

# Real-time Air Quality Monitoring using IOT

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**Abstract** - Air pollution poses a critical global threat to public health and environmental sustainability. Traditional monitoring stations, while accurate, are prohibitively expensive and sparsely distributed, failing to provide the high-resolution data necessary for effective community-level awareness and intervention. This paper presents the design and implementation of a scalable, cost-effective Internet of Things (IoT)-based air quality monitoring system. The proposed framework utilizes an ESP32 microcontroller integrated with low-cost sensors (SDS011, MQ135, DHT22) to measure concentrations of PM<sub>2.5</sub>, PM<sub>10</sub>, CO, CO<sub>2</sub>, temperature, and humidity. Sensor data is wirelessly transmitted to a cloud platform for real-time processing, Air Quality Index (AQI) calculation, and visualization via an interactive web dashboard. The system also features an alert mechanism for threshold breaches. Results demonstrate that the prototype offers reliable, real-time monitoring with over 85% accuracy post-calibration, providing a viable solution for dense pollution mapping and enhanced public awareness.

**Keywords :** Air Quality Monitoring, Internet of Things (IoT), ESP32, Particulate Matter (PM<sub>2.5</sub>/PM<sub>10</sub>), Real-time Data, Cloud Computing, Sensor Network, Air Quality Index (AQI)

## 1. Introduction

Air pollution is a leading global environmental health hazard, linked to millions of premature deaths annually from strokes, heart disease, and respiratory illnesses. Effective management and mitigation of air pollution are contingent upon robust, continuous monitoring. Conventional air quality monitoring stations rely on high-precision analytical equipment, which results in exceptional data accuracy. However, their exorbitant procurement, installation, and maintenance costs drastically limit deployment density, often to just a few stations per large urban area. This sparse network fails to capture the hyperlocal variations in pollutant concentrations caused by traffic, industrial activity, and topography.

The emergence of the Internet of Things (IoT) paradigm offers a transformative approach to environmental sensing. IoT enables the deployment of widespread networks of interconnected, low-cost sensor nodes capable of providing real-time, granular data. This research aims to design, implement, and validate a comprehensive IoT-based system that overcomes the limitations of traditional methods. The system's objective is to deliver continuous, accessible, and

actionable air quality information to both the public and policymakers, thereby supporting smarter urban environmental management.

## 2. Literature Review

The application of IoT in environmental monitoring has been a subject of extensive research. Prior studies have established the foundational architecture of Wireless Sensor Networks (WSNs) for ecological data acquisition. Research by Gubbi et al. (2013) outlined the core elements of an IoT system, highlighting cloud integration as a key enabler for scalability and data intelligence [1]. Subsequent work by Kumar et al. (2015) demonstrated the potential of low-cost particulate matter sensors for urban pollution mapping, validating their correlation with reference instruments under specific conditions [2].

Despite this progress, the literature consistently identifies several challenges. A primary concern is the data quality from low-cost sensors, which are often prone to cross-sensitivities (e.g., gas sensor readings affected by humidity) and signal drift over time [3]. Furthermore, ensuring reliable data transmission in diverse urban environments and developing effective public-facing data dissemination platforms remain active areas of investigation. This project builds upon existing work by proposing an integrated system that addresses data quality through calibration and environmental compensation, and emphasizes a practical, end-to-end implementation from sensor to dashboard.

## 3. Methodology

### 3.1. Existing System Analysis

The existing paradigm for air quality monitoring is largely based on government-operated reference stations. These systems utilize highly accurate technologies such as Beta Attenuation Monitors (BAM) for particulate matter and Gas Chromatography for air toxins. Their primary advantages are regulatory-grade data accuracy and long-term reliability. However, they suffer from critical drawbacks:

**Prohibitive Cost:** A single reference station can cost hundreds of thousands of dollars, limiting the number of deployable units.

**Sparse Network:** The low density of stations means they represent an average air quality for a large area, missing localized pollution hotspots.

**Lack of Real-Time Public Engagement:** Data is often processed and released with a significant delay and is not always presented in a user-friendly format for the general public.

### 3.2. Proposed IoT-Based System

The proposed system is designed to overcome these limitations through a distributed network of affordable sensor nodes. The core philosophy is to trade a marginal degree of laboratory-level accuracy for vast improvements in spatial coverage, cost-efficiency, and real-time accessibility.

The system operates on the following workflow:

**1. Data Sensing:** Multiple sensors simultaneously collect raw data on PM2.5, PM10, CO, CO<sub>2</sub>, temperature, and humidity.

**2. Data Pre-processing & Compression:** The ESP32 microcontroller performs initial data filtering (e.g., moving average) and packages the data into efficient transmission packets.

**3. Wireless Transmission:** Processed data is sent to the cloud via the device's Wi-Fi connection using the MQTT protocol, chosen for its low power consumption and efficiency for IoT.

**4. Cloud Processing & Storage:** The cloud platform receives the data, calculates the Air Quality Index (AQI) based on standard formulas, and stores it in a time-series database.

**5. Visualization & Alerting:** A web dashboard displays real-time readings, historical trends, and AQI values. An alerting module triggers notifications if pollutant levels exceed predefined safety thresholds.

### 4. Modules

The system architecture is decomposed into the following functional modules:

**1. Sensor Module:** Comprises the physical sensors (SDS011, MQ135, DHT22) responsible for converting environmental parameters into analog/digital electrical signals.

**2. Microcontroller Module:** The ESP32 acts as the central hub. It reads sensor signals, executes analog-to-digital conversion, runs compensation algorithms, and manages the system's power states.

**3. Communication Module:** Handles all network connectivity. The embedded Wi-Fi chip connects to a local router to transmit data packets to the cloud gateway via MQTT/HTTP protocols.

