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Real-Time Automobile Air Pollution Monitoring System

R. Sireesha B. Raj[1,*], Moulya M.[1], Nithya N.[1], Basavaraj[1]

Abstract

The system proposed in this study aims to be a novel approach for real-time detection and quantification of vehicular emissions, integrated into smart city infrastructures. The structured workflow enhances accuracy and efficiency. OCR captures the license plate, while the ground clearance is simultaneously measured, allowing the thermal camera to dynamically adjust its position to align with the tailpipe level. The emission data is collected and transmitted to a centralized dataset, where it is matched with the registration details of the vehicle. With a machine learning model to evaluate the emission levels, it compares the same to predefined healthy thresholds, sends a notification if the limit exceeds the acceptable level, and fines the owner of that vehicle. This non-intrusive, automated process, therefore, ensures continuous monitoring toward effective urban emission management. Car-related air pollution is becoming a bigger problem, particularly in cities with heavy traffic. Real-time monitoring and mitigation of this pollution can greatly improve human health and air quality. The design, operation, and possibilities of a Real-Time Automobile Related Air Pollution Management System, an inventive way to deal with vehicle emissions, are examined in this article. Conventional techniques for tracking vehicle emissions depend on routine inspections, which are inadequate for gathering data and trends in real-time. The goal of a real-time monitoring system is to close this gap by giving the public, urban planners, and regulators access to ongoing data.

Keywords: Vehicular emissions, air pollution, real-time monitoring, thermal imaging technology, automated emission detection, continuous monitoring, automobile emissions monitoring

INTRODUCTION

Vehicular emissions are one of the biggest sources of air pollution, especially in highly populated urban areas, where vehicular use is intense. The incineration of fossil fuels within an internal combustion engine releases significant air pollutants, such as carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter (PM), and hydrocarbons, posing immense environmental and public health concerns. The traditional methods for checking the exhaust emissions of vehicles are fixed inspection cycles through manual evaluation, which are not only time-consuming, cover less area, and are less frequent. As cities become smart, advanced real-time monitoring of solutions for emission data across an entire urban region is emerging as one of the largest demands. This study proposes a new system that applies thermal imaging technology to detect and measure vehicular emissions in real-time. Non-intrusive and automated monitoring through integration into smart city infrastructure allows traffic flow without interruption and direct contact with vehicles, thus making emission tracking continuous. This approach will improve the scope and accuracy of monitoring emissions and provide governments with actionable insights into the management and control of pollution in urban areas. Vehicular emissions are the main cause of air

***Author for Correspondence**
R. Sireesha B. Raj
E-mail: sireeshabraj1711@gmail.com

[1]Student, Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering, Bengaluru, Karnataka, India

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pollution and contribute to environmental degradation and public health crises. These emissions have a well-documented trigger role for diseases in the respiratory and cardiovascular fields and affect people most severely in cities where vehicle density is high. Automobile emissions, besides having direct health impacts, are a leading factor in smog formation, which intensifies climate change through increased emission of greenhouse gases into the atmosphere.

