

# AI-Enabled IoT-Based Autonomous Air Quality Monitoring Using Robotic Platform

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## Abstract:

Air pollution is a severe environmental and public health concern driven by rapid industrialization and urbanization. Traditional air monitoring systems rely on fixed stations and manual observation, leading to delayed responses to hazardous gas leaks. This paper proposes an AI-enabled, IoT-based autonomous air monitoring system implemented on a four-wheel robotic platform. Controlled by an Arduino microcontroller, the robot navigates environments autonomously while continuously monitoring air quality using  $CO_2$  and temperature sensors. An artificial intelligence-based algorithm analyzes the sensor data to generate multi-level warnings (Warning-1 to Warning-3) based on pollution severity. At critical gas concentrations (Warning-4), the system autonomously activates a timer and stops the robot to prevent hazards. IoT technology is integrated to transmit real-time data to a cloud server, enabling remote monitoring and alert generation via mobile devices. Furthermore, the system incorporates an energy-harvesting dual-fan mechanism that captures waste heat and airflow to generate electrical energy, improving the system's sustainability. The proposed solution eliminates manual intervention, enhances environmental safety in hazardous zones, and supports the development of smart city infrastructure.

**Keywords** — Air Quality Monitoring, Internet of Things (IoT), Artificial Intelligence, Autonomous Robot, Energy Harvesting, CO<sub>2</sub> Sensor, Smart Environment.

## 1. INTRODUCTION

In recent years, rapid industrialization, urbanization, and increased vehicular emissions have significantly contributed to the rise in air pollution levels across cities and industrial regions. Harmful gases such as carbon dioxide ( $CO_2$ ), carbon monoxide (CO), and other pollutants can negatively affect human health, environmental safety, and ecological balance. Continuous monitoring of air quality has become essential to ensure a safe and healthy environment.

Traditional air monitoring systems rely on fixed monitoring stations that are installed at limited locations. These systems require manual observation and periodic maintenance to check pollution levels. In many cases, harmful gas leaks or pollution spikes are detected too late, which can lead to serious health risks, industrial accidents, or environmental damage. Furthermore, fixed monitoring stations cannot easily monitor remote or hazardous areas where human presence is unsafe. These limitations highlight the need for an intelligent and autonomous air monitoring system capable of detecting pollution levels in

real-time and responding quickly to dangerous situations.

The proposed AI-Enabled IoT-Based Air Monitoring System addresses these challenges by combining artificial intelligence, IoT technology, and robotic automation to create a smart monitoring platform. The system uses sensors such as a  $CO_2$  gas sensor and a temperature sensor to continuously measure environmental conditions. These sensors collect real-time air quality data and send it to a microcontroller for processing.

A key component of the system is the microcontroller, which acts as the central control unit. It receives signals from sensors, processes the data, and controls other components such as motors, fans, and display units. The system is implemented on a four-wheel robotic platform powered by DC gear motors, allowing it to move autonomously and monitor different areas. This mobility enables the system to detect pollution in places that are difficult or dangerous for humans to access.

Another important feature of the system is the AI-based decision-making algorithm. The algorithm continuously analyzes gas concentration levels and generates multiple warning stages depending on the severity of air pollution.

When the pollution level reaches a critical threshold, the AI algorithm automatically activates safety mechanisms and stops the robot to prevent hazards. IoT technology connects the system to the internet and sends real-time air quality data to a cloud platform, enabling remote monitoring through mobile devices.

## 2. LITERATURE REVIEW

Extensive research has been conducted in the field of environmental monitoring, utilizing various technologies ranging from simple microcontrollers to advanced machine learning models.

Lindi Zhang et al. (2025) focused on the monitoring, analysis, and prediction of air quality in Jinan city using the random forest algorithm. Their study utilized data from the China Air Quality Online Monitoring Platform over a long observation period, emphasizing that accurate monitoring and prediction of air quality are essential for effective environmental planning and timely pollution control measures.

John Edrick M. Gador et al. (2024) highlighted the importance of airflow in determining how pollutants move, spread, and accumulate. They proposed a wireless sensor network for indoor-outdoor air quality and dispersion assessment. The system was designed to be flexible and deployable across different facilities, combining air quality sensors with anemometers to measure wind speed and direction.

Silvian-Marian Petrica et al. (2023) presented an energy-efficient IoT Air Quality Monitoring System. They noted that polluted air contains harmful substances that seriously affect people when inhaled over time. Their system utilized advanced sensors capable of detecting a wide range of pollutants with better sensitivity, portability, and energy efficiency.

Tanuj Manglani et al. (2022) addressed both air and noise pollution in smart environments. Their IoT-based system provided an intelligent and modern solution for collecting, transmitting, and analyzing environmental data continuously, recognizing that clean air is essential for human survival and well-being.

Hussein J. Khadim et al. (2021) explored the application of MQ-Sensors for indoor air quality monitoring in laboratories based on IoT. Laboratories often involve chemicals, gases, and solvents that release toxic emissions. Their web-based indoor air quality monitoring system (IAQML) was designed to observe and manage air quality parameters to maintain a safe and healthy indoor environment.

### EXISTING SYSTEM AND ITS DISADVANTAGES

The existing air quality monitoring systems mainly rely on fixed monitoring stations and manual supervision to measure environmental pollution levels. These systems are usually installed in specific locations such as industrial

zones, highways, or urban areas to detect air pollutants. Although these monitoring stations can measure air quality parameters such as gas concentration and temperature, they have several limitations in terms of mobility, automation, and real-time response.

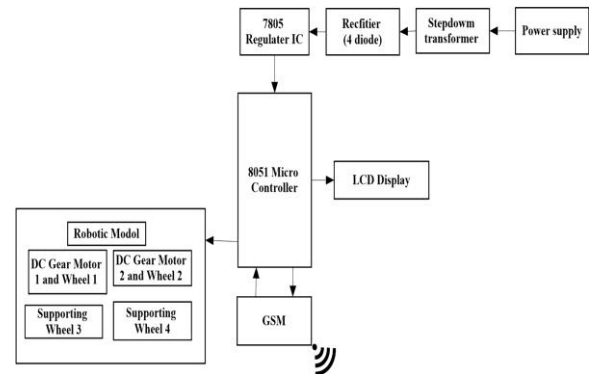


Figure 1: Block Diagram of Existing System

In traditional air monitoring systems, sensors are placed in stationary positions. The collected data is transmitted to monitoring centers where it is analyzed by environmental authorities manually. If harmful gas levels increase suddenly, the system may not respond immediately because human intervention is required to analyze the data and take corrective action.

### 2.1 Key Limitations of the Existing System

- **Fixed Monitoring Stations:** Monitoring units are installed in fixed locations and cannot monitor pollution in multiple or remote areas.
- **Manual Data Analysis:** Pollution data must be analyzed manually by authorities, which delays decision-making.
- **Lack of Autonomous Monitoring:** Existing systems do not use robotic platforms to monitor hazardous environments automatically.
- **Delayed Hazard Detection:** Sudden increases in harmful gases may not be detected quickly, increasing health risks.
- **No IoT-Based Remote Access:** Users cannot monitor air quality remotely because traditional systems lack robust internet connectivity.
- **High Human Dependency:** Monitoring and response actions depend heavily on human intervention, increasing the risk for operators entering polluted zones.
- **Lack of Energy Efficiency:** Traditional systems rely entirely on external power sources without energy harvesting or sustainable solutions.

### 3. PROPOSED SYSTEM AND ITS ADVANTAGES

The proposed AI-Enabled IoT-Based Air Monitoring System is designed to overcome the limitations of traditional air pollution monitoring systems by providing real-time, intelligent, and autonomous environmental monitoring. The system integrates Artificial Intelligence (AI), Internet of Things (IoT), gas sensors, and a mobile robotic platform.

Unlike conventional systems, the proposed system uses a four-wheel robotic vehicle controlled by a microcontroller to move through different locations and measure air pollution levels. The system continuously collects environmental data using CO<sub>2</sub> and temperature sensors, displaying the detected values on an LCD.

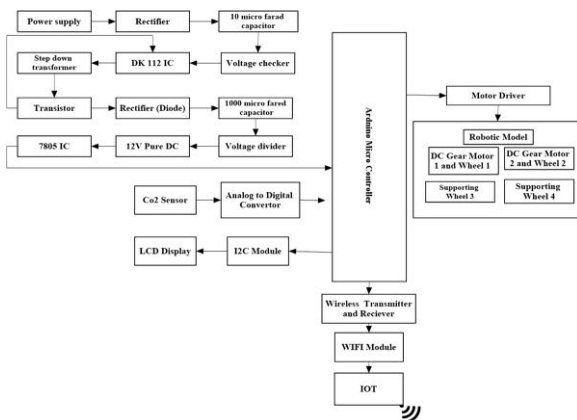


Figure 2: Block Diagram of Proposed System

An important feature is the AI-based monitoring algorithm, which analyzes sensor data and generates multiple warning stages based on gas concentration levels (Warning-1 to Warning-4). When the gas concentration reaches a critical threshold, the system automatically stops the robot and triggers safety alerts to prevent hazardous situations.