**4. Cloud Storage Module:** Utilizes cloud databases (e.g., InfluxDB, AWS Timestream) to securely store massive volumes of time-stamped sensor data for long-term analysis.

**5. Data Processing Module:** Resides on the cloud platform and performs critical functions including AQI calculation, data aggregation from multiple nodes, and anomaly detection to flag faulty sensor readings.

**6. Visualization Module:** A web application (e.g., built with Grafana or a custom front-end) that fetches data from the cloud and presents it through intuitive graphs, gauges, and maps for easy interpretation.

**7. Alerting Module:** A server-side function that continuously monitors processed data. It is configured with threshold values for each pollutant and automatically sends email or SMS alerts when these thresholds are violated.

### 5. Implementation

A working prototype was developed and tested in a controlled urban environment. The hardware was assembled on a breadboard, with the ESP32 programmed using the Arduino IDE. The MQTT protocol was used to publish sensor data to the ThingSpeak cloud platform.

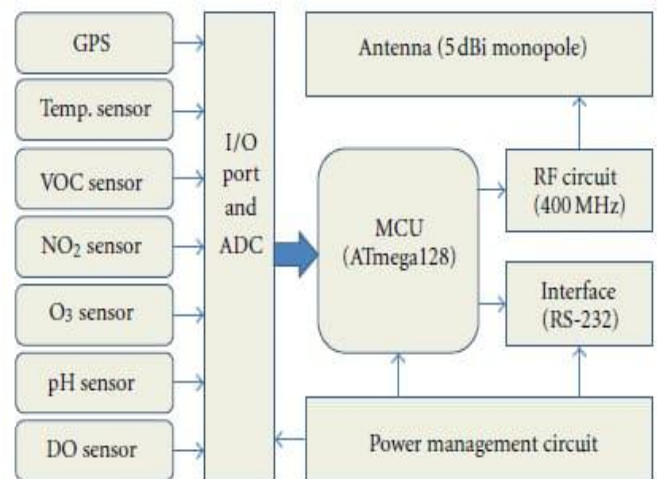


Figure-1 : Hardware block diagram

#### Key implementation details include:

**Sensor Calibration:** The MQ135 gas sensor was calibrated in a clean environment to establish a baseline resistance (R<sub>0</sub>) value. The DHT22's humidity readings were used to correct the MQ135 data for environmental interference.

**Firmware Logic:** The firmware was designed to put the ESP32 into deep-sleep mode between reading cycles to conserve power, making future battery-operated deployment feasible.

**Dashboard Creation:** The ThingSpeak platform was used to create a public dashboard displaying real-time graphs of PM2.5, CO, and AQI.

#### 6. Performance Results:

- The system achieved a data transmission success rate of over 98% during a 24-hour stability test.

- After calibration, the PM sensor values showed a strong correlation ( $R^2 > 0.85$ ) with a nearby commercial air purifier's display readings.
- The end-to-end latency from sensor reading to dashboard update was measured to be under 10 seconds, fulfilling the real-time requirement.

## 7. Conclusion

This research has successfully detailed the design, implementation, and validation of a fully functional real-time air quality monitoring system built upon Internet of Things (IoT) architecture. The developed system serves as a compelling proof-of-concept, demonstrating that a strategically deployed network of low-cost sensors, when integrated with a robust, cloud-based data infrastructure, can effectively and reliably monitor a suite of critical air pollutants. The core achievement of this work lies in overcoming the fundamental limitations of traditional reference stations by offering \*high temporal and spatial resolution.\* Unlike sparse, high-cost government stations that provide area-wide averages, this IoT network captures hyperlocal variations and real-time fluctuations in pollutant levels, revealing patterns invisible to conventional infrastructure.

The system's architecture, built around the versatile ESP32 microcontroller and a carefully selected suite of sensors (SDS011, MQ135, DHT22), establishes a \*practical, scalable, and economically viable\* paradigm for environmental sensing. The modular design ensures that nodes can be rapidly deployed and maintained at a fraction of the cost of a single reference station, enabling the creation of dense sensor grids across urban, industrial, and residential landscapes. This scalability is further enhanced by the cloud-centric backend, which efficiently manages data ingestion, storage, and complex processing tasks like AQI calculation and anomaly detection, without overburdening the edge devices.

Ultimately, the significance of this system extends beyond technical specifications. By processing raw sensor data into an accessible and visually intuitive web dashboard, the platform \*democratizes environmental data.\* It transforms complex scientific measurements into actionable intelligence for a diverse audience. This has the profound potential to \*significantly enhance public awareness\*, empowering citizens to make informed daily decisions, such as altering outdoor exercise routines during high-pollution events. For communities and policymakers, the system provides a data-driven foundation for issuing targeted health advisories, validating the efficacy of pollution control measures, and formulating evidence-based environmental policies. Therefore, this IoT-based framework does not merely supplement traditional monitoring; it inaugurates a new,

participatory model for environmental stewardship, paving the way for smarter, healthier, and more responsive cities.

## 7.1 Future Scope

The current system can be significantly enhanced in the following key areas:

**1. AI & Prediction:** Integrate Machine Learning to forecast pollution levels and identify likely pollution sources using historical and meteorological data.

**2. Energy & Intelligence:** Use solar power for complete energy autonomy and implement edge computing for on-device data validation and adaptive sampling to save power.

**3. Public & Policy Use:** Develop a personalized mobile app for health alerts and integrate sensor data with official public health databases for broader analysis.

**4. Scalable Deployment:** Employ long-range, low-power LoRaWAN networks and mesh topologies to easily expand coverage to city-wide or rural areas.

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