LITERATURE SURVEY

In this study, the author emphasized that traditional systems lack features related to real-time data and predictive analysis, especially in industrial settings. However, the advent of the Internet of Things (IoT)-based solutions has revolutionized monitoring, allowing for cost-effective and continuous data collection and real-time analysis using interconnected sensors. Long short-term memory (LSTM) and Random Forest AI models have dramatically enhanced the accuracy of pollutant forecasting, providing better opportunities for proactive management of pollution. Although IoT and AI systems have been introduced in urban environments, they are very limited in dynamic industrial contexts. This study bridges this gap by integrating IoT sensors and AI models for real-time air quality monitoring and forecasting in chrome plating facilities, addressing critical health risks, and enabling timely intervention [1]. This project primarily used IoT-based vehicles to set up an effective system for monitoring air pollution. Hence, our module can be set up in a running vehicle, and the system can track the level of air pollution at any required location. An independent government can detect the absorption of air pollutants to take legal actions against pollution and pressure in an air pollution rule [2]. The objective of this study is to monitor air pollution on roads and track vehicles that cause pollution over a specified limit. The increasing number of automobiles is a long-standing and severe problem. This study proposes the use of IoT to address this problem. Here, a combination of a wireless sensor network, electrochemical toxic gas sensors, and the use of a Radio Frequency Identification (RFID) tagging system are used to monitor car pollution records anytime and anywhere [3]. The designed IoT kit can be physically mounted in the exhaust system of any vehicle. The gas sensors connect data regarding vehicle emissions and relay the data to the controller that transmits the data to the cloud through the Wi-Fi module. The web server is designed to maintain the data of each vehicle emission, and only the vehicle authority can access the data from the website so that authorities can check the data to inform the vehicle owner [4]. This study introduces an innovative idea for air quality monitoring through a low-cost, portable system that can work both statically and dynamically. The system measures the concentrations of pollutants such as CO and NO_2 in real-time through the integration of sensors with GPS and Zigbee to collect and transmit data. Compared with traditional monitoring, where an internet connection is used continuously, it stores and relays data through short-range communication; thus, it is cost-effective and versatile. This proves that this system is highly effective in both static and mobile environments. This test in Quetta, Pakistan, opens a way to make accessible environmental monitoring for everyone [5]. Vehicular air pollution poses significant health and environmental risks and thus calls for effective monitoring systems. Traditional approaches use hybrid Zigbee-Wi-Fi networks for IoT integration; however, they are unreliable. Modern solutions use microcontrollers such as ESP8266 and sensors such as MQ7, which are sensitive to carbon monoxide (CO), to detect vehicle emissions in real-time. Integrating these systems with secure cloud platforms such as AWS IoT enables functionalities such as data processing, storage, and push notifications using the Simple Notification Service (SNS). Vehicle IDs ensure proper identification and accountability. Thus, this streamlined approach enhances control over emissions, public health, and environmental sustainability [6]. The main goal of this study was to use remote sensing to measure on-road emissions and to study the impact and utility of additional measurement devices at three sites. Augmenting remote sensing device (RSD) equipment with supplementary equipment enhanced the capture rate by using the anomaly detection method, followed by the detection of cold start conditions of operation using infrared vehicle profiles [7]. This study addresses an IoT-based vehicle monitoring system for air quality monitoring, where sensors measure pollutants such as PM2.5, CO, NO_2, and O_3. Communication technology has been chosen based on LoRa WAN with low power consumption and wide geographical coverage. Sensors mounted on vehicles capture data and upload it to a cloud server for real-time access by users and government agencies. This system helps manage traffic and pollution, making it a very important factor in the creation of smart cities. This illustrates an efficient method for large-scale air quality monitoring using mobile platforms [8]. The focus of this study is to design cost-effective industrial wireless networks for the use of data transfer from NOx sensors to an on-board visual display, and to access, transmit, and provide data to the driver [9]. This study discusses a smoke and exhaust detection system that has been developed for exhaust gas monitoring to enforce environmental laws and regulations, a method that adopts two cameras, a far-infrared camera, and a high-resolution visible wavelength camera, as a detection system for smoky vehicles. A far-infrared camera is used to detect the location of vehicle exhaust fumes. This thermal information was combined with information from a high-resolution camera in the visible spectrum. The algorithm checks whether the detected vehicles emit visible exhaust smoke. When smoke was detected, the evidence was stored for the next steps. The first prototype version of the system required an automatic adaptation procedure to calibrate the far-infrared and high-resolution images. The system is mechanically easy to set up at a selected roadside location [10].

To overcome the shortcomings of traditional monitoring approaches, we propose a real-time monitoring system that utilizes thermal cameras and IoT technology. This system can be strategically deployed at key urban locations such as traffic intersections, streetlights, and even vehicles. It continuously measures key pollutants, including carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and PM, providing comprehensive coverage of vehicular emissions. Thermal imaging is a key component in the system, as it can detect heat signatures from vehicle exhausts, thereby identifying high-emission vehicles under low-light or night-time conditions with greater accuracy and reliability. Thermal cameras quickly identify vehicles that emit high levels of pollutants, which then allows for targeted actions to mitigate pollution spikes.

The real-time data capabilities of the system are supported by robust communication networks, including 5G, Wi-Fi, and ensuring swift data transfer and minimal latency. These technologies allow monitoring stations to interface seamlessly with centralized databases and analytical platforms, thereby continuing the tracking of emissions over vast areas of the city. The data gathered by the system is subjected to sophisticated machine algorithms that identify and identify patterns, predict pollution trends, and even enable the detection of anomalies in real-time. The analyzed data were visualized through user-friendly interfaces, such as dashboards, heat maps, and real-time graphs, providing city authorities and the public with actionable insights.

CHALLENGES IN IMPLEMENTATION

Although the proposed system offers several technical advantages, it poses several technical, financial, and regulatory hurdles. The deployment of advanced sensors and high network infrastructure requires heavy investment. Coordination with regulatory bodies is essential to comply with emission standards when adopting this system. Long-term benefits, such as improved air quality and proper policymaking, outweigh the challenges associated with the proposed system.

BENEFITS OF THE PROPOSED SYSTEM

The real-time monitoring system allows for efficient management of air quality by providing authorities with the data necessary to respond rapidly to spikes in pollution and enforce emission regulations. It also increases public awareness and involvement by offering real-time data, encouraging cleaner transportation, and promoting more sustainable behaviors. Finally, in protecting public health, the system plays a vital role in reducing exposure to harmful pollutants and preventing pollution-related diseases.