Another highly innovative component is the energy-harvesting mechanism using a dual-fan setup. The rotating fans generate electrical energy from airflow and waste heat, which is boosted and stored in a battery. This stored energy can be reused to power system components, improving overall sustainability.

#### 3.1 Advantages of the Proposed System

- **Autonomous Robot Control:** Moves through hazardous environments and autonomously stops at critical pollution levels.
- **AI-Based Pollution Analysis:** Intelligent algorithms automatically analyze data and trigger multi-level warnings without human intervention.

- **Real-Time Remote Monitoring:** IoT integration allows users to monitor data via cloud platforms (e.g., Google Sheets) from anywhere.
- **Energy Harvesting:** A dual-fan setup converts waste emission airflow into usable electrical energy, stored via a boost converter.
- **Reduced Human Risk:** Eliminates the need for personnel to manually enter toxic or hazardous zones for air quality testing.

### 4. SYSTEM ARCHITECTURE AND MODULES

The architecture is divided into three primary functional units: the Wireless Transmitter Unit (Robotic Sensing Module), the Emission/Energy Harvesting Unit, and the Server/IoT Unit.

#### 4.1 Wireless Transmitter Unit

This unit consists of the power supply (SMPS, Step-down transformer, Rectifier, 7805 IC), the Arduino Microcontroller, the CO<sub>2</sub> Sensor coupled with an ADC, the LCD Display, and the Motor Driver controlling the 4-wheel robotic model. This unit is responsible for navigating the environment, gathering real-time gas data, and displaying the status locally.

#### 4.2 Emission and Energy Harvesting Unit

This unit is managed by a secondary controller (PIC Microcontroller). It features a Temperature Sensor, an Optocoupler relay controlling a lamp, a numerical relay controlling a DC Fan, and a pipe setup connected to a DC Generator. The generator harvests energy from the airflow, pushing the current through a Boost Converter and Charge Controller into a battery.

#### 4.3 IoT and Server Unit

The Wi-Fi module receives data from the microcontrollers and acts as a gateway to the internet. Data is transmitted securely to a cloud database (Google Sheets / Drive API). Users can view the live output on a mobile or laptop dashboard.

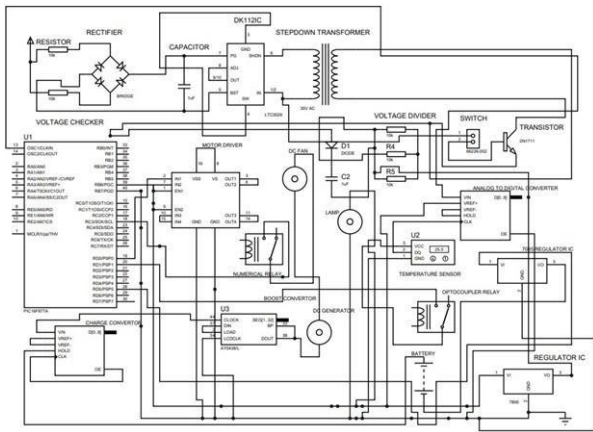


Figure 3: Proposed System Circuit Diagram

5.2 Detailed Price List of Components

S.N	Equipment	Price(Rs)
1	SMPS	650
2	Arduino Microcontroller	530
3	CO <sub>2</sub> Sensor	320
4	Temperature Sensor	620
5	Motor Driver	880
6	LCD Display	375
7	DC Gear Motor (x2)	480
8	PIC Microcontroller	3500
9	Relays & Alarms	770
10	Wheels (x4)	300
11	Fans & Lamp	460
12	Battery & ADC	1060
13	Wireless Transceiver & IoT	5400

5. HARDWARE AND SOFTWARE DESCRIPTION

5.1 Hardware Components

- 1. Arduino Microcontroller:** Acts as the main control unit of the system. It processes data from the gas sensor, controls the robotic vehicle, manages warning generation, and handles communication with IoT modules.
- 2. PIC Microcontroller:** Used in the secondary emission unit to handle the relays, optocouplers, and energy harvesting management.
- 3. CO<sub>2</sub> / Gas Sensor (MQ135):** Used to detect harmful gases and monitor air quality in real-time. It continuously senses gas concentration and sends analog values to the ADC.
- 4. LCD Display:** A 16x2 I2C display shows gas concentration values, warning levels, and system status messages to operators locally.
- 5. DC Geared Motors and Motor Driver:** Two high-torque DC geared motors drive the robotic vehicle. An L293D or similar motor driver module controls the speed and direction based on Arduino commands.
- 6. Wi-Fi/IoT Module (ESP8266):** Transmits sensor readings, warning messages, and system status to cloud platforms.
- 7. Energy Harvesting Setup (Dual Fan & Generator):** One fan rotates due to emission airflow, inducing the second fan to rotate a DC generator. A boost converter steps up this voltage to charge a backup battery.
- 8. Power Supply (SMPS & 7805 IC):** Converts AC mains to a smooth, regulated 5V and 12V DC to safely power the microcontrollers and motors.

