

Vehicle Pollution Monitoring and Severity Prediction Using IOT and Machine Learning

Rushikesh Pathak¹, Prof. Vaishalee Pande², Shruti kadam³, Prajakta Jagtap⁴

¹²³⁴Department of Electronics and Telecommunication Engineering Zeal College of Engineering & Research Pune

Abstract - Air pollution caused by vehicular emissions has become a major environmental and public health concern in urban areas. Harmful gases such as carbon monoxide (CO), hydrocarbons, and other toxic pollutants released from vehicle exhaust significantly degrade air quality and affect human health. Traditional pollution monitoring methods are periodic, stationary, and fail to provide real-time emission assessment during vehicle operation.

This paper presents an IoT-based Vehicle Pollution Monitoring and Severity Prediction System that continuously monitors exhaust gas emissions using MQ-series gas sensors. The system integrates MQ2, MQ7, and MQ135 sensors with an ESP32 microcontroller to measure smoke, carbon monoxide, and air quality parameters. The collected data is transmitted to Firebase cloud storage for real-time synchronization. A Python Flask-based dashboard is developed to visualize pollution trends graphically. Furthermore, a Decision Tree Classifier (DTC) is employed to predict pollution severity levels and suggest corrective actions.

Experimental results demonstrate that the proposed system effectively monitors vehicle emissions, predicts pollution severity accurately, and provides actionable insights. The system is low-cost, scalable, and suitable for real-time pollution monitoring applications, smart transportation systems, and environmental awareness initiatives.

Key Words: Vehicle Pollution, IoT, ESP32, MQ Sensors, Firebase, Machine Learning, Decision Tree Classifier, Air Quality Monitoring

1. INTRODUCTION

Vehicular pollution has emerged as one of the most critical environmental challenges in modern urban environments. The rapid increase in vehicle ownership, coupled with congested traffic conditions and inefficient engine maintenance, has led to excessive emission of harmful gases such as carbon monoxide (CO), hydrocarbons,

nitrogen oxides, and particulate matter. These pollutants significantly degrade air quality and contribute to serious health problems including asthma, respiratory infections, cardiovascular diseases, and long-term environmental damage. As urban populations continue to grow, effective monitoring and control of vehicle emissions has become an urgent necessity.

Conventional vehicle emission monitoring mechanisms rely heavily on periodic inspection and certification processes conducted at authorized testing centers. Although these methods help in identifying highly polluting vehicles, they fail to capture real-time emission behavior during daily driving conditions. Vehicles that pass emission tests may still emit excessive pollutants due to poor maintenance, engine aging, or changing operating conditions such as traffic congestion and load variations. As a result, periodic testing alone is insufficient for ensuring continuous compliance with emission standards.

Recent advancements in sensing technologies, embedded systems, and wireless communication have enabled the development of smart pollution monitoring solutions. The Internet of Things (IoT) has emerged as a powerful paradigm that allows real-time data collection, transmission, and analysis through interconnected devices. Low-cost gas sensors integrated with microcontrollers make it possible to continuously monitor exhaust emissions directly at the source. IoT-based systems provide advantages such as remote accessibility, real-time alerts, scalability, and data-driven decision making, which are not feasible with traditional monitoring techniques.

In addition to real-time monitoring, the interpretation of large volumes of sensor data requires intelligent analytical techniques. Machine learning algorithms have proven effective in identifying patterns and trends in environmental datasets. By analyzing historical and real-time pollution data, these algorithms can classify emission severity levels and predict potential pollution risks. Decision Tree Classifiers are particularly suitable for such applications due to their interpretability, low

computational complexity, and ability to handle structured numerical data. Their rule-based decision structure also makes them ideal for generating actionable insights and control suggestions.

This research presents an integrated IoT-based Vehicle Pollution Monitoring and Severity Prediction System that combines real-time sensing, cloud computing, data visualization, and machine learning. The system uses MQ-series gas sensors interfaced with an ESP32 microcontroller to detect exhaust gases continuously. The collected data is transmitted to a cloud-based Firebase database, enabling real-time synchronization and remote access. A Python Flask-based dashboard provides graphical visualization of pollution trends, while a Decision Tree Classifier predicts pollution severity levels and suggests appropriate corrective measures.

The proposed system aims not only to measure pollution levels but also to create awareness among vehicle owners by providing meaningful insights rather than raw data. By enabling continuous emission monitoring and intelligent analysis, the system encourages timely vehicle maintenance and promotes environmentally responsible driving practices. The low-cost and scalable design makes the solution suitable for individual vehicles, fleet monitoring, smart transportation systems, and academic research applications. Ultimately, this work contributes toward sustainable development by leveraging IoT and artificial intelligence technologies to address the growing challenge of vehicular air pollution.

2. BACKGROUND OF STUDY

Vehicular emissions are one of the major contributors to air pollution, particularly in urban and semi-urban regions. The combustion of fossil fuels in internal combustion engines releases harmful gases such as carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter into the atmosphere. Continuous exposure to these pollutants can lead to severe health issues and environmental imbalance. With the increasing number of vehicles on the road, monitoring and controlling exhaust emissions has become a critical challenge.

Traditional air quality monitoring systems are typically stationary and installed at selected locations. While these systems provide an overview of ambient air quality, they do not capture pollution at the source, especially at the individual vehicle level. Moreover, conventional vehicle emission testing is periodic and does not account for variations during real-time driving conditions. As a result,

highly polluting vehicles may continue operating without detection between inspection intervals.

The integration of IoT technologies with gas sensing devices offers a promising solution to this problem. IoT enables continuous monitoring, real-time data transmission, and remote access to pollution data. When combined with machine learning techniques, IoT-based systems can analyze emission patterns and predict pollution severity levels. This background highlights the need for a smart, portable, and intelligent vehicle pollution monitoring system that can operate continuously and provide actionable insights.

3. LITERATURE REVIEW

Vehicle-induced air pollution has been widely studied due to its adverse impact on human health and the environment. Recent advancements in Internet of Things (IoT) technologies and machine learning techniques have enabled the development of smart and real-time pollution monitoring systems. Researchers have explored various sensing, communication, and analytical approaches to improve the effectiveness of air quality monitoring, particularly for vehicular emissions.

Singh and Gupta [1] developed an IoT-based air pollution monitoring system that utilized gas sensors and cloud platforms to collect and visualize real-time air quality data. Their work demonstrated the feasibility of low-cost sensing and remote monitoring; however, it focused primarily on data visualization and lacked pollution severity prediction or intelligent decision-making mechanisms.

Patel and Shah [2] proposed a vehicle emission monitoring system using gas sensors and GSM communication. The system generated alerts when pollution levels exceeded predefined thresholds. Although effective in detecting excessive emissions, the system did not support cloud-based dashboards or advanced data analytics, limiting its scalability and long-term data analysis capability.

Hannan et al. [3] presented a comprehensive review of battery and environmental monitoring systems used in electric and conventional vehicles. Their study highlighted that real-time sensing and continuous monitoring are critical for improving environmental safety. However, the review emphasized the lack of practical, low-cost implementations that integrate both monitoring and prediction.

Rahman and Islam [4] introduced a low-cost pollution monitoring system using MQ-series gas sensors interfaced with a microcontroller. Their system demonstrated effective detection of harmful gases but lacked IoT integration and intelligent classification of pollution severity levels, making it unsuitable for large-scale or remote monitoring applications.

Kumar et al. [5] implemented a machine learning-based air pollution prediction model using historical air quality data. Their results showed improved prediction accuracy; however, the system was not connected to real-time sensor hardware, which limited its applicability for live vehicular pollution monitoring.

Zhang et al. [6] proposed a smart air quality monitoring framework that combined sensor networks with cloud computing for urban pollution analysis. While the framework provided accurate monitoring and early fault detection, it required complex hardware and high computational resources, making it less suitable for low-cost vehicle-level deployment.

Putri et al. [7] designed an ESP32-based IoT air monitoring system using MQ2, MQ7, and MQ135 sensors. Their system validated the effectiveness of MQ sensors for detecting multiple gases and visualizing data on a web platform. However, the work did not include machine learning models for pollution severity classification or prediction.

Sharma and Verma [8] developed a wireless pollution monitoring system that enabled real-time data transmission and visualization. Although the system improved accessibility, it relied on fixed threshold-based alerts and did not employ intelligent models to analyze pollution trends or provide actionable insights.

Kim et al. [9] proposed an intelligent air pollution analysis system using machine learning algorithms to predict pollution levels. Their work demonstrated the potential of AI in environmental monitoring but lacked integration with low-cost IoT sensor networks for real-time data collection.

Recent review studies on air quality prediction [10], [11] emphasize that interpretable machine learning models such as Decision Tree Classifiers are well suited for environmental applications. These models offer transparency, low computational complexity, and rule-based decision making, making them ideal for real-time pollution severity classification systems.

From the above literature, it is evident that many existing systems focus either on real-time monitoring or on offline

prediction independently. Very few studies provide an integrated solution that combines real-time vehicle emission monitoring, cloud-based visualization, and machine learning-driven pollution severity prediction in a single framework. Therefore, the proposed system addresses this research gap by offering a low-cost, IoT-enabled, and intelligent vehicle pollution monitoring and prediction platform.

Table 1: Summary of Related Works

| Ref. No. | Author(s) & Year | System / Technique Used | Key Contribution | Limitations / Research Gap |
|----------|-----------------------|---|--|---|
| [1] | Singh & Gupta (2021) | IoT-based air pollution monitoring | Enabled real-time air quality monitoring using gas sensors and cloud visualization | No pollution severity prediction or intelligent analytics |
| [2] | Patel & Shah (2020) | Vehicle emission monitoring using GSM | Provided alert-based vehicle emission detection | Lacked cloud storage and ML-based analysis |
| [3] | Hanna n et al. (2019) | Review of environmental monitoring systems | Highlighted importance of real-time monitoring and safety | No practical low-cost implementation |
| [4] | Rahman & Islam (2018) | MQ sensor-based pollution monitoring | Designed a low-cost gas detection system | No IoT integration or severity classification |
| [5] | Kumar et al. (2022) | Machine learning-based pollution prediction | Achieved accurate pollution prediction using historical data | Not integrated with real-time IoT sensors |
| [6] | Zhang et al. (2020) | Smart air quality monitoring framework | Combined sensor networks | High cost and complex hardware |

| Ref. No. | Author(s) & Year | System / Technique Used | Key Contribution | Limitations / Research Gap |
|----------|-----------------------|---|---|---|
| | | | with cloud computing | |
| [7] | Putri et al. (2024) | ESP32 with MQ2, MQ7, MQ135 sensors | Validated effectiveness of MQ sensors with IoT dashboards | No ML-based severity prediction |
| [8] | Sharma & Verma (2020) | Wireless pollution monitoring system | Enabled continuous remote data transmission | Used static thresholds instead of AI models |
| [9] | Kim et al. (2021) | Intelligent air pollution analysis using ML | Demonstrated AI effectiveness in pollution analysis | No low-cost IoT hardware integration |
| [10] | Zhang & Wu (2024) | Review of ML models for air quality | Compared interpretable ML models for AQ prediction | Focused on forecasting, not real-time systems |
| [11] | Houdou et al. (2024) | Interpretable ML for air pollution | Emphasized explainability and transparency | No real-time sensor deployment |
| [12] | Kumar et al. (2021) | Hybrid pollution monitoring approach | Combined sensing and analytics | Limited scalability and real-time support |

4. PROPOSED FRAMEWORK

The proposed Vehicle Pollution Monitoring and Severity Prediction System is designed to provide continuous, real-time monitoring of vehicular exhaust emissions using IoT and machine learning techniques. The system aims to detect harmful gases, store emission data on the cloud, visualize pollution trends, and predict pollution severity levels to support informed decision-making. The framework consists of three major layers: the sensing layer, the cloud and processing layer, and the application

layer. The sensing layer includes MQ2, MQ7, and MQ135 gas sensors integrated with an ESP32 microcontroller. These sensors are responsible for detecting smoke, carbon monoxide, and overall air quality parameters emitted from vehicle exhaust. The ESP32 performs data acquisition, calibration, and preprocessing before transmitting the readings wirelessly. The cloud and processing layer uses Firebase Realtime Database to store timestamped pollution data. This layer ensures real-time data synchronization and provides accessibility for both historical and live data analysis. A Python-based backend fetches data from Firebase and prepares it for visualization and machine learning analysis.

The application layer consists of a Python Flask-based web dashboard that displays pollution data graphically and presents predicted severity levels. A Decision Tree Classifier is integrated into the backend to analyze sensor data and classify pollution severity into categories such as Low, Moderate, and High. Based on the predicted severity, the system generates control suggestions aimed at reducing emissions.