METHODOLOGY

Integrate Technologies

The developed system uses advanced thermal cameras, IoT technology, and machine learning algorithms for real-time vehicular emissions, as shown in Figure 1. In addition, a mounted camera, with the controller measures the ground clearance to precisely align the thermal camera with the tailpipe

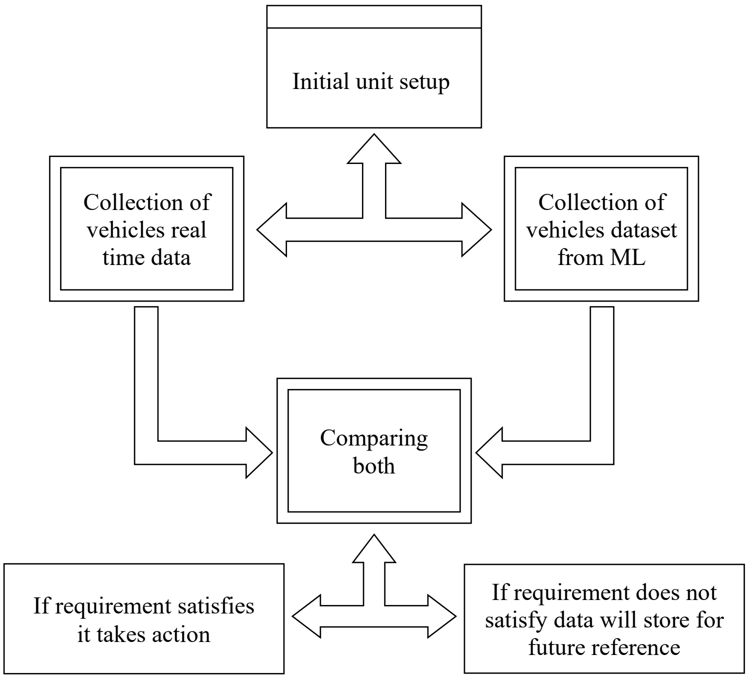

Figure 1. Block diagram of the proposed system.

level for the accurate capture of exhaust emissions. The data was communicated to the machine learning model for assessing the level of emissions against a set of data of healthy emissions thresholds. The integrated technologies of capture, transmission, processing, and analysis of automobile emission data work together in a single process for the collection, transmission, processing, and analysis of automobile emission data. Strategically deployed at key intersections and major highways, the system ensures the continuous and comprehensive monitoring of vehicular pollution within urban areas. The proposed system monitors and analyzes pollutants directly from vehicles in real-time by combining cutting-edge sensors, IoT devices, and cloud computing technology. The important parts of the system are as follows:

- *Sensors for emissions:* Pollutants from car exhaust systems, including CO, NOx, HC, and PM, were detected using high-precision sensors. These sensors are small and strong and can be used in a variety of environmental settings.
- *IoT module:* IoT Module Sensors are linked to an IoT module that uses cellular networks or wireless communication protocols, such as Wi-Fi or LoRa to send real-time data to a central database.
- *Integration of GPS:* Geographical mapping of emission hotspots along with evaluation of emission trends based on traffic patterns is made possible by a GPS module that tracks the vehicle's location.
- *Cloud-based computing:* A cloud platform receives data gathered by the sensors and IoT module for analysis and storage. The data is processed using machine learning algorithms and advanced analytics to identify trends and abnormalities.
- *Interface for users:* Real-time pollution data are displayed in an easy-to-use interface that can be accessed through mobile devices or the web. Users of this interface, including car owners and government agencies, may monitor emissions and receive alerts about any infractions.

Thermal Cameras

At strategic points, thermal cameras are installed to capture the heat signatures from the tailpipes of passing vehicles. The thermal energy emitted by exhaust gases varies with the emission levels of the vehicle. Each pollutant has a specific thermal signature similar to that of carbon monoxide (CO), nitrogen oxides (NOx), VOCs, and PM. This non-intrusive method allows for real-time detection without disrupting the traffic flow or requiring physical contact with vehicles.