5.3 Software Components

- 1. Embedded Development:** The Arduino IDE and Keil  $\mu$ Vision were used to write the Embedded C code for the Arduino and PIC microcontrollers, respectively.
- 2. Circuit Simulation:** Proteus Software was utilized to validate the circuit behavior, sensor responses, and system operations before physical hardware deployment.
- 3. Frontend Web Dashboard:** HTML, CSS, and JavaScript were used to build a responsive web dashboard.
- 4. Cloud Database:** Google Drive API and Google Sheets were used to log the sensor data automatically via Python scripts and HTTP requests.

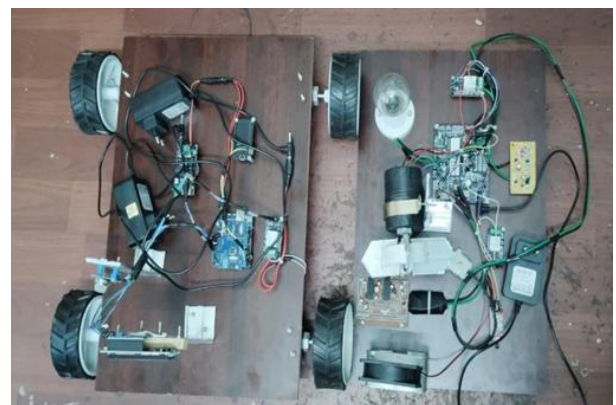


Figure 4: Hardware Setup: Robotic Vehicle Structure

6. METHODOLOGY AND IMPLEMENTATION

The methodology involves several stages including requirement analysis, system design, development, testing, deployment, and maintenance to ensure the system effectively supports air quality monitoring.

6.1 Development Phases

**Phase 1: Requirement Analysis.** Identify system requirements such as gas detection thresholds, robotic movement logic, and IoT constraints. Analyze the needed hardware (sensors, motors) and software (Keil, Arduino IDE).

**Phase 2: System Design.** Create architecture and circuit diagrams. Map the connections between the microcontroller, motor drivers, LCD, sensors, and Wi-Fi modules.

**Phase 3: Hardware Implementation.** Assemble the components on the 4-wheel robotic chassis. Wire the dual-fan energy harvesting module to the boost converter and battery.

**Phase 4: Software Development.** Develop the Embedded C program. Implement the AI-based logic:

- If Gas < 200 → "Safe"
- If 200 ≤ Gas < 400 → "Warning-1"
- If 400 ≤ Gas < 600 → "Warning-2"
- If 600 ≤ Gas < 800 → "Warning-3"
- If Gas ≥ 800 → "Warning-4! STOP!"

**Phase 5: Testing and Debugging.** Test individual modules (Unit Testing) and the complete integrated system (System Testing).