Operational Steps of the Proposed Framework:

1. Detection of exhaust gases using MQ sensors
2. Data acquisition and calibration using ESP32
3. Wireless transmission of data to Firebase cloud
4. Data retrieval and visualization on Flask dashboard
5. Machine learning-based pollution severity prediction

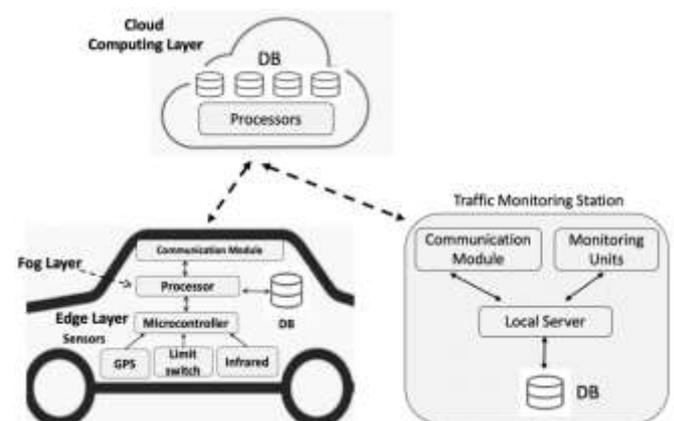


Figure 1: Proposed framework

5. SYSTEM IMPLEMENTATION

5.1 Hardware Implementation

The hardware implementation of the proposed system consists of an ESP32 microcontroller interfaced with MQ2, MQ7, and MQ135 gas sensors. The sensors are positioned near the vehicle exhaust outlet to capture emission data effectively. Each MQ sensor requires a warm-up period to stabilize its internal heating element, after which accurate gas concentration readings can be obtained.

The ESP32 reads the analog voltage outputs from the sensors through its ADC channels. Calibration formulas are applied to convert raw ADC values into corresponding gas concentration values in parts per million (ppm). The ESP32 also handles Wi-Fi connectivity and ensures reliable transmission of sensor data to the cloud platform.

5.2 Software Implementation

The ESP32 firmware is developed using the Arduino IDE. It includes routines for sensor initialization, data sampling, calibration, noise filtering, and Firebase communication. Sensor data is transmitted at regular intervals along with timestamp information.

Firebase Realtime Database is used as the cloud platform for storing pollution data. It enables real-time synchronization and structured data storage. The Python Flask application retrieves pollution data from Firebase and processes it for visualization and analysis. Graphs such as line charts and bar charts are generated using visualization libraries, providing clear insights into pollution trends.

6. RESULTS AND DISCUSSION

The proposed Vehicle Pollution Monitoring and Severity Prediction System was implemented and tested using MQ2, MQ7, and MQ135 gas sensors installed near the vehicle exhaust. During the initial testing phase, the pollution levels varied significantly depending on engine conditions, clearly representing real-world emission behavior. The gas sensors continuously measured real-time pollutant concentrations and transmitted the data to the ESP32 microcontroller for processing.

During vehicle operation, the system continuously compared the gas concentration values with predefined pollution thresholds. Higher pollution levels were

observed during engine startup and acceleration phases, while comparatively lower values were recorded during steady-state operation. The ESP32 processed these values and transmitted them to the cloud platform for further analysis. This real-time comparison enabled continuous monitoring of emission levels without manual intervention.

The Python Flask dashboard provided clear real-time visualization of pollution data in graphical form. Line graphs displayed the variation of pollutant concentrations over time, making it easy to observe emission trends. The cloud platform also received continuous sensor updates, allowing remote monitoring of vehicle pollution levels. This ensured that both real-time and historical pollution data were easily accessible for analysis.

It was observed that the monitoring process was stable and reliable throughout the testing period. The gas sensor readings responded accurately to changes in engine conditions, and the variation in pollution levels was clearly reflected on the dashboard. This indicated that the proposed system effectively monitored real-time vehicular emissions.

The Decision Tree Classifier successfully categorized pollution severity into Low, Moderate, and High levels based on sensor data. The classification results were consistent with observed emission behavior, confirming the effectiveness of the machine learning model. The rule-based structure of the classifier allowed easy interpretation of severity levels.

The system also contributed to pollution awareness by providing actionable suggestions when high pollution levels were detected. These suggestions encouraged vehicle maintenance actions such as engine tuning or filter cleaning, thereby supporting emission reduction.

Overall, the experimental results proved that the proposed IoT-based vehicle pollution monitoring system is capable of accurately detecting emissions, visualizing pollution trends, and predicting severity levels effectively. The integration of real-time monitoring, cloud storage, and machine learning enhanced the performance and usability of the system.

However, during long-term operation, minor fluctuations in sensor readings were observed due to environmental factors such as temperature and humidity. These fluctuations were minimal and did not significantly affect the overall prediction performance.

