



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

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Abstract: 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, CO₂, and NO_x, 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.

Keywords: Embedded System, Gas Sensor, Number Plate Recognition

I. INTRODUCTION

One of the main causes of air pollution, environmental damage, and public health issues is vehicle emissions. Smog, respiratory diseases, and climate change are all intimately related to exhaust gases such as carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and hydrocarbons (HC). These growing worries highlight how urgently practical solutions that can track and control vehicle emissions in real time are needed. A Vehicle Emission Monitoring System is presented in this project, which is intended to continuously identify and analyze dangerous pollutants. In order to ensure prompt response, the system measures emission levels using gas sensors interfaced with an ESP32 microcontroller and sends out notifications when readings above allowable thresholds. This system's incorporation of Automatic Number Plate Recognition (ANPR) technology via a webcam is a significant innovation. This system automatically detects high-emission automobiles by capturing and processing their license plates using ANPR algorithms, in contrast to traditional emission monitors that merely detect pollutant levels. Authorities can use this capability to monitor non-compliant vehicles and carry out specific measures like owner notifications, penalties, or required maintenance.

The system is ideal for deployment at toll booths, metropolitan areas, pollution control zones, and highway checkpoints because it is affordable, portable, and easy to operate. It provides a useful tool for air quality control and regulatory enforcement with capabilities like wireless connectivity, real-time notifications, and automated vehicle recognition. The suggested method enhances environmental protection initiatives, promotes sustainable urban development, and lessens the health hazards associated with vehicle pollution by connecting intelligent identification and emission monitoring.

II. LITERATURE REVIEW

Vehicle emission monitoring research has drawn a lot of interest because of its potential to lower urban air pollution and aid in the enforcement of regulations. Numerous investigations have looked into data-driven, automated, and sensor-based techniques for efficiently detecting and managing vehicle emissions. An intelligent automated emission quality monitoring system for traffic signals was proposed by Sricharan et al. (2013). Their method used sensor arrays and lane-based vehicle sorting to identify pollution levels in real time. When pollutants surpassed allowable limits, the system used a camera to take a picture of the license plate and issued SMS alerts to the owner and authorities. The promise of automation in urban pollution management was demonstrated by this centralized, economical design. An automated method for identifying and managing vehicle emissions was presented by Tiwari et al. Their system used sensors to continuously monitor pollutants like CO and NO_x, and when thresholds were surpassed, it imposed real-time



intervention. The technology used GPS to record the vehicle's location, automatically turned off the engine, and GSM to send an SMS notification to pre-specified recipients. Although there were still practical issues including user acceptance and safety concerns, the system provided a proactive way to reduce environmental pollution by combining detection with direct control techniques.

When vehicle fuel type and registration information were unknown, such as in the case of new or non-local automobiles, He et al. (2020) addressed the difficulties associated with emission monitoring. In order to analyze remote sensing data, their study used machine learning algorithms such as decision trees, random forests, AdaBoost, and XGBoost. Data-driven estimation of vehicle features and emission levels was made possible via a cascaded classification architecture, which increased prediction accuracy. When direct vehicle information was unavailable, this method showed the value of advanced analytics. By integrating machine learning and on-road remote sensing (ORRS) for quick evaluation of light-duty gasoline vehicle emissions, Xia et al. (2022) made progress in this regard. Their study connected ORRS readings with inspection and maintenance records through license plates and vehicle identification numbers, using a sizable dataset of 103,831 automobiles. High accuracy in estimating CO, HC, and NO_x emissions was attained by an ensemble model that used neural networks with XGBoost, especially when driving normally. This method effectively separated high and low emitters, demonstrating the value of integrating machine learning and large-scale monitoring for ongoing emission control.

When taken as a whole, these studies show a distinct progression from sensor-based monitoring at specific locations to sophisticated, data-driven systems that allow for extensive, real-time vehicle emissions evaluation. They stress how crucial it is to combine automated control, machine learning, and sensing technologies in order to provide scalable solutions for managing urban air quality and adhering to regulations.

III. WORKING OF THE PROPOSED SYSTEM

The block diagram for the suggested system is displayed in Figure 1. An Internet of Things based architecture called the Vehicle Emission Monitoring System was created to track, evaluate, and manage vehicle emissions in real time. The system offers a complete solution for tracking emissions and enforcing regulations by integrating sensors, microcontroller processing, alert mechanisms, and image recognition modules. The ESP32-S microcontroller, which serves as the control unit, is the central component of the system. The MQ-7 gas sensor detects carbon monoxide (CO), whereas the MQ-135 sensor measures nitrogen oxides (NO_x) and carbon dioxide (CO₂). For real-time monitoring, these sensors continuously gather emission data, which is then processed and shown on an LCD module and an OLED display. The system initiates many reactions when emission levels surpass predetermined thresholds: An instantaneous audio alert is provided by activating a buzzer. A webcam that takes a picture of the license plate is activated by a Wi-Fi signal sent by the ESP32. The EasyOCR model is used to perform Automatic Number Plate Recognition (ANPR) on the acquired image. Authorities can then detect non-compliant vehicles and take corrective action, such as advising repair, sending alerts, or imposing fines, by seeing the extracted license plate number on the output displays. The system records emission data for regulatory analysis and compliance monitoring in addition to detection and enforcement. Wireless data transfer to cloud platforms is one of its possible improvements. It is made to be portable and scalable. Because of these characteristics, the system can be installed in toll booths, smart cities, highway checkpoints, and urban pollution control zones, offering an economical and effective alternative to enhance air quality and guarantee legal compliance. The block diagram for the suggested system is displayed in Figure 1.

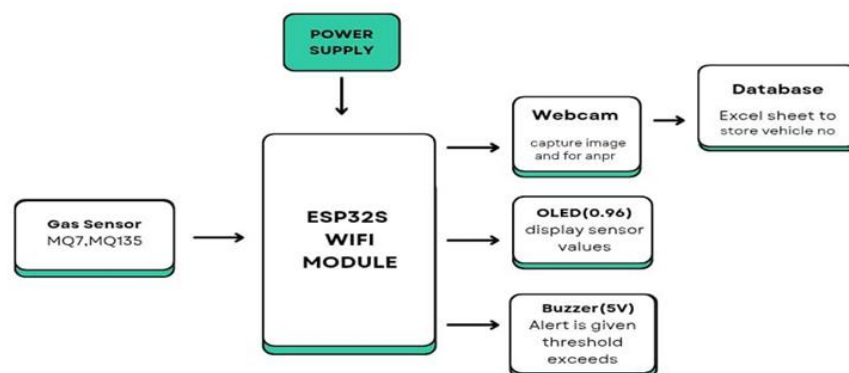


Figure 1 illustrates the block diagram of the proposed system.



The Initialization Phase, when the ESP32-S turns on and turns on sensors (MQ-7 and MQ-135) to track emission levels. The ESP32 reads the CO, CO₂, and NO_x levels from the sensors and shows the results on the OLED screen during the Sensor Data Processing stage. The system starts the Alert and Response Mechanism when any emission level is over a predetermined threshold. The ESP32 sends a WiFi signal to activate a webcam that is linked, and a 5V buzzer is activated to notify high pollution. The webcam takes a picture of the license plate during the Automatic Number Plate Recognition (ANPR) stage, and a Python-based ANPR server processes the image. For documentation purposes, the detected license plate number is entered into an Excel file. At last, the process completes the monitoring and alert workflow by reaching the End Process step.

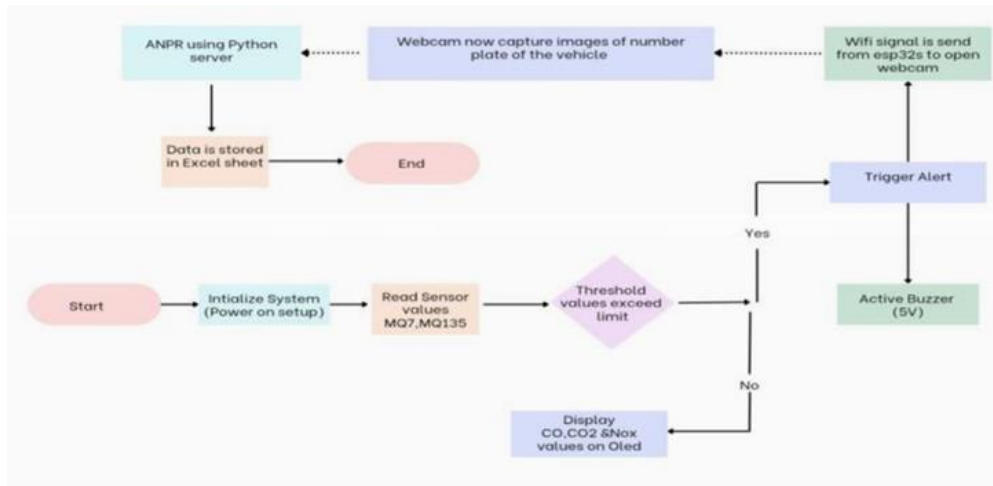


Figure 2 shows the flowchart of the proposed system

IV. RESULTS AND DISCUSSION

Figure 3. Experimental setup of the proposed system. To identify, show, and react to elevated pollution levels, the Vehicle Emission Monitoring System (VEMS) combines hardware and software components. The ESP32-S (NodeMCU) is the central component, a high-performance microcontroller with Bluetooth and Wi-Fi capabilities, a dual-core 32-bit processor, many GPIO ports, and low power consumption that is appropriate for real-time Internet of Things applications. The MQ-7 sensor, which detects carbon monoxide (CO), and the MQ-135 sensor, which detects several gases, including CO₂, NO_x, NH₃, and benzene, are used to monitor air quality. Both sensors have analog outputs and need to be preheated in order to provide reliable results. A 0.96-inch OLED display with an I2C interface handles data visualization and shows system status and sensor information in real time. When pollution thresholds are surpassed, a webcam records license plates for automatic vehicle identification. Tesseract OCR, OpenCV, and Python process the photos and store the numbers that are recognized in Excel. When gas concentrations surpass safe limits, a 5V active buzzer is activated to produce audible alerts. The system software facilitates effective real-time monitoring, data processing, and hardware and software component integration by including Python for ANPR operations and the Arduino IDE for ESP32 programming.