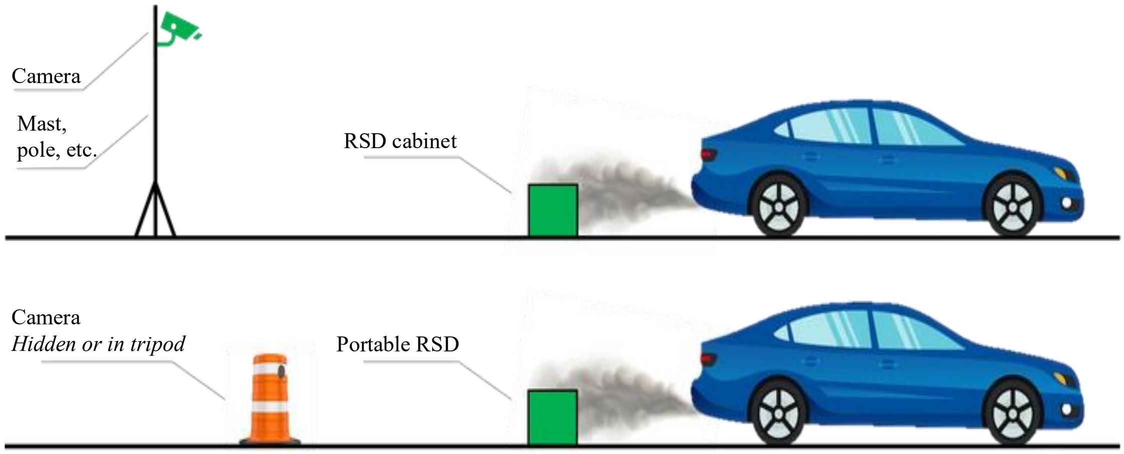

Figure 2. Device placement.

Data Transmission and Processing

The data collected from the thermal cameras are transmitted to a central server through wireless IoT networks such as 5G, Wi-Fi, and LoRa WAN. These robust communication technologies enable high-speed and reliable data transfer, thereby ensuring that the system has real-time functionality. The choice of the network depends on the deployment site and specific data transmission requirements, thereby providing flexibility in the design of the system. Raw data coming into the central server is preprocessed and features are extracted. Preprocessing includes noise reduction, temperature normalization, and filtering out irrelevant data points. Feature extraction was performed to select and isolate the attributes most relevant for emission analysis, such as heat intensity, ambient temperature, and pollutant signatures. Thus, only relevant data are transmitted to the next stage for analysis, thus reducing noise and irrelevant information.

Machine Learning Analysis and Data Visualization

The system uses machine learning algorithms to analyze the processed emission data and identify vehicles that exceed healthy emission thresholds, as shown in Figure 2. The machine learning model was trained on a dataset of vehicles with predefined healthy emission levels, thus making it possible to accurately compare them to detect and classify polluted vehicles. Classification models categorize vehicles as high or low emitters, whereas regression models predict pollutant concentrations over time and location. Anomaly detection algorithms identify outliers that emit exceptionally high levels of pollutants, thus allowing for targeted interventions. Continuous learning of the system improves the accuracy and reliability of predictions over time. The results were visualized through dashboards, heat maps, and real-time graphs, providing actionable insights to city planners, environmental agencies, and the general public. For example, heat maps indicate areas of high pollution and real-time graphs show the trend of emissions, which allows stakeholders to make informed decisions to reduce urban pollution.

RESULTS AND DISCUSSION

1. *Model:* Random Forest Regressor (Figure 3).
2. *Hyperparameters:* Optimized using Grid Search CV.
3. *Best parameters found:*
   - i. Max. depth = 20,
   - ii. Min. samples split = 5,
   - iii. N estimators = 100
4. *Performance metrics:*
   - i. *R^2 Score:* 82.53% (strong predictive power)
   - ii. *RMSE:* 4.25 (average deviation from actual values)
   - iii. *MAE:* 3.61 (average absolute error)
   - iv. *Explained variance:* 83.29% (model explains most of the variance in emissions)


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INFO:root:Model Performance Metrics:
INFO:root: - RMSE (Root Mean Squared Error): 0.000
0
INFO:root: - MSE (Mean Squared Error): 0.0000
INFO:root: - MAE (Mean Absolute Error): 0.0000
INFO:root: - R² Score: 1.0000
INFO:root: - Explained Variance Score: 1.0000
INFO:root: - Prediction Accuracy (based on R²): 10
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Figure 3. Source code for system.

5. *Real-time data processing:* Simulated waiting for backend real-time data with a timeout of 5 min.
6. If data are received, predictions are made; otherwise, the system will be timed out after five minutes.

CONCLUSION

An important step in reducing vehicle emissions and enhancing air quality is a real-time automobile-used air pollution monitoring system. Through the integration of cutting-edge technologies and creative design, the system offers a workable and expandable answer to a critical problem worldwide. Adopting such technologies is essential to guarantee a sustainable and healthy future as urbanization and car usage continue to increase. An innovative approach to addressing vehicle emissions is real-time automobile-generated air pollution monitoring technology. Real-time data collection, regulatory compliance, and public awareness are made possible by utilizing sophisticated sensors, the IoT, and analytics. Reducing air pollution in an urbanizing world is crucial because of its flexible and scalable architecture, which provides a route to healthier cities and a more sustainable planet.

Uses and Prospects

There are several situations in which the real-time automobile caused air pollution monitoring.

- The system's data may be utilized to optimize traffic flow and create low-emission zones.
- Researchers can use real-time data to investigate how vehicle pollution affects air quality and climate change.
- Legislators can ensure efficient pollution control efforts by basing rules on precise up-to-date data.

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