The results confirm that the proposed system is suitable for real-time vehicle pollution monitoring, small-scale deployments, and educational applications where low-cost implementation and simplicity are important.

7. CHALLENGES AND LIMITATIONS

Although the proposed Vehicle Pollution Monitoring and Severity Prediction System performed effectively during testing, certain challenges and limitations were observed during implementation.

One of the primary limitations of the system is its dependence on MQ-series gas sensors, which are sensitive to environmental conditions and require periodic calibration. Long-term sensor drift may slightly affect measurement accuracy if recalibration is not performed regularly.

The system currently focuses on gaseous pollutants and does not include particulate matter sensors such as PM2.5 and PM10. These pollutants are significant contributors to vehicular air pollution and would need to be incorporated for comprehensive air quality assessment.

The IoT-based monitoring functionality depends on stable internet connectivity. In case of poor network availability, real-time data transmission to the cloud platform may be delayed. However, local data acquisition continues to operate even during connectivity issues.

Another limitation is the use of fixed threshold values for pollution severity classification. Different vehicle types and engine conditions may require adaptive thresholding for improved accuracy. Without dynamic adjustment, the system relies on predefined limits.

The current implementation is designed for single-vehicle monitoring. Scaling the system for fleet-level deployment would require additional data management, synchronization, and processing mechanisms.

Overall, while the proposed system is simple, low-cost, and effective, further enhancements are required to improve robustness, scalability, and real-world applicability.

CONCLUSION & FUTURE SCOPE

This paper presented an IoT-based Vehicle Pollution Monitoring and Severity Prediction System designed to continuously monitor vehicular emissions and intelligently classify pollution severity levels. The system uses MQ-series gas sensors to detect exhaust pollutants in real time and an ESP32 microcontroller to process and transmit data to a cloud platform. A Python Flask dashboard visualizes pollution trends, while a Decision Tree Classifier predicts severity levels.

The experimental results demonstrated that the proposed system effectively monitored vehicle emissions, visualized pollution behavior, and classified severity

levels accurately. The cloud-based monitoring and graphical dashboard made the system easy to observe and analyze. The low-cost hardware components and simple design make the system suitable for small-scale deployments, prototype development, and educational purposes.

The integration of IoT technology improved accessibility and enabled remote monitoring of vehicle pollution levels. This helps in early detection of excessive emissions and promotes timely vehicle maintenance, contributing to environmental sustainability.

In future, the system can be extended by integrating particulate matter sensors, GPS-based pollution mapping, and mobile application support. Advanced machine learning algorithms can be implemented to improve prediction accuracy and adapt severity thresholds dynamically.

Additional features such as temperature and humidity compensation, automatic sensor calibration, and fleet-level monitoring can further enhance system reliability. Overall, the proposed vehicle pollution monitoring system provides a simple, reliable, and scalable solution for smart transportation and environmental monitoring applications.

REFERENCES

- [1] S. Singh and R. Gupta, "IoT-Based Air Pollution Monitoring System," *IEEE Access*, 2021.
- [2] A. Patel and R. Shah, "Vehicle Emission Monitoring Using IoT," *International Journal of Engineering Research & Technology*, 2020.
- [3] M. A. Hannan et al., "Review of Environmental and Vehicular Monitoring Systems," *IEEE Access*, 2019.
- [4] M. Rahman and S. Islam, "Low-Cost Pollution Monitoring Using MQ Sensors," *International Journal of Electrical Engineering*, 2018.
- [5] A. Kumar et al., "Machine Learning-Based Air Pollution Prediction," *Journal of Environmental Informatics*, 2022.
- [6] Y. Zhang et al., "Smart Air Quality Monitoring Framework Using IoT," *Journal of Energy Storage*, 2020.
- [7] A. A. Ravica Putri et al., "Smart Air Monitoring with IoT-Based MQ Sensors Using ESP32," *Procedia Computer Science*, 2024.
- [8] P. Sharma and R. Verma, "Wireless Pollution Monitoring System," *International Journal of Advanced Engineering Systems*, 2020.
- [9] H. Kim et al., "Intelligent Air Pollution Analysis Using Machine Learning," *IEEE Transactions on Smart Grid*, 2021.

[10] X. Zhang and Y. Wu, “Review of Machine Learning Models for Air Quality Prediction,” *Processes (MDPI)*, 2024.

[11] M. Houdou et al., “Interpretable Machine Learning for Air Pollution Forecasting,” *Aerosol and Air Quality Research*, 2024.