



Smart-Iot Enabled Catalytic Convertor For Real-Time Vehicle Emission Control

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ABSTRACT

Air pollution in urban traffic areas has become a serious environmental and public health concern due to the rapid growth in the number of vehicles and the continuous release of harmful exhaust gases. Major pollutants emitted from vehicles include carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM_{2.5} and PM₁₀), which significantly degrade air quality and create hazardous living conditions in densely populated regions. Continuous exposure to these pollutants can lead to severe respiratory diseases, cardiovascular problems, reduced visibility, environmental degradation, and climate change. Existing air quality management systems are primarily designed for monitoring pollution levels and generating reports; however, they lack the capability to provide real-time corrective actions to reduce pollution at the source. Therefore, there is a growing need for an intelligent, automated, and cost-effective system that not only monitors air quality but also actively reduces harmful pollutants in high-traffic areas.

This project proposes an **IoT-Enabled Smart Catalytic Air Purification System** designed specifically for deployment in traffic-congested urban locations such as road intersections, highways, bus stops, and commercial zones. The proposed system integrates multiple technologies, including gas sensing, particulate filtration, catalytic conversion, and Internet of Things (IoT)-based monitoring, to create an efficient and automated air purification solution. The system continuously monitors air quality using gas sensors such as MQ-series sensors for detecting harmful gases and particulate matter sensors for detecting dust and smoke particles. These sensors provide real-time data to a microcontroller unit, which processes the collected information and compares it with predefined threshold values.

When pollutant levels exceed safe limits, the system automatically activates an air intake mechanism consisting of a high-speed fan that draws polluted air into the purification unit. The incoming polluted air first passes through a mechanical dust filter that removes large particulate matter and suspended particles. After initial filtration, the air enters a catalytic converter chamber containing catalytic materials such as platinum (Pt), palladium (Pd), and rhodium (Rh). These catalysts facilitate chemical reactions that convert harmful gases into less toxic substances. For example, carbon

monoxide is converted into carbon dioxide, nitrogen oxides are converted into nitrogen gas, and hydrocarbons are converted into carbon dioxide and water vapor. This multi-stage purification process significantly reduces the concentration of toxic pollutants in the air.

INTRODUCTION

Air pollution has become one of the most critical environmental challenges faced by modern urban societies. Rapid urbanization, industrial growth, and a significant increase in the number of vehicles have contributed to the deterioration of air quality, especially in traffic-congested areas such as city intersections, highways, bus terminals, and commercial zones. Vehicles powered by fossil fuels emit large quantities of harmful pollutants, including **carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM_{2.5} and PM₁₀)**. These pollutants accumulate in densely populated urban environments, creating hazardous conditions for human health and the environment.

Among the various sources of air pollution, vehicular emissions are considered one of the dominant contributors to urban air quality degradation. Carbon monoxide is a poisonous gas that reduces oxygen delivery in the human body, while nitrogen oxides contribute to smog formation and acid rain. Hydrocarbons react with nitrogen oxides in the presence of sunlight to form photochemical smog, which reduces visibility and causes respiratory problems. Fine particulate matter, especially PM_{2.5}, can penetrate deep into the lungs and bloodstream, leading to serious health issues such as asthma, bronchitis, cardiovascular diseases, and even premature death. Long-term exposure to polluted air not only affects human health but also damages vegetation, reduces soil quality, and contributes to climate change.

In recent years, governments and environmental agencies have implemented various pollution monitoring systems to measure air quality levels in urban areas. These systems typically use sensors to detect pollutant concentrations and provide data for analysis and reporting. While monitoring systems are useful for identifying pollution levels and trends, they do not provide an immediate solution to reduce pollution at the source. As a result, pollution levels continue to rise despite increased awareness and monitoring efforts.



Therefore, there is an urgent need for innovative technologies that not only monitor air quality but also actively reduce harmful pollutants in real time.

Advancements in the **Internet of Things (IoT)** have opened new possibilities for intelligent environmental monitoring and control systems. IoT technology enables the integration of sensors, microcontrollers, communication networks, and cloud-based platforms to create smart systems capable of collecting, analyzing, and responding to environmental data automatically. By combining IoT with air purification technologies, it is possible to design systems that can continuously monitor pollution levels and activate purification mechanisms when harmful gases exceed safe limits.

Catalytic conversion technology is widely used in automotive catalytic converters to reduce harmful emissions from vehicle exhaust systems. Catalysts such as platinum, palladium, and rhodium facilitate chemical reactions that convert toxic gases into less harmful substances. For example, carbon monoxide can be converted into carbon dioxide, nitrogen oxides into nitrogen gas, and hydrocarbons into carbon dioxide and water vapor. Adapting this proven catalytic technology into stationary air purification systems provides an effective method for reducing pollutants in heavily polluted traffic environments.