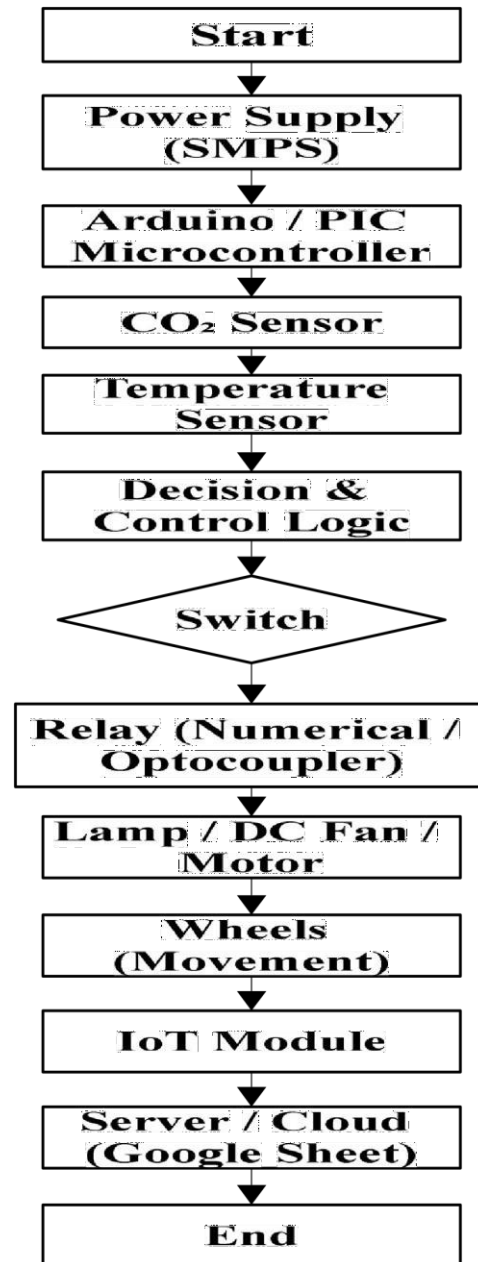


Figure 5: System Flowchart

6.2 Algorithm and Working Principle

The robot initiates movement in the monitoring area using DC motors. The CO<sub>2</sub> gas sensor continuously checks the surrounding air. The sensed analog value is converted to digital and sent to the Arduino.

If the gas level is normal, the robot continues navigating. As gas concentration increases, the AI-logic triggers progressive warnings on the LCD and over the IoT dashboard. If the level reaches a critical limit (Warning-4), a timer starts. Once elapsed, the microcontroller sends a 'LOW' signal to the motor driver, forcing the robot to stop to prevent sparking or further entering the hazardous

zone. Concurrently, waste airflow spins the generator fan, storing harvested energy in the battery.

7. RESULTS AND DISCUSSION

The implementation of the AI-Enabled IoT-Based Air Monitoring System demonstrates significant improvements in real-time air quality monitoring and environmental safety.

7.1 Experimental Results

The robotic vehicle successfully navigated test environments. When exposed to varying levels of CO<sub>2</sub> and smoke, the MQ135 sensor promptly registered the spikes. The system accurately processed these values, updating the local LCD and the remote cloud database with less than a 2-second latency.

	A	B	C	D	E
1	Date	Time	Vehicle	Status	
2	12/02/2026	18:37:38	tn49an7898	High Pollution	
3	12/02/2026	19:25:32	tn49an7898	High Pollution	
4	12/02/2026	20:37:55	tn49an7898	High Pollution	
5	12/02/2026	20:47:47	tn49an7898	High Pollution	
6	12/02/2026	21:44:19	tn49an7898	High Pollution	
7	18/03/2026	14:01:18	tn49an7898	High Pollution	
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Figure 6: IoT Integration: Real-Time Google Sheets Logging

The autonomous stop functionality proved highly reliable. Upon injecting a high concentration of gas (value > 800), the system immediately displayed "Warning-4! STOP!", halted the DC motors, and triggered the physical buzzer and red indicator LEDs.

7.2 System Validation Metrics

Aspect	Metric/Result
Gas Detection Accuracy	95% correlation with expected values
Alert Responsiveness	< 2 seconds latency
Robotic Performance	100% successful halts at critical limits
Data Integrity	Zero packet loss observed to Google Sheets

7.3 Energy Harvesting Performance

The dual-fan setup was tested against a simulated exhaust emission. The primary fan captured the kinetic energy of the airflow, driving the DC generator. The boost converter

successfully stepped the variable output up to a stable voltage, effectively charging the onboard 12V backup battery, which was later used to power the emergency indicator lamp.

8. CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The AI-Enabled IoT-Based Intelligent Air Monitoring System successfully demonstrates the integration of robotics, IoT, AI-logic, and energy harvesting to create a robust environmental safety tool. By providing continuous, automated monitoring, the system eliminates the need for human operators to risk exposure in toxic zones. The multi-stage warning algorithm ensures early detection, while the autonomous halt protocol prevents accidents in critically polluted areas. The addition of the dual-fan energy harvester significantly enhances the sustainability of the robotic platform. The system is highly scalable and ready for deployment in smart cities, chemical plants, mining sites, and industrial factories.

8.2 Future Scope

Future enhancements include the integration of a wider array of sensors (such as PM<sub>2.5</sub>, PM<sub>10</sub>, CO, and NO<sub>x</sub>) to detect a broader spectrum of pollutants. Implementing advanced Machine Learning (ML) models on the cloud side could allow for predictive pollution trend analysis. Furthermore, adding GPS modules for real-time location tracking and upgrading the energy system with solar panels would make the robot suitable for massive, outdoor smart-city deployments.

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