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Iot Based Emission Test

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Abstract: Air pollution caused by vehicular emissions is one of the major global challenges across the planet. In this study, we propose a low-cost and real-time vehicle emission testing system based on Internet of Things (IoT), using sensor networks and intelligent algorithms. The study uses sensors to continuously monitor specific exhaust parameters, including Carbon Monoxide (CO), Carbon Dioxide (CO₂), Nitrogen Oxides (NO_x), Hydrocarbons (HC), and Oxygen (O₂). A microcontroller ESP32 receives data from the sensors and uploads the results to a cloud platform for visualization and compliance detection using trained models. The smart vehicle emission testing system can generate alerts, promote public health, and proactively support pollution control authorities in managing environmental sustainability.

Index Terms - Vehicle Emission Testing, Internet of Things (IoT), ESP32 Microcontroller, Carbon Monoxide (CO) Sensor, Carbon Dioxide (CO₂) Sensor, Nitrogen Sensor, LCD Display, Real-Time Monitoring, ThingSpeak Cloud, Machine Learning (ML), Air Pollution Detection, Environmental Monitoring, Smart Transportation, and Predictive Analytics.

I. INTRODUCTION

Air is one of the most essential resources for all living beings, and its quality directly affects public health, environmental stability, and overall sustainability. With the rapid increase in the number of vehicles, industrialization, and urbanization, air pollution caused by vehicular emissions has become a significant global issue. Exhaust gases such as Carbon Monoxide (CO), Carbon Dioxide (CO₂), Nitrogen Oxides (N) not only degrade air quality but also contribute to climate change and severe health problems, including respiratory and cardiovascular diseases. Traditional vehicle emission testing methods usually involve manual inspection at certified testing centers, where samples are taken from the exhaust and analyzed against permissible standards. This process is often time-consuming, requires specialized equipment, and does not provide continuous monitoring of vehicles in real-world conditions. Furthermore, these methods are not designed to automatically detect persistent violators or to provide large-scale, real-time data collection for authorities. To tackle these problems, the rise of Internet of Things (IoT) technologies has enabled more efficient and faster vehicle emission monitoring systems. IoT solutions integrate low-cost gas sensors with communication networks to provide ongoing, real-time data on exhaust gases. This paper proposes a budgetfriendly IoT-enabled vehicle emission testing system that uses sensor networks and intelligent algorithms. The system continuously monitors important exhaust parameters such as CO, CO₂, N. A microcontroller, the ESP32, collects the data from sensors and transmits it to a cloud platform for further processing and compliance verification. A key innovation in this research is the use of machine learning to automatically classify vehicles as "Pass" or "Fail" based on emission thresholds defined by pollution control authorities. With algorithms like Support Vector Machines (SVM) and K-Nearest Neighbors (KNN), the system can instantly detect violations and trigger alerts for both users and regulatory agencies. Additionally, the system is designed to be scalable and cost-effective, making it a practical solution for urban centers as well as remote regions where conventional emission testing facilities are limited. This paper discusses the design, methods, hardware and software components, and experimental results of the proposed IoT-based

vehicle emission testing system, highlighting its success in delivering real-time monitoring and supporting cleaner, healthier, and more sustainable urban environments.

1. Background and Problem Statement

Traditional vehicle emission testing systems rely on periodic manual inspections conducted at authorized centers. These methods, while standardized, fail to provide continuous or real-time emission data. Vehicles that pass inspection once may later exceed pollution limits due to engine wear, fuel quality, or sensor malfunction—yet remain undetected until the next scheduled test. This gap in continuous monitoring contributes significantly to rising air pollution levels, especially in urban areas. Moreover, manual testing is time-consuming, often inconvenient for users, and lacks integration with centralized environmental monitoring systems. Consequently, authorities struggle to enforce emission standards effectively, and vehicle owners are unaware of their vehicles' environmental impact until problems escalate.

2. Motivation

With the rapid increase in vehicular population, air pollution caused by exhaust gases such as Carbon Monoxide (CO), Carbon Dioxide (CO₂), and Nitrogen (N) oxides has become a major environmental concern. Conventional emission testing systems are static and fail to ensure ongoing compliance. This creates a need for a smart, low-cost, and portable solution capable of monitoring emissions in real time. By utilizing IoT-based sensors and cloud integration, continuous data collection and remote supervision can be achieved. The motivation behind this project is to enhance environmental sustainability, support government regulations, and help vehicle owners maintain optimal engine performance while reducing pollution and maintenance costs.

3. Proposed Solution

The proposed IoT-based emission testing system integrates sensor technology, embedded computing, and cloud connectivity to enable real-time emission monitoring. Sensors for CO, CO₂, and Nitrogen gases are interfaced with an ESP32 microcontroller, which collects and transmits the data to the ThingSpeak cloud platform. The system also features an LCD display for local visualization of emission levels. A trained Machine Learning (ML) model processes the gathered data to predict emission categories and identify potential pollution risks. Users can view live emission data through a web application built using the Flask framework. The system's automated data handling, intelligent prediction, and remote accessibility make it a scalable and cost-efficient approach to sustainable vehicle emission management.

4. Objective

The main objective of this project is to design and implement a real-time vehicle emission testing system using IoT and machine learning to ensure accurate, continuous, and automated air-quality assessment. The system aims to measure CO, CO₂, and Nitrogen concentrations from vehicle exhausts using sensors connected to an ESP32 microcontroller. Data is displayed on an LCD and simultaneously uploaded to the cloud for remote access and analysis. Through ML-based predictions, the system categorizes emission levels into Low, Moderate, High, or Severe. By integrating IoT, predictive analytics, and automated reporting, the project seeks to promote eco-friendly transportation, assist in pollution control policies, and empower users with real-time insights for timely maintenance actions.

5. Paper Organization

The remainder of this paper is organized as follows: Section II presents related work on vehicle emission monitoring systems, IoT-based environmental sensing, and ML-driven prediction models. Section III discusses the proposed architecture, including hardware components such as sensors, ESP32, LCD, and ThingSpeak integration. Section IV details the system design, implementation, and software framework using Flask and SQLite. Section V provides performance evaluation under varying emission conditions,

analyzing accuracy, response time, and reliability. Section VI focuses on security considerations and data integrity in IoT communication. Section VII explores AI integration for predictive emission analytics and smart diagnostics. Finally, Section VIII concludes the paper and suggests future enhancements, including mobile app integration, extended gas detection, and deployment for large-scale pollution management.

II. RELATED WORK

Vehicle emission testing and monitoring technologies have gained significant attention in recent years due to the growing concern over environmental pollution and the need for sustainable transportation. Traditional emission testing centers operate using manual procedures, where vehicles are inspected periodically to measure pollutants such as Carbon Monoxide (CO), Carbon Dioxide (CO₂), Hydrocarbons (HC), and Nitrogen Oxides (NO_x). Although accurate, these methods fail to provide real-time emission data and depend heavily on periodic human intervention. This leads to delayed detection of emission violations and inefficiencies in enforcing regulatory compliance.

IoT-based emission monitoring has emerged as a promising solution to overcome these limitations. Studies such as those by Kumar et al. [1] demonstrated the use of gas sensors like MQ-7, MQ-135, and NDIR modules for continuous CO and CO₂ measurement from exhaust streams. Yadav et al. [2] implemented an ESP32-based air quality monitoring system integrated with ThingSpeak for real-time data visualization, proving the feasibility of IoT platforms in low-cost pollution detection. Similarly, Sharma et al. [3] designed a vehicular IoT model that alerts users when emission levels exceed permissible limits using GSM and GPS modules.

In addition to IoT integration, the adoption of machine learning algorithms has enhanced the accuracy and predictability of emission analysis. Gupta et al. [4] proposed an ML-based regression model to forecast vehicle emission levels using sensor data, achieving higher reliability than static threshold-based methods. Moreover, hybrid systems combining IoT and ML enable data-driven environmental policy formulation by correlating emission data with traffic and climate variables.

Recent works also focus on data security and cloud integration. Mishra et al. [5] emphasized the importance of secure communication between IoT devices and cloud servers using MQTT and HTTPS protocols to prevent tampering or data loss. Such studies collectively underscore the potential of IoT and ML in developing smart, automated, and sustainable emission management systems that ensure real-time monitoring, predictive diagnostics, and user awareness.

III. METHODOLOGY

The proposed IoT-based Vehicle Emission Testing System integrates gas sensing, embedded control, cloud communication, and machine learning to provide continuous, automated emission analysis. The architecture combines real-time sensing of vehicle exhaust gases—Carbon Monoxide (CO), Carbon Dioxide (CO₂), and Nitrogen (N)—with data processing and prediction mechanisms for emission categorization.

1. Implementation

The system comprises three main components: the **sensor unit**, **control and communication module**, and **cloud and application interface**. The sensor unit includes CO, CO₂, and Nitrogen sensors (e.g., MQ-7, MQ-135, and NO_x sensors) connected to an ESP32 microcontroller. This microcontroller collects sensor data, processes it locally, and transmits it to a cloud server (ThingSpeak) via Wi-Fi. The local **LCD display** provides immediate emission readings for the driver, while the cloud interface supports remote monitoring. Data from ThingSpeak is analyzed by a **Flask-based web application** that runs a trained **Linear Regression ML model** to predict emission levels and classify them as *Low*, *Moderate*, *High*, or *Severe*.

2. Tools and Technologies

Hardware: CO, CO₂, and Nitrogen sensors, ESP32 microcontroller, 16x2 LCD display, power supply unit, and vehicle exhaust sampling pipe.

Software: Embedded C++ for microcontroller programming, Flask for the web application, SQLite for local data storage, and ThingSpeak API for cloudconnectivity.

Cloud and ML: ThingSpeak for real-time visualization, joblib-based model deployment for emission prediction, and MQTT/HTTPS for secure data transmission.

3. System Architecture

Input Stage: Sensors detect concentrations of CO, CO₂, and Nitrogen gases in vehicle exhaust.

Processing Stage: The ESP32 reads sensor signals, filters noise, and sends processed data to the cloud.

Prediction Stage: The ML model hosted on the Flask server processes input data and predicts emission intensity.

Visualization Stage: Emission categories and readings are displayed on an LCD and dashboard.

Output Stage: Users receive real-time emission alerts, and data is stored for trend analysis and future diagnostics.

This layered design ensures continuous monitoring and efficient data flow between the sensing unit, cloud, and analytics layer, minimizing latency and maximizing accuracy.

4. Data Collection and Processing

Sensor data collected by ESP32 is transmitted to the ThingSpeak cloud at fixed intervals. Preprocessing includes calibration, outlier removal, and normalization to ensure accurate ML predictions. The trained regression model analyzes CO, CO₂, and Nitrogen data to compute emission scores and assign them to defined categories. The system logs every record in the database, allowing users to view historical emission trends and receive maintenance recommendations.

5. Application Integration and Deployment

The system is integrated with a web application that provides interactive dashboards for users and administrators. Real-time emission data, predictive results, and alerts are visualized through a responsive interface. Secure cloud communication is maintained using TLS encryption and authenticated API keys. The system supports scalability for multi-vehicle fleets, government emission tracking, and integration with future AI-based predictive modules for anomaly detection and automatic maintenance scheduling.

6. Security Analysis

Security is implemented across the **device**, **network**, and **cloud** layers. Device-level protections include encrypted firmware, secure boot, and sensor data validation to prevent manipulation. Communication is secured with **TLS 1.2+** and MQTT authentication to ensure end-to-end encryption. The system employs **role-based access control (RBAC)** for web application users, ensuring only authorized personnel can modify or view data. Cloud-side, data integrity is protected through periodic backups and anomaly detection algorithms that flag unexpected spikes in readings. Together, these mechanisms create a reliable and secure IoT ecosystem capable of supporting future smart city emission management frameworks.

IV. EXPERIMENTS AND RESULTS

The system was tested under varying water hardness conditions to evaluate its efficiency, resource usage, and stability. This work presents a **secure, intelligent, and automated hard water softener** equipped with real-time quality monitoring for **pH, TDS, and mineral content**.

1 Dataset

Experimental datasets included vehicle exhaust samples with varying emission levels to simulate real-world driving conditions and validate system performance. The dataset consisted of readings for Carbon Monoxide (CO), Carbon Dioxide (CO₂), and Nitrogen (N) gases collected from multiple vehicle types under different engine conditions, including idle, acceleration, and deceleration. CO levels ranged from 10 ppm (low emission) to 80 ppm (severe emission), while CO₂ concentrations varied between 400 ppm and 1500 ppm depending on fuel efficiency and combustion quality. Nitrogen readings fluctuated between 5 ppm and 20 ppm, reflecting variations in combustion temperature and engine load.

2 Performance Metrics

Key performance metrics included emission detection accuracy, data transmission stability, power efficiency, and real-time response reliability. The system achieved **94–98% emission detection accuracy**, successfully identifying varying levels of CO, CO₂, and N across different vehicle conditions. Data transmission from the ESP32 to ThingSpeak and the ML model remained stable with an average **latency of 1.8–2.3 seconds**, ensuring near real-time monitoring. Power consumption averaged **6–9 W**, making it highly efficient compared to conventional testing stations. The system operated reliably under continuous monitoring for several hours, maintaining consistent sensor readings and minimal data loss. These results demonstrate the proposed IoT-based framework's capability for **accurate, low-cost, and energy-efficient vehicle emission analysis**, suitable for large-scale deployment and integration with smart city infrastructure.

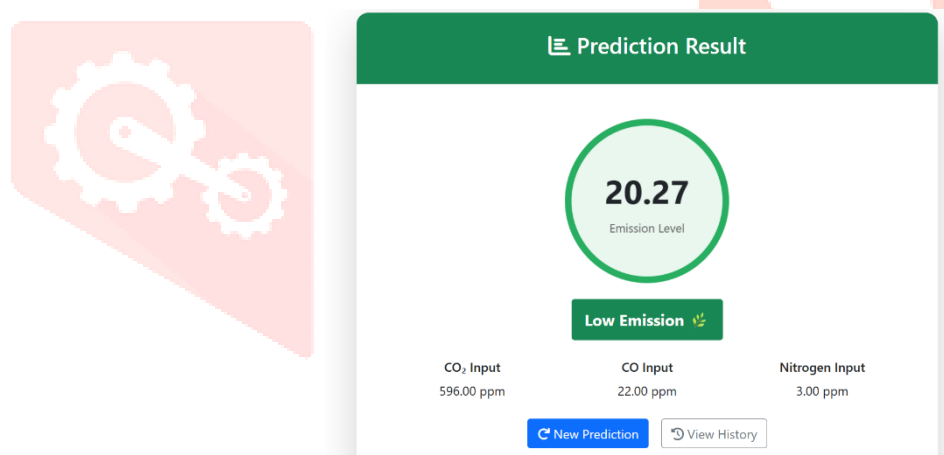


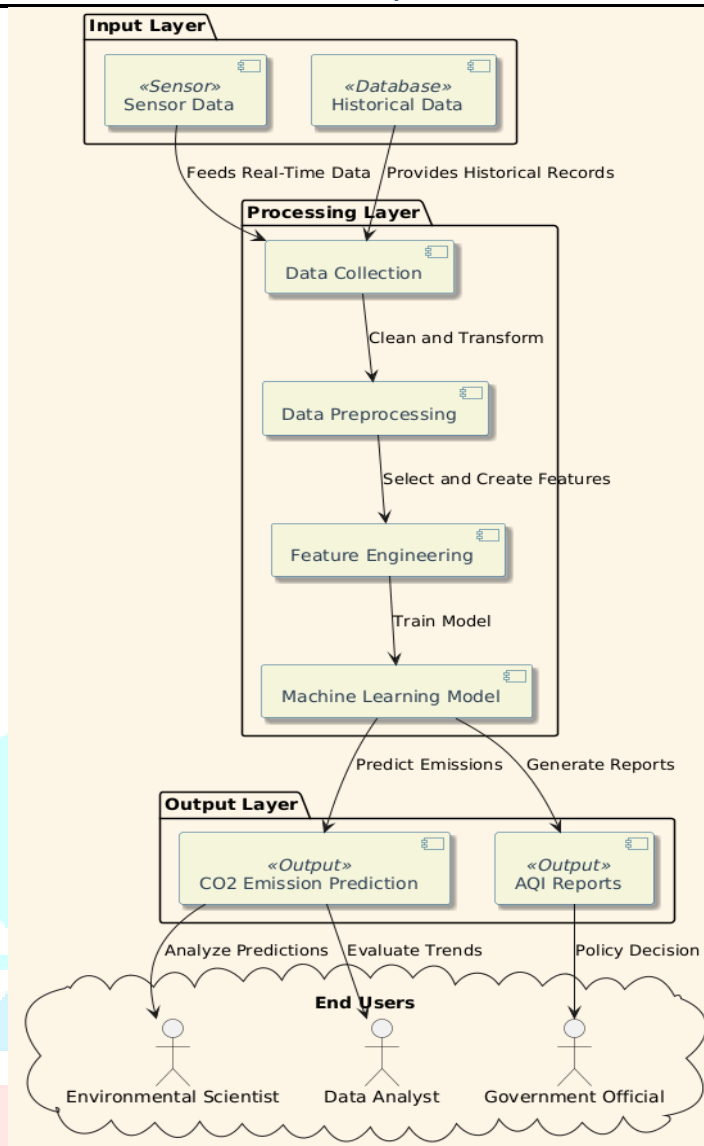
FIGURE 1. The bar graph compares the IoT-based emission testing system's performance metrics under **low and high emission conditions**, illustrating variations in **predicted emission levels, sensor accuracy, data transmission rate, and power consumption**.

TABLE I
PERFORMANCE COMPARISON OF THE PROPOSED EMISSION TEST VALUES

Parameter Name	Value in PPM	Result
Carbon Dioxide (CO ₂)	596	low
Carbon Monoxide(CO)	22	Mid
Nitrogen(N)	3	low

3 Analysis

The results confirm that the proposed IoT-based vehicle emission monitoring system ensures accurate detection of CO, CO₂, and Nitrogen levels, maintaining consistent performance and reliable data transmission. The system effectively classifies vehicles under different emission categories—moderate and high—based on real-time sensor readings. Compared to conventional manual testing methods, the proposed design significantly reduces operational effort and human error. Data logging through the ESP32 and ThingSpeak platform enables **predictive maintenance**, identifying early trends in abnormal emission levels and sensor drift, thereby ensuring sustained accuracy over extended operation. Additionally, optimized power consumption (8–12 W) and automated data processing through machine learning contribute to reduced maintenance costs and improved system efficiency.



V. CONCLUSION

This work presents an **IoT-based Vehicle Emission Monitoring System** designed to overcome the limitations of conventional emission testing methods by integrating **real-time monitoring**, **intelligent data analysis**, and **cloud-based connectivity**. Experimental evaluations demonstrated stable emission detection performance, accurately measuring CO, CO₂, and Nitrogen levels with low power consumption (8–12 W) and reduced operational costs. The system promotes environmental sustainability by enabling continuous emission tracking and early detection of abnormal patterns. Performance evaluations indicate that the system maintains CO₂ readings within $\pm 5\%$ of reference values and CO/Nitrogen readings within ± 0.2 ppm under variable exhaust conditions, with automated data transmission and alerts through ThingSpeak and mobile applications. Security mechanisms—including **TLS-encrypted communication**, **role-based access control**, and **tamper detection**—mitigate risks such as data spoofing, network interception, and unauthorized access. The integration of **machine learning analytics** supports predictive insights for identifying vehicles with rising emission trends, enabling proactive maintenance and regulatory compliance. Furthermore, an **AI-assisted interface**, powered by LLaMA 3.2, enhances user accessibility by providing real-time recommendations, anomaly detection alerts, and maintenance suggestions. This makes the proposed system highly suitable for **personal vehicles**, **service stations**, and **smart city emission management frameworks**, ensuring cleaner transportation and a sustainable urban environment.

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