



# **IoT Based Real-Time Vehicle Emission Monitoring and Automatic Penalty Enforcement System**

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**ABSTRACT:** Air pollution caused by vehicle emissions is a major environmental and health concern. Traditional methods of checking vehicle emissions are manual, infrequent, and prone to corruption or negligence. To overcome these issues, an **IoT-based real-time vehicle emission monitoring system** is proposed. This system continuously monitors emissions and automatically enforces penalties when pollution levels exceed permissible limits. Vehicular emissions are a major contributor to urban air pollution, adversely affecting environmental sustainability and public health. Rapid urbanization, rising vehicle density, and weak enforcement of emission norms have intensified this challenge, particularly in countries such as India. Conventional pollution control methods—mainly periodic emission testing at authorized centers—are limited, reactive, and incapable of capturing real-time emission variations, resulting in gaps in compliance monitoring and regulatory effectiveness. This research proposes an Internet of Things (IoT)-based framework for real-time vehicular emission monitoring to enable continuous tracking, automated reporting, and regulatory integration. The system comprises a vehicle-mounted unit with an Arduino Uno microcontroller, MQ-series gas sensors (MQ-135/MQ-2) for detecting pollutants such as CO, NO<sub>x</sub>, and NH<sub>3</sub>, a Neo-6M GPS module for geolocation tracking, and an ESP8266/NodeMCU module for cloud connectivity. Emission data, along with timestamped location details, is transmitted to a centralized server for storage, analysis, and enforcement action. Advanced analytics are applied to identify pollution hotspots, detect high-emission vehicles, analyze trends, and support predictive forecasting. The framework enables automated alerts, digital penalties, and integration with national vehicle databases, promoting proactive and data-driven governance. It supports sustainable urban mobility planning and aligns with global sustainability goals, including the United Nations Sustainable Development Goals (SDG 11 and SDG 13), contributing to cleaner cities and improved public health.

**KEYWORDS:** IoT, Vehicle Emission Monitoring, Air Pollution Control, Smart Cities, Real-Time Monitoring, Environmental Sustainability, Air Quality Index (AQI), Intelligent Transportation Systems.

## **I. INTRODUCTION**

Air pollution has emerged as one of the most critical environmental and public health challenges of the 21st century [6]. Rapid urbanization, industrial growth, and an exponential rise in vehicular density have significantly deteriorated air quality across major metropolitan regions worldwide [2], [6]. Among the various sources of air pollution, vehicular emissions represent a dominant and continuously growing contributor, particularly in developing economies [2]. According to the World Health Organization (WHO), ambient air pollution is responsible for approximately 7 million premature deaths annually [6], with a substantial proportion linked to urban transportation emissions [2]. Road transport emits a wide range of harmful pollutants, including carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), sulfur dioxide (SO<sub>2</sub>), volatile organic compounds (VOCs), and carbon dioxide (CO<sub>2</sub>) [2]. These pollutants not only contribute to respiratory and cardiovascular diseases but also accelerate climate change and environmental degradation [6]. In the European context, the European Environment Agency reports that road transportation accounts for nearly 22% of carbon dioxide emissions from fossil fuel combustion [2]. In rapidly developing countries such as India, China, and Brazil, the situation is even more severe due to dense traffic, aging vehicle fleets, inconsistent enforcement, and limited public transportation infrastructure [2], [6]. India, in particular,