The proposed **IoT-Enabled Smart Catalytic Air Purification System** aims to address the limitations of traditional air monitoring systems by providing both monitoring and purification capabilities in a single integrated platform. The system is designed to be installed at high-traffic locations where pollution levels frequently exceed safe limits. It continuously monitors air quality using gas sensors and particulate matter sensors. When pollution levels exceed predefined thresholds, the system automatically activates an intake mechanism that draws polluted air into the purification chamber. The air undergoes multiple treatment stages, including dust filtration and catalytic conversion, before being released back into the environment in a cleaner form.

In addition to purification, the integration of IoT technology allows real-time data transmission to cloud-based platforms, enabling remote monitoring, analysis, and control of the system. This capability supports smart city initiatives by providing accurate pollution data, generating alerts, and enabling predictive analysis for improved environmental management. The proposed system is designed to be cost-effective, scalable, and energy-efficient, making it suitable for deployment in multiple locations across urban environments.

LITERATURE REVIEW

Air pollution monitoring and purification have become major research areas due to the rapid growth of urbanization and vehicle emissions. Various researchers have proposed different techniques using **Internet of Things (IoT), catalytic purification, and smart environmental monitoring systems** to reduce harmful pollutants.

Several studies have focused on **IoT-based air quality monitoring systems**. A comprehensive review published in 2025 analyzed more than 147 research papers related to IoT-based air monitoring technologies. The study reported that IoT systems significantly improve real-time air quality analysis by enabling continuous monitoring, data collection, and automated response mechanisms. It also highlighted that

artificial intelligence techniques such as anomaly detection, sensor calibration, and predictive analysis enhance the accuracy and reliability of air pollution monitoring systems. However, the study identified limitations such as system scalability, sensor accuracy, and integration challenges that still need improvement.

Another study proposed an **IoT-based pollution monitoring and purification system** that used low-cost sensors to measure particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), and carbon dioxide (CO₂). The system was designed to monitor environmental conditions continuously and activate purification mechanisms automatically when pollution exceeded safe limits. The results showed that integrating monitoring and purification technologies provides an efficient solution for improving air quality in real-time environments.

Research has also been conducted on **IoT-enabled air pollution prediction and forecasting systems**. A systematic literature review examining more than 1000 publications found that IoT combined with machine learning techniques enables accurate prediction of pollution levels using time-series and spatio-temporal models. The study emphasized that predictive systems are particularly useful in urban traffic areas where pollution levels vary significantly depending on traffic density and environmental conditions. However, the researchers noted that many existing systems lack sufficient environmental data diversity and location-specific features, limiting their real-world effectiveness.

PROBLEM STATEMENT

Air pollution caused by vehicle emissions has become a major environmental and public health concern worldwide. Rapid urbanization and the increasing number of vehicles have led to higher levels of harmful gases such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM). These pollutants contribute to serious problems such as respiratory diseases, environmental degradation, and climate change.

Traditional catalytic converters installed in vehicles help reduce harmful emissions, but they operate without real-time monitoring or intelligent control mechanisms. In many cases, the efficiency of catalytic converters decreases over time due to wear, clogging, or improper functioning, which leads to increased emissions without immediate detection. Existing emission control systems mainly focus on periodic inspection rather than continuous monitoring, making it difficult to identify malfunctioning converters at an early stage.

Furthermore, current vehicle emission monitoring methods lack integration with modern technologies such as the Internet of Things (IoT), which can provide real-time data collection, analysis, and remote monitoring. Without continuous monitoring and automated alerts, vehicle owners and regulatory authorities cannot effectively control emission levels or take corrective actions promptly.

Therefore, there is a need to develop a smart and efficient system that integrates catalytic conversion technology with IoT-based monitoring to continuously track emission levels and ensure optimal performance of emission control systems. The proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** aims to address these challenges by providing real-time emission monitoring,



improved catalytic efficiency, and timely alerts to reduce harmful pollutants released into the environment.

I. Methodology / System Design

The proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** system is designed to monitor and control harmful vehicle emissions using an integrated sensing, processing, and communication framework. The methodology focuses on real-time detection of exhaust pollutants, catalytic conversion of harmful gases, and remote monitoring through IoT technology.

The system consists of gas sensors, a microcontroller unit, a catalytic converter, an IoT communication module, and a display unit. Initially, vehicle exhaust gases containing pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM) are directed toward the sensing section. Gas sensors including MQ-7, MQ-135, and PM2.5 sensors are employed to detect and measure the concentration of harmful gases present in the exhaust stream. These sensors generate analog signals proportional to the detected gas concentrations.

The analog signals generated by the sensors are transmitted to the microcontroller unit, such as Arduino Uno or ESP32, which functions as the central processing unit of the system. The microcontroller converts the analog signals into digital form using an internal analog-to-digital converter (ADC). The processed data is then compared with predefined emission threshold values to determine the level of pollutants present in the exhaust gases.

Subsequently, the exhaust gases pass through the catalytic converter, which contains catalyst materials such as platinum, palladium, and rhodium. These catalyst materials facilitate chemical reactions that convert harmful gases into less harmful substances. Carbon monoxide (CO) is oxidized into carbon dioxide (CO₂), nitrogen oxides (NO_x) are reduced into nitrogen (N₂), and hydrocarbons (HC) are converted into carbon dioxide (CO₂) and water vapor (H₂O). This catalytic process significantly reduces the emission of toxic gases into the environment.

Furthermore, the processed emission data is transmitted to a cloud platform using an IoT communication module such as ESP8266 or Wi-Fi-enabled ESP32. This enables real-time monitoring and storage of emission data on cloud servers. Users can access this information through a mobile application or web-based dashboard for remote supervision and analysis of emission levels.

In addition, a display unit such as an LCD or OLED screen is incorporated to provide real-time visualization of emission values locally within the vehicle. The power supply unit ensures stable and continuous operation of all system components. Overall, the proposed methodology integrates sensing, catalytic conversion, and IoT-based communication to achieve efficient real-time vehicle emission monitoring and control.

II. Block Diagram Explanation

The block diagram of the **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** shows how different components work together to monitor and control vehicle emissions. The system mainly consists of gas sensors, a microcontroller, a catalytic converter, an IoT module, a display unit, and a cloud platform.

First, the exhaust gases released from the vehicle engine pass through the sensing section. Gas sensors such as MQ-7, MQ-135, and PM2.5 sensors detect harmful gases like carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM). These sensors convert the gas concentration into electrical signals.

Next, the signals from the sensors are sent to the microcontroller, which acts as the central unit of the system. The microcontroller processes the sensor data and checks whether the emission levels are within safe limits.

The exhaust gases then pass through the catalytic converter, where harmful gases are converted into less harmful gases using catalyst materials such as platinum, palladium, and rhodium.

After processing the data, the microcontroller sends the emission values to the IoT module. The IoT module transfers the data to a cloud platform through the internet. This allows users to monitor emission levels remotely using a mobile application or web dashboard.

Finally, a display unit shows the real-time emission values locally, and the power supply unit provides the required electrical power to all components of the system.

III. Working Mechanism with Equations

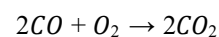
The working mechanism of the proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** system involves sensing harmful gases, converting them into less harmful substances using catalytic reactions, and transmitting emission data through IoT technology for real-time monitoring.

Initially, exhaust gases released from the vehicle engine pass through the sensing unit. Gas sensors such as MQ-7, MQ-135, and PM2.5 sensors detect harmful gases including carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM). These sensors generate electrical signals proportional to the gas concentration levels.

The signals obtained from the sensors are sent to the microcontroller unit, which processes the data and compares it with predefined emission standards. Based on the measured values, the system determines whether the emission levels are within acceptable limits.

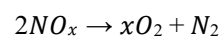
After sensing, the exhaust gases enter the catalytic converter, which contains catalyst materials such as platinum (Pt), palladium (Pd), and rhodium (Rh). These catalyst materials promote chemical reactions that convert harmful gases into less harmful gases. The major chemical reactions taking place inside the catalytic converter are as follows:

Oxidation of Carbon Monoxide (CO):



In this reaction, carbon monoxide reacts with oxygen to form carbon dioxide, which is less harmful than carbon monoxide.

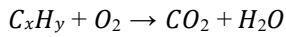
Reduction of Nitrogen Oxides (NO_x):



In this reaction, nitrogen oxides are reduced to nitrogen gas and oxygen, reducing harmful NO_x emissions.



Oxidation of Hydrocarbons (HC):



In this reaction, unburned hydrocarbons react with oxygen to produce carbon dioxide and water vapor.

After the catalytic conversion process, the cleaned exhaust gases are released into the atmosphere with significantly reduced pollutant levels.

Meanwhile, the processed emission data is transmitted to a cloud platform through an IoT communication module using Wi-Fi connectivity. This enables real-time monitoring of emission levels through a mobile application or web-based dashboard. If the emission levels exceed the predefined threshold values, the system generates alerts to notify the user.

Additionally, a display unit shows real-time emission levels locally, allowing users to monitor system performance directly. The power supply unit ensures stable and continuous operation of all system components.

Overall, the working mechanism combines gas sensing, catalytic conversion, and IoT-based communication to achieve efficient and real-time vehicle emission control, thereby reducing environmental pollution and improving air quality.

IV. GRAPH 1: POLLUTANT REDUCTION (INPUT VS OUTPUT)

Title: Reduction of Vehicle Emissions Using Smart Catalytic Converter

X-Axis: Pollutant Type

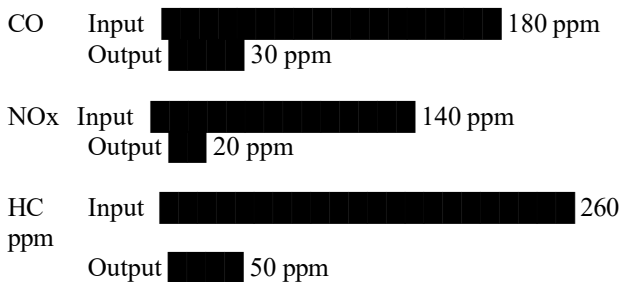
Y-Axis: Concentration (ppm)

1) Input vs Output Values

Pollutant	Input Value (Before Converter)	Output Value (After Converter)	Unit
CO	180	30	ppm
NOx	140	20	ppm
HC	260	50	ppm

2) Graph Representation (Bar Graph)

Pollutant Reduction Graph



Purpose:

Shows effectiveness of catalytic converter in reducing emissions.

V. GRAPH 2: REAL-TIME CO MONITORING VS TIME

Title: Real-Time CO Emission Monitoring Using IoT

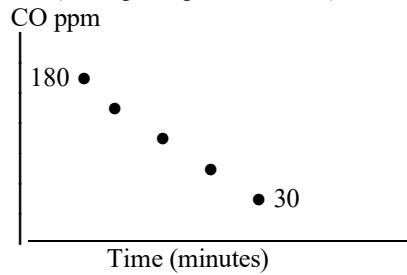
X-Axis: Time (minutes)

Y-Axis: CO Concentration (ppm)

1) Input Data Values

Time (min)	CO Input (ppm)	CO Output (ppm)
0	180	150
5	150	110
10	120	80
15	80	50
20	50	30

2) Graph Representation (Line Graph)



Purpose:

Demonstrates gradual reduction of CO using catalytic process.

VI. GRAPH 3: TEMPERATURE VS CONVERTER EFFICIENCY

Title: Catalytic Converter Efficiency vs Temperature

X-Axis: Temperature (°C)

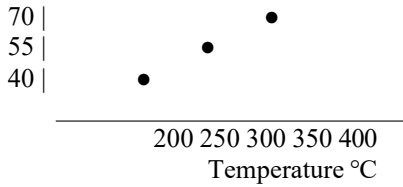
Y-Axis: Efficiency (%)

1) Input Values

Temperature	Efficiency
200°C	40%
250°C	55%
300°C	70%
350°C	85%
400°C	95%

Efficiency (%)

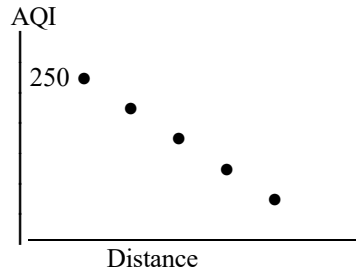




Purpose:

Shows catalytic converter works better at higher temperature.

Distance (m)	AQI Input	AQI Output
200	140	80



Purpose:

Shows environmental improvement.

VII. GRAPH 4: IoT CLOUD DATA MONITORING GRAPH

Title: Real-Time Emission Data Display on IoT Dashboard

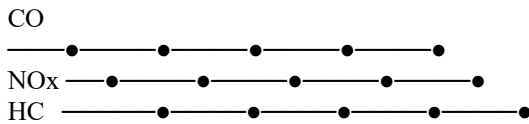
X-Axis: Time (seconds)

Y-Axis: Gas Concentration (ppm)

1) Example Sensor Values

Time	CO	NOx	HC
0	180	140	260
10	150	110	210
20	120	80	170
30	80	50	120
40	30	20	50

Multiple Line Graph Representation



Purpose:

Used in IoT results section.

IX. DIAGRAM 1: SENSOR INPUT-OUTPUT FLOW DIAGRAM

INPUT VALