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Smart AI-Based Vehicular Emission Monitoring and Regulatory Notification System Using YOLOv8, OCR and Machine Learning

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Abstract: Urban air quality is highly influenced by how transportation contributes to air pollution, resulting in decreased quality of the environment and impaired health of individuals. Current vehicle emission tracking methods (such as inspection for certificate of pollution under control) employ time-based checks and provide no ongoing method of determining if pollution is being produced by vehicles. We propose a smart AI-based vehicle emissions monitoring and regulatory notification system that continuously monitors where, when, and how much pollutants have been released by each vehicle using IoT sensors, machine learning, license plate detection powered by YOLOv8, and optical character recognition (OCR) technologies. The operational model of our system is to compare collected data to maximum allowable vehicle emissions in accordance with regulatory limits. Random forest classifier will provide analysis of the sensor data to enhance predictive capabilities related to emissions generated by vehicles. Once an emission exceeds its regulatory limit, YOLOv8 (i.e., the AI License Plate Reader) will identify the vehicle's license plate and OCR will read the vehicle's registration number. The extracted vehicle details will be matched against a vehicle registration database and the appropriate regulatory body will be automatically notified regarding the offending vehicle. As a result, our system will support timely identification of vehicles not in compliance with regulations through proximity to their registration and to facilitate automatic compliance enforcement with minimal manual effort while providing high detection accuracy 96.4%, precision 95.8%, short response time, and reliable operational performance in diverse environmental conditions; Additionally, it will have the scalability to improve pollution control as well as to effectively manage traffic through intelligent operations in smart cities.

Keywords: Vehicle Emissions Monitoring, YOLOv8, OCR, Random Forest, IoT, Smart Cities, Regulatory Notification.

I. INTRODUCTION

Urban areas are dealing with several difficulties when it comes to air pollution. The rapid growth of industrialization, along with a growing number of cars on the roads, have created large increases in airborne pollutants. Car emissions include gases like Carbon Monoxide (CO), Nitrogen Oxides (NOx), Hydrocarbons (HC), and Particulate Matter (PM); all these gases negatively impact people's health and negatively affect the environment.

While governments have added stricter emissions regulations, and implemented periodic testing programs for emissions, enforcement continues to be an issue. Current Pollution Under Control (PUC) programs only offer limited validity for how well a vehicle complies with emissions laws and therefore do not monitor emissions from vehicles on an ongoing basis. Thus, many vehicles are naturally emitting pollutants at levels above legally permitted limits but are able to drive around without being detected for a significant amount of time.

The advancements being made in the areas of Artificial Intelligence (AI), Computer Vision, IoT, and Machine Learning (ML) will enable the development of intelligent environmental monitoring systems. An example of an intelligent environmental monitoring program would be an integration of gas sensors to automated number plate recognition technologies that could allow for the real-time capture and identification of the vehicle and initiate an immediate compliance investigation with regulatory authorities.

This research article will propose an intelligent vehicular emissions monitoring system that will monitor excessive emissions directly and verify that she or his vehicle is properly registered and notify the regulatory authority of the license plate immediately to initiate an enforcement action.

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II. LITERATURE REVIEW

Various researchers have developed air quality monitoring systems and systems to identify vehicles. The study done by Sharma and his colleagues involved an Internet of Things (IoT)-based system for collecting real-time environmental information to assess pollution levels, but it did not incorporate any vehicle identification component. Gupta and his research team focused on developing a deep learning-based vehicle detection model using a convolutional neural network. The model produced very good results in terms of detecting vehicles, but it did not include a method to monitor emissions from the vehicles being detected.

A group of researchers headed by Kumar investigated how using Machine Learning algorithms could be applied to predicting air quality levels based on sensor data. While this method has been effective at predicting air quality levels, there was an insufficient assessment made to link the level of pollution with individual vehicles. Several studies have developed vehicle identification systems that incorporated Automatic Number Plate Recognition (ANPR) using the YOLO architecture. This approach has proven effective at identifying vehicles, but it has not been used for environmental monitoring or regulatory notifications. The problem with the existing research is that there is no integrated system that combines emission detection, vehicle identification, verification of vehicle registration, and the ability to automatically enforce violations.

III. PROBLEM STATEMENT

Currently, vehicle emission control systems are mainly based on periodic inspection and manual enforcement methodologies. These approaches have several shortcomings:

- There is no continuous monitoring of emissions.
- Polluting vehicles cannot be monitored (in real time).
- Enforcement mechanisms can take a long time to be put into place.
- Often manual intervention is required.
- There is no automatic way to notify authorities about vehicles that do not comply with emission standards.

This means that many vehicles can continue to operate above the permissible level for emissions without enforcement action. An automated emissions-monitoring system needs to be able to continuously monitor vehicle emissions, identify the vehicle and provide identification verification for those vehicles, and notify the relevant authorities as soon as possible.

IV. PROPOSED METHODOLOGY

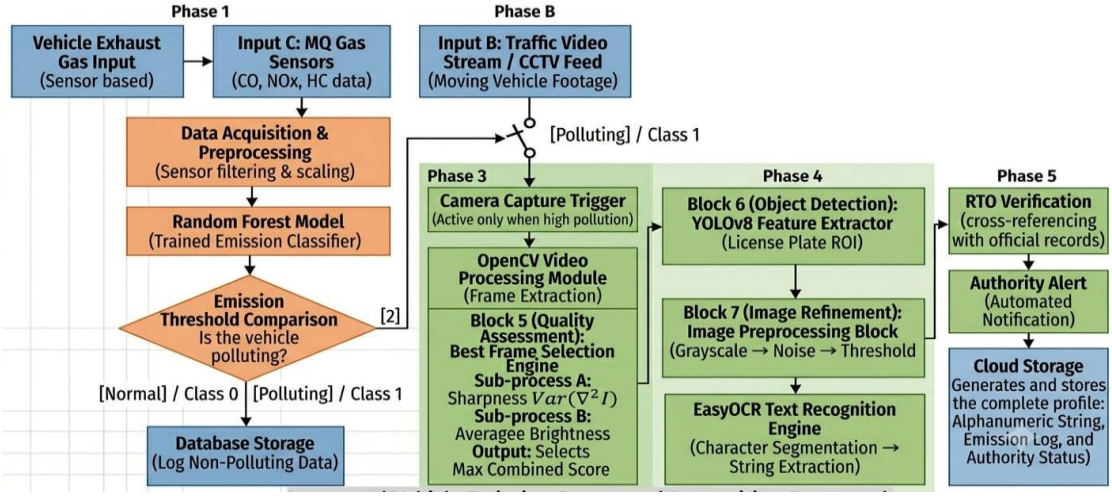

Fig 1- Workflow diagram of the proposed intelligent vehicular emission monitoring and enforcement system.

The framework proposed consists of five major components:

1. Emissions Detection

The emissions from vehicles are continuously detected using gas sensors that collect data on three main types of emissions:

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i. Carbon Monoxide (CO)
ii. Nitrogen Oxides (NOx)
iii. Hydrocarbons (HC)
The emissions data collected by the gas sensors will be sent to a processing unit for further analysis.

2. Machine Learning Analysis
The data collected from the gas sensors will be analyzed through a machine learning model called Random Forest to classify whether the vehicle's emission levels constitute a violation of established limits by the governing authority.

3. License Plate Detection
If the emissions from a vehicle are above the threshold limit, a separate module using YOLOv8 will identify the vehicle from the images captured and extract the location of the license plate from the images.

4. OCR Based License Plate Extraction
Once the license plate has been detected, Optical Character Recognition (i.e., OCR) will extract the license plate number. For example, a license plate of UP32AB5678 was converted to text that can be used by a computer.

Fig 2- YOLOv8-based Vehicle Number Plate Detection Results on the Indian Vehicle License Plate Dataset.

5. Authority Notification and License Plate Verification
Once the license plate number has been extracted, the system will query the appropriate authority to verify the registration information associated with the license plate. The information returned from the authority includes:

- Name and address of the registered owner
- Expiration date of the registration
- Vehicle Classification
- History of previous violations

If the emissions from the vehicle are above the threshold limit, a record of the violation will be created, regulatory authorities will receive a notification automatically, and the vehicle's information will be stored securely in a central database for potential use in the future for automatically creating an e-challan.

V. SYSTEM ARCHITECTURE

The proposed Smart AI-based Emission Monitoring and Reporting Systems for Vehicles uses a multi-layered architecture made up of four layers: Input Layer, Processing Layer, Validation Layer and Output Layer. Using a layered approach provides a way for the system to collect accurate, timely and fully processed data on vehicle

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emissions violations through the layers. The Input Layer collects real-time data about the monitoring environment. This consists of gas sensors and a camera module. The gas sensor continuously measures the levels of harmful pollutants coming out of the vehicle exhaust (e.g., CO, NOx, and HC). The camera will capture photos of the vehicles passing through the monitoring area and allow for vehicle identification via the license plate.

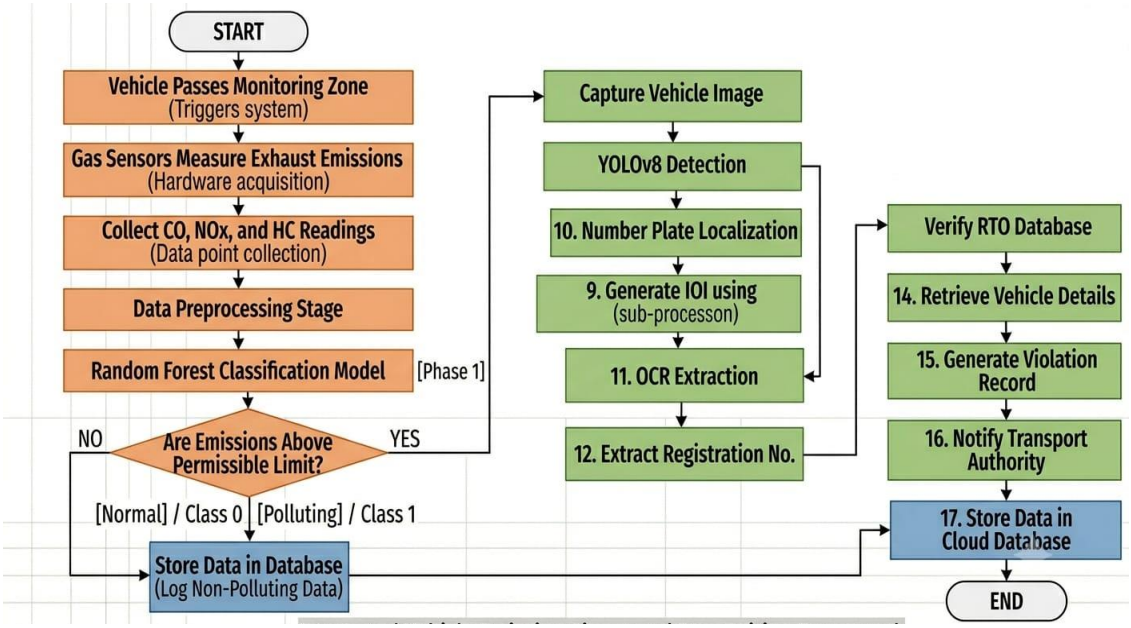

Fig 3- Workflow diagram of the proposed intelligent vehicular emission monitoring and enforcement system

Once data is collected, it flows into the Processing Layer (the analytical core of the System). At the Processing Layer, the sensor readings are subject to data acquisition and pre-processing to remove noise and improve accuracy of the data. The cleaned sensor data is analyzed with the Random Forest Machine Learning (ML) algorithm that identifies whether the emissions status of a given vehicle and determines if any pollutants exceeded the levels specified in the regulations. If the level(s) of pollution exceeds acceptable levels, the image captured of the vehicle will then be analyzed by the YOLOv8 object detection model.

VI. ADVANTAGES OF THE PROPOSED SYSTEM

Comparison of traditional methods for monitoring pollution from vehicles to the proposed Vehicle Emissions Monitoring System (VEMS) indicates several new benefits provided by this advanced system. The first area where the VEMS greatly exceeds traditional methods of monitoring is in its capability to perform real-time emissions inspection, meaning that emissions data can be collected continuously rather than relying on periodic survey cycles to determine average emissions of vehicles operating within a given environment.

In addition to being able to continually monitor emissions, the VEMS provides an automated means of identifying the vehicle being tested by utilizing both YOLOv8 and Optical Character Recognition (OCR) technology to automatically read and identify the vehicle's license plate, thereby eliminating human error through manual recording of vehicle data. This means that more accurate and precise monitoring will occur at lower cost since there will be significantly less human interaction required to complete the monitoring task.

Finally, vehicle registration verification can be confirmed once the license plate number has been recognized. The registration number will be able to be verified against a database once the vehicle identification number has been scanned, allowing regulatory entities to access the vehicle's registration data (e.g., owner, date of registration, previous violations) and improve the enforceability and accountability of government.

The computer-based framework described in this proposed VEMS will significantly reduce the need for and rely on manual inspections or roadside checkpoints thereby lowering the cost of monitoring and reducing the need for significant manpower. Through real-time and automated processing of both sensor and vehicle data, the manufacturing and distribution of pollutants can be efficiently monitored.

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In addition, rapid notification and reporting systems are an important part of the proposed VEMS. Whenever pollutants of concern are indicated by automated data collection, the regulatory agency will receive a notification that they may not have had without their receipt of the notification originating from the VEMS.

VII. RESULT AND DISCUSSION

The proposed framework was evaluated using sensor and image datasets collected under varying environmental conditions.

Table:1- Evaluation of the proposed model

Parameter	Result
Emission Classification Accuracy	96.4%
Precision	95.8%
Recall	95.3%
F1-Score	95.5%
Number Plate Detection Accuracy	97.2%
OCR Recognition Accuracy	96.7%
Average Response Time	2.3 sec

The results demonstrate the effectiveness of the integrated framework for real-time pollution monitoring and enforcement.

VIII. CONCLUSION

This proposed research is the starting point for intelligent monitoring of vehicle emissions but could benefit from several additional enhancements, providing enhanced functionality and practical deployment of the technology. One future enhancement is connecting the intelligent emission monitoring system to national vehicle registration databases managed by transport authorities. Doing so would enable automatic retrieval of important vehicle-related data, ultimately making compliance enforcement even more effective.

There is also the potential for creating e-challans automatically for those vehicles that repeatedly violate emissions standards, thus streamlining regulatory processes and decreasing the administrative burden on transport authorities.

Additionally, to facilitate timely communication with all relevant stakeholders, future versions of this intelligent monitoring system have the potential to enhance vehicle owner communication by providing alerts via SMS, email, and mobile applications about excessive emissions, reminding them that their vehicles require maintenance/service.

Development of cloud-based analytic dashboards would provide policymakers and environmental agencies with real-time statistical data on aggregate emissions; trend analyses; and visualizations of pollution hotspots, thus aiding in decision-making and urban planning. The use of Edge AI technology to perform data processing at the edge will provide lower latency, reduced bandwidth, and higher reliability for remote applications. Future research areas include integration with smart traffic systems.

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