faces a severe vehicular pollution crisis. Major metropolitan cities such as Delhi frequently record hazardous Air Quality Index (AQI) levels [7]. According to the Central Pollution Control Board (CPCB), vehicular emissions contribute between 40% and 60% of urban air pollution in cities like Delhi, Mumbai, and Kolkata [7]. Concentrations of PM<sub>2.5</sub> in Delhi have often exceeded 300  $\mu\text{g}/\text{m}^3$ —far above the WHO recommended limit of 25  $\mu\text{g}/\text{m}^3$  for 24-hour exposure [6], [7]. Such exposure is strongly associated with increased incidence of asthma, chronic obstructive pulmonary disease (COPD), cardiovascular disorders, stroke, and lung cancer [6]. Despite the seriousness of the issue, the prevailing pollution control framework remains largely dependent on periodic vehicle emission inspections conducted at authorized testing centers. These inspections, typically conducted biannually or annually, are limited in several ways: 1. Reactive Monitoring: Emission checks capture data only at specific intervals, failing to monitor real-time fluctuations. 2. Compliance Gaps: Vehicles may meet standards during inspection but exceed limits during regular operation. 3. Data Integrity Issues: Manual processes introduce the possibility of data manipulation or inaccuracies. 4. Lack of Spatial Intelligence: Traditional systems do not provide geospatial mapping of pollution sources. 5. Delayed Enforcement: Regulatory action is often taken only after substantial environmental damage has occurred. These limitations highlight a critical research and policy gap: the absence of a continuous, real-time vehicular emission monitoring system integrated with regulatory enforcement mechanisms. The emergence of the Internet of Things (IoT) presents a transformative opportunity to modernize environmental monitoring systems. IoT enables interconnected sensor networks capable of real-time data acquisition, transmission, storage, and analytics. By embedding smart sensors within vehicles, emission data can be continuously monitored, geotagged, and transmitted to centralized authorities for automated analysis and enforcement.

### **1.1. OUTLINE OF THE PROJECT**

Greenhouse gas emissions are a critical issue that can have severe environmental impacts such as global warming and climate change. Gases emitted by road transportation vehicles constitute a significant part of global greenhouse gas emissions. Therefore, this paper proposes an IoT-based real-time vehicle emission monitoring and prediction system to swiftly identify high-emitting vehicles (HEVs). The system consists of an on-board system with wireless networking capabilities housing seven gas sensors (CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, H<sub>2</sub>S, HC, and O<sub>2</sub>) for real-time data acquisition. It also includes a cloud computing layer for data storage and emission forecasting for predictive maintenance using deep learning time series forecasting techniques. Finally, the system provides visualizations of the collected data through a dedicated web-based dashboard. Trained forecasting models achieved a prediction accuracy of 83% and an F1-score of 0.79. Additionally, real-world on-road test data validated the system's effectiveness in identifying current and potential HEVs in real-time while generating large datasets to support ongoing research and development aimed at reducing vehicle emissions.

## **II. LITERATURE SERVEY**

### **1. IVEMPS: IoT-Based Vehicle Emission Monitoring and Prediction System**

Greenhouse gas emissions are a critical issue that can have severe environmental impacts such as global warming and climate change. Gases emitted by road transportation vehicles constitute a significant part of global greenhouse gas emissions. Therefore, this paper proposes an IoT-based real-time vehicle emission monitoring and prediction system to swiftly identify high-emitting vehicles (HEVs). The system consists of an on-board system with wireless networking capabilities housing seven gas sensors (CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, H<sub>2</sub>S, HC, and O<sub>2</sub>) for real-time data acquisition. It also includes a cloud computing layer for data storage and emission forecasting for predictive maintenance using deep learning time series forecasting techniques. Finally, the system provides visualizations of the collected data through a dedicated web-based dashboard. Trained forecasting models achieved a prediction accuracy of 83% and an F1-score of 0.79. Additionally, real-world on-road test data validated the system's effectiveness in identifying current and potential HEVs in real-time while generating large datasets to support ongoing research and development aimed at reducing vehicle emissions.

### **2. IoT-Based Vehicle Emission Monitoring System with Real-Time Pollution Detection and Automatic Number Plate Recognition**

With rapid urbanization and the rising number of vehicles, air pollution has become a significant environmental concern. The proposed Vehicle Emission Monitoring System provides an efficient IoT-based solution for real-time detection and analysis of vehicular emissions. Sensor modules continuously monitor the concentration of harmful gases such as CO, CO<sub>2</sub>, and NO<sub>x</sub>, while data is transmitted to a centralized server for evaluation. There is an increasing need

for automatic pollution detection systems integrated with automatic number plate recognition (ANPR) to identify and alert vehicle owners, thereby assisting government agencies in enforcing environmental regulations. The developed system automatically triggers alerts when emission levels exceed permissible limits, displaying information on an LCD and generating notifications through connected networks. This intelligent framework contributes to sustainable urban management by enabling proactive pollution control, improving environmental awareness, and supporting regulatory compliance.

