urbanization, industrial growth, and increased vehicular emissions have significantly degraded air quality. To communicate air pollution levels effectively to the public and policymakers, the Air Quality Index (AQI) is widely used. AQI converts complex air pollution data into a single number, category, and color code that represents overall air quality and associated health risks.

A government regulatory framework for air quality monitoring establishes legal mandates (like India's Air Act, 1981), defines roles for agencies (CPCB, SPCBs), sets National Ambient Air Quality Standards (NAAQS) for pollutants, and implements monitoring networks (NAAQM) to collect data for assessing pollution levels, identifying problem areas, and informing policies for prevention and control, often integrating meteorological data and early warning systems to manage public health impacts.Laws like the Air (Prevention and Control of Pollution) Act, 1981, and the Environment (Protection) Act, 1986, provide the authority for regulation and enforcement.The framework establishes National Ambient Air Quality Standards (NAAQS) for key pollutants (PM10, PM2.5, SO2, NO2, etc.) and uses the Air Quality Index (AQI) for public communication.

Air quality Index measurement steps

a) Sensing: Sensors (low-cost IoT to highly precise analyzers) detect pollutants, temperature, humidity, etc.
b) Data Collection: Data is transmitted wirelessly (Wi-Fi, cellular) from monitoring nodes to a central control system.
c) Analysis: Data is processed, converted into the Air Quality Index (AQI) for easy understanding, and forecasts are made.
d) Dissemination: Information is shared with authorities, uploaded to public display boards, apps, and websites.

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II. LITERATURE SURVEY

The review papers on Air quality measurement focus on IoT-based solutions, comparing low-cost sensors (like MQ series, PM sensors) with costly stations, analyzing communication protocols (Wi-Fi, LTE, LoRa), and evaluating data analytics/cloud platforms for real-time monitoring, often highlighting challenges in calibration, deployment, and achieving accuracy while improving scalability and accessibility for smart cities and health applications.

A. Previous work

"Association between air pollutants particulate matter (PM2.5, PM10), nitrogen dioxide (NO2), sulfur dioxide (SO2), volatile organic compounds (VOCs), ground-level ozone (O3) and hypertension [1]. In this paper impact of air pollutants on hypertension was investigated through a compilation of 28 studies, from multiple countries, encompassing a total sample size of 2,540,441. Increased exposure to environmental pollutants PM2.5 (OR = 1.05; 95 % CI:1.02, 1.08; $p < 0.01$); PM10 (OR = 1.25; 95 % CI: 1.04, 1.49; $p = 0.02$); NO2 (OR = 1.12; 95 % CI: 1.01, 1.25; $p = 0.04$); SO2 (OR = 1.17; 95 % CI:1.04, 1.31; $p = 0.02$); and VOCs (OR = 2.45;95 % CI:1.36, 4,41; $p = 0.01$) were significantly associated with increased incidence of HTN. The author concluded that air pollutants PM2.5, PM10, NO2, SO2, and VOC positively and significantly enhanced the risk of hypertension. Environmental pollutants-reducing policies could be a dynamic planned approach to lessen cardiovascular risks in global populations [1].

The paper " IoT-Based Air Quality Monitoring and Prediction System [2]" uses MQ-2, MQ-4, MQ-7, MQ-9, and MQ-135 sensors in conjunction with a DHT-11 temperature and humidity sensor. The sensor data is processed using the Random Forest algorithm to provide predictions for AQI. The data is streamed over the ThingSpeak IoT cloud, graphed, and made accessible via a mobile application [2]. Even though the suggested system performed well under different test scenarios, the following vulnerabilities were revealed:

i) Sensor Calibration Issues – MQ-series sensors are required to be calibrated at regular intervals to obtain precise measurements because the environmental conditions may affect their sensitivity.
ii)Network Dependency – Cloud-based data transmission is network-dependent, and any break in the stable internet connection might cause delayed or lost data due to weak network signals in the region.
iii) Environmental Impact on Sensors – Changes in temperature and humidity can cause slight effects on sensor readings, thus the application of compensation techniques to maintain precision.
iv) Power Consumption – The system requires a constant supply of power, making it hard to incorporate the system into outlying regions.

“The rise of low-cost sensing for managing air pollution in cities” [3] paper eplore the reie serey on low ost sensor. Increasing effort from scientists and instrument manufacturers, as well as improvements in wireless automated systems, have made it possible to reduce the cost of air pollution sensors from thousands to hundreds of pounds or less. But as mentioned in paper at present, the manufacturing (capital) cost of these systems is not a major barrier, however the costs involved in their installation, maintenance and data analysis need to be reduced[3]. In fact, the cost of labour to maintain sensor networks, as well as the post-processing of collected data is likely to exceed the cost of the sensors themselves[3].

The paper “Design and Implementation of an Indoor and Outdoor Air Quality Measurement Device for the Detection and Monitoring of Gases with Hazardous Health Effects”[5] presents a detailed step-by-step design and construction of an indoor and outdoor air quality monitoring device, composed of electronic sensors capable of measuring gases such as Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3), in addition to measuring temperature and humidity, as well as concentrations of PM2.5 and PM10 particulate matter suspended in the environment. Author concluded that to improve the performance of the device and to extend the time we want to use it, some recommendations are highlighted [5]. Replace the MQ131 and MQ1335 sensors with other sensors more developed and intended for specific gases, the MQ sensor family, despite taking measurements with a very low margin of error and ensuring stability during measurement time, these types of sensors are generic and are intended for the measurement of a wide range of gases and over time are losing sensitivity for the detection.