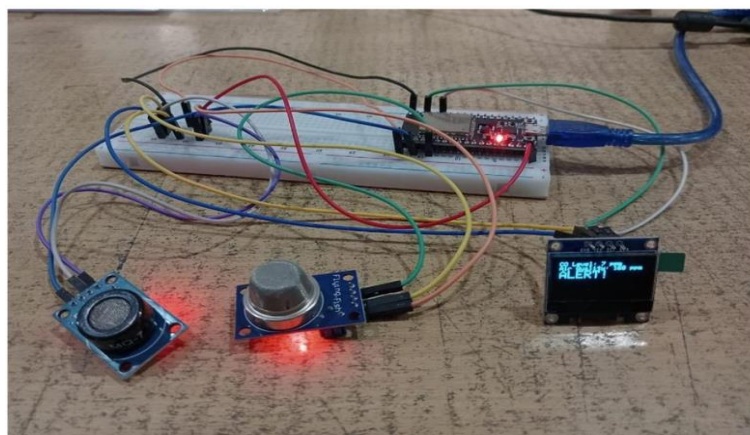


Figure 3 shows the setup the proposed system



	A	B	C	D	E	F	G	H
1	Timestamp	Plate Num	Image Path					
2	#####	22 Bh6517	captured_20250310_201144.jpg					
3	#####	Bh6517	captured_20250310_201151.jpg					
4	#####	22BH6517	captured_20250310_201156.jpg					
5	#####	2le46517a	captured_20250310_203800.jpg					
6	#####	22 bhss17	captured_20250310_203806.jpg					
7	#####	22Bh6517	captured_20250310_203811.jpg					
8	#####	KL 41	captured_20250318_152818.jpg					
9	#####	KL 41 U73	captured_20250318_153006.jpg					
10	#####	KIA46 %3	captured_20250318_202824.jpg					
11	#####	KL 41 E 83	captured_20250318_202840.jpg					
12	#####	KL 41 E 83	captured_20250318_202911.jpg					
13	#####	KL 41 E 83	captured_20250318_202916.jpg					
14	#####	KL 41 E 83	captured_20250318_202921.jpg					
15	#####	KL 41 U73	captured_20250319_114936.jpg					
16	#####	KL L U7222	captured_20250319_115226.jpg					
17	#####	KL 41 U73	captured_20250319_170737.jpg					
18	#####	KL 41 0732	captured_20250319_170743.jpg					
19	#####	KL 41	captured_20250319_170749.jpg					
20	#####	KL 41 U73	captured_20250319_170755.jpg					
21	#####	KL 41 0732	captured_20250319_170801.jpg					
22	#####	KL 41 E 83	captured_20250319_224633.jpg					
23	#####	KL 41 E 83	captured_20250320_094503.jpg					
24	#####	KL 41 E 83	captured_20250320_094614.jpg					
25	#####	KL 41 E 83	captured_20250320_094620.jpg					
26	#####	KL 41 E 83	captured_20250320_094916.jpg					
27	#####	KL 41 E 83	captured_20250320_094942.jpg					
28	#####	KL 41 E 83	captured_20250320_095108.jpg					
29	#####	KL 45	captured_20250320_095305.jpg					
30	#####	KL 41 U732	captured_20250320_095525.jpg					

Figure 4 Displays the vehicle plate number output stored in a CSV file.

Following a successful detection of the car license plates, the plate numbers are automatically entered into an Excel sheet for later use, allowing regulatory bodies to access and use the information as required. A screenshot of the stored database is shown in Figure 4.

V. CONCLUSION

To conclude, the Vehicle Emission Monitoring System (VEMS) presents an advanced Internet of Things (IoT)-based approach for real-time monitoring and analysis of vehicular emissions. With the growing concern over urban air quality, there is an increasing need for automatic pollution detection systems integrated with automatic number plate recognition (ANPR) to identify and alert users while assisting government agencies in enforcing emission control regulations. The system detects vehicles emitting excessive pollutants, after which a camera identifies the corresponding number plate and links it to a database, thereby assisting government regulatory authorities in monitoring and enforcing emission standards. The proposed system effectively combines gas sensors, automated alert mechanisms, and license plate recognition to detect high-emission vehicles and transmit real-time data for regulatory action. Its scalability, accuracy, and reliability make it a valuable tool for government bodies, environmental organizations, and traffic management authorities. Overall, VEMS represents a practical and sustainable solution that contributes to improved air quality, smarter urban management, and a cleaner, healthier environment for future generations.

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