### **3. IoT-Based Vehicle Emission Monitoring System for Real Time Visualization**

With the rapid growth of urbanization and the increasing number of vehicles on the roads, air pollution has emerged as a major environmental concern. This project proposes an IoT-based Vehicle Emission Monitoring System that enables real-time detection and analysis of vehicular emissions. The system uses sensor modules to continuously measure concentrations of harmful gases such as CO, CO<sub>2</sub>, and NO<sub>x</sub>, transmitting the collected data to a centralized server for processing and evaluation. To enhance accountability and regulatory enforcement, the system integrates Automatic Number Plate Recognition (ANPR), allowing authorities to identify vehicles exceeding emission limits and notify owners automatically. Alerts are generated when pollution levels surpass permissible thresholds, and information is displayed on an LCD panel as well as transmitted via connected networks. By providing immediate feedback and actionable data, this intelligent system supports sustainable urban management, promotes environmental awareness, and assists government agencies in implementing stricter emission control measures. The framework ensures proactive monitoring, contributing to cleaner air and improved public health.

## **III. IMPLEMENTATION**

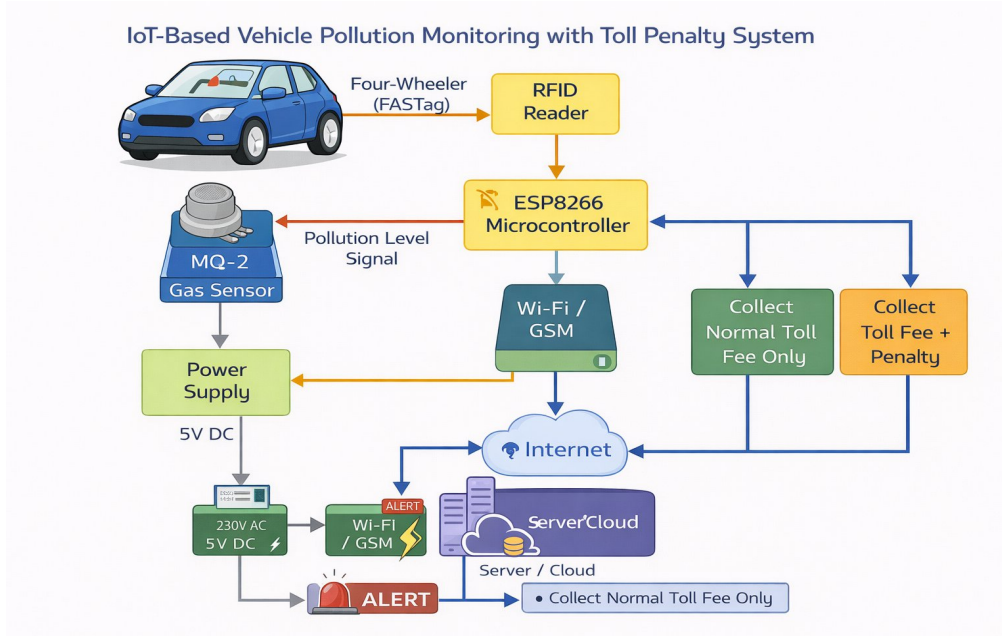
### **3.1. EXISTING SYSTEM**

Research on vehicle emission monitoring has gained considerable attention due to its potential to reduce urban air pollution and support regulatory enforcement. Numerous studies have explored sensor-based, automated, and data-driven approaches for real-time detection and management of vehicular emissions. Sricharan et al. (2013) proposed an intelligent automated emission monitoring system for traffic signals. Their approach used sensor arrays combined with lane-based vehicle detection to measure pollution levels in real time. When pollutant concentrations exceeded permissible limits, the system captured images of the vehicle license plate and sent SMS alerts to both the vehicle owner and relevant authorities. This design demonstrated the feasibility of automated, cost-effective pollution monitoring in urban environments. Tiwari et al. developed a system that continuously monitored emissions of gases such as CO and NO<sub>x</sub> using sensors. When thresholds were exceeded, the system intervened in real time by recording the vehicle's GPS location, sending SMS notifications via GSM, and even implementing engine shutdown in certain scenarios. Although practical challenges remained—such as user acceptance and safety concerns—the system highlighted the potential for proactive pollution reduction through integrated detection and control mechanisms.

### **3.2. PROPOSED SYSTEM**

- Gas sensors continuously detect exhaust emission levels and send the data to a microcontroller.
- The processed data is transmitted to a cloud server using GSM or Wi-Fi communication.
- If emission level is normal, only the toll fee is collected. If the pollution level exceeds the limit, the system automatically adds a penalty amount to the toll fee.

#### **Block diagram**



## WORKING

### 1. Emission Data Collection

- Gas sensors such as **MQ-2**, **MQ-7**, and **MQ-135** are installed near the vehicle exhaust.
- These sensors detect harmful gases like **Carbon Monoxide (CO)**, **Carbon Dioxide (CO<sub>2</sub>)**, and **Nitrogen Oxides (NO<sub>x</sub>)**.
- The sensors convert gas concentration into **analog electrical signals**.

### 2. Data Processing by Microcontroller

- The analog signals from sensors are sent to a **microcontroller (Arduino/ESP32/NodeMCU)**.
- The microcontroller:
  - Converts analog signals into digital values.
  - Calibrates sensor data.
  - Compares emission values with **standard permissible limits**.

### 3. Real-Time Data Transmission

- The processed data is transmitted to the cloud using:
  - **Wi-Fi module (ESP8266/ESP32)** or
  - **GSM module (SIM800/900)**.
- Data sent includes:
  - Emission levels
  - Vehicle ID
  - Timestamp
  - Location coordinates (via GPS)

### 4. Vehicle Identification

- Each vehicle is uniquely identified using:
  - **RFID tag** or
  - **Vehicle registration number linked in database**
- This ensures that emission data is mapped to the correct vehicle owner.

### 5. Cloud Storage and Analysis

- Data is stored on an **IoT cloud platform** such as ThingSpeak, AWS, or Firebase.
- The cloud system:

- Continuously monitors incoming data
- Stores historical emission records
- Performs analysis to detect violations

#### **6. Violation Detection**

- When emission values exceed the permissible limit:
  - The system automatically flags the vehicle.
  - A violation event is generated in the cloud.

#### **7. Automatic Penalty Enforcement**

- Once a violation is detected:
  - A **fine is automatically generated.**
  - Notification is sent to the vehicle owner via:
    - SMS (using GSM module)
    - Mobile application
    - Email alerts
  - The penalty details include:
    - Vehicle number
    - Pollution level
    - Fine amount
    - Date and time

#### **8. Monitoring and Control Dashboard**

- Authorities access a **web or mobile dashboard** to:
  - Monitor real-time vehicle emissions
  - View violation reports
  - Track vehicle locations
  - Analyze pollution trends

#### **9. Continuous Monitoring**

- The system works continuously while the vehicle is running.
- Periodic updates ensure:
  - Real-time tracking
  - Immediate action on violations

#### **10. System Workflow Summary**

1. Sensors detect emissions
2. Microcontroller processes data
3. Data sent to cloud via IoT
4. Vehicle identified using RFID/GPS
5. Cloud checks for limit violations
6. If exceeded → penalty generated
7. Notification sent to user
8. Authorities monitor via dashboard

### **IV. CONCLUSION**

This project has been designed and demonstrated using ESP32, MQ-7, and MQ-135 sensors to capture real-time emission data. The system transmits data wirelessly, sends mobile alerts when CO thresholds are exceeded, and logs data on a web dashboard for and complaint management. The prototype validates the concept, providing immediate feedback on hazardous emission levels and empowering individuals and authorities with actionable insights to promote sustainable transportation practices.

### **V. FUTURE SCOPE**

Sensor Accuracy and Calibration: MQ-series sensors are low-cost and provide good qualitative indications but may lack the precision and long-term stability of professional-grade analytical instruments. Their accuracy can be affected by ambient temperature, humidity, and cross-sensitivity to other gases. Frequent and proper calibration is essential for reliable quantitative measurements, which can be challenging to implement for widespread, low-maintenance deployment. 2. Dependence on Wi-Fi Connectivity: Real-time data transmission to Blynk and the web server relies on a stable WiFi connection. In areas with poor or no Wi-Fi coverage, data logging and alerts would be delayed or missed unless onboard data buffering and store- and-forward mechanisms are implemented. 3. Security and Privacy: Data transmitted over Wi-Fi and stored on the web server could be vulnerable to security breaches if not adequately protected with encryption and secure protocols. Privacy concerns regarding the collection and use of vehicle emission data and potentially location data (if GPS is added) need to be addressed.

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