“Air Pollution Monitoring System Using IOT”[6] The system is developed as shown in fig.1 with help of sensors, microcontroller, I2C and mobile phone with blynk application. All sensors used in system are connected to ESP32 microcontroller. The system has given a successful results which yields an accuracy rate of 97%. By the help of this system monitoring air pollution can be made easier. Soon everyone will know the quality of the air around them and take appropriate action if the quality drops.

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Table 1. Percent error measurement [5].

Variables	Average Readings (µg/m3)	Reference Readings (µg/m3)	Rate of Error (%)
Temperature	27.79	28	0.75
Humidity	74.54	75	0.613
NO2	3.61	3.65	1.096
O3	59.84	60.49	1.075
CO	125.27	124.6	0.538
PM2.5	14.67	14.49	1.24
PM10	28.08	27.82	0.935

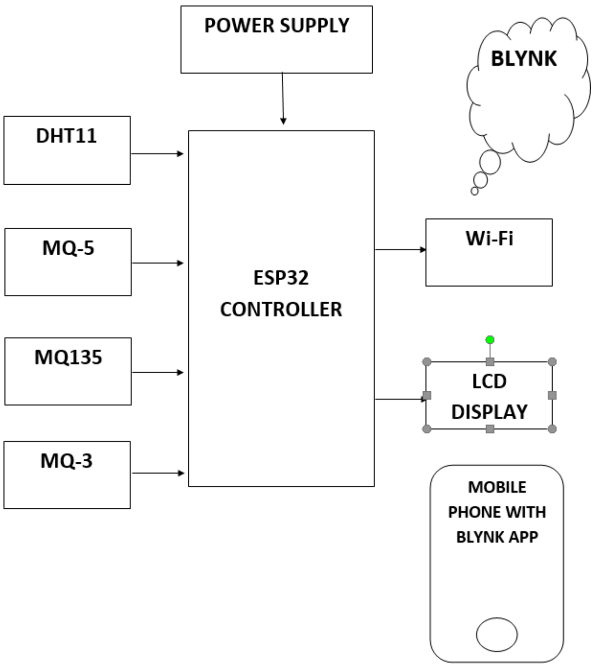

Fig. 1 Air pollution monitoring system using IoT

"Air Quality Monitoring System" [7]. This paper deals with measuring Air Quality using MQ135 sensor along with Carbon Monoxide CO using MQ7 sensor. Measuring Air Quality is an important element for bringing lot of awareness in the people to take care of the future generations a healthier life. These techniques are elaborately discussed in the paper [7]. In this system, one of the most preferred Technique is Cloud Based air quality monitoring system.

"Survey Paper on Air Quality Monitoring Systems" [8] papers author concluded that the future lies in integrating AI, remote sensing, and low-cost sensors for widespread, efficient, and inclusive air quality monitoring. Global collaboration, innovation, and public engagement are essential to tackle air pollution and ensure a cleaner environment for future generations.

"Air Quality Index Over IoT [9]" In this system consists of three sensors: the MQ2 gas sensor, the MQ7 carbon monoxide sensor, and the DHT11 temperature and humidity sensor. These sensors are connected to an Arduino Uno board, which collects the data and sends it to the ESP8266 Wi-Fi module [9]. This system can be extended to detect other air pollutants such as particulate matter and nitrogen dioxide.

The paper title "Performance and applicability of low-cost PM sensors to assess global pollution variability through machine learning techniques" [10] explored the different technologies and sensors and examined the deployment, monitoring, and performance outcomes of LCS networks across high, middle, and low income group countries focusing on variations in emission sources, performance parameters, and use of ML approaches for local source categorization.

Advancements in air quality monitoring: a systematic review of IoT-based air quality monitoring and AI technologies [11]. This paper reviews recent advances in air quality monitoring, emphasizing the importance of state-of-the-art AI models such as convolutional neural networks (CNNs), LSTM networks, transformer architectures, and auto encoders.

These models address common issues such as data reliability, sensor calibration, missing data management, and anomaly detection, thereby improving the accuracy and effectiveness of monitoring systems.

B. Research gap

i) Data Accessibility & Equity:

Low- and Middle-Income Countries (LMICs): Significant lack of monitors and funding for reference-grade equipment, despite highest pollution exposure.

Low-Cost Sensors (LCS): Need for better calibration, physical size cut-point validation, and integration into official networks.

ii) Index Calculation & Reporting:

Capped Values: Official AQI systems (like India's) cap values at 500, masking extreme pollution levels. Averaging Periods: 24-hour averages can mask dangerous short-term peaks, making air seem better than it is.

Factor Analysis: Insufficient analysis of how different pollutants (PM2.5, Ozone, etc.) interact and influence the overall index.

iii) Integration & Technology:

Data Fusion: Better methods to combine monitoring station data with satellite imagery, traffic data, and land-use data for higher accuracy.

IoT & Machine Learning: Moving beyond basic prediction to create actionable insights, user-friendly visualizations, and timely alerts for the public.

iv) Health & Pollutant Focus:

Ultrafine Particles (UFPs): Lack of data and monitoring for UFPs, which have significant health impacts.

Multipollutant Exposures: Limited understanding of the independent and combined health effects of multiple pollutants.

v) User Actionability:

Behavioral Science: Bridging the gap between knowing the AQI and taking effective protective actions, especially for vulnerable populations.

III. CONCLUSION

The fusion of artificial intelligence with IoT and developing user-friendly interfaces for public action, AQI monitoring plays a vital role in assessing air pollution and protecting public health. While traditional monitoring systems provide high accuracy, IoT-based and AI-driven approaches offer cost-effective, scalable, and real-time solutions. Future AQI monitoring systems are expected to be more intelligent, predictive, and citizen-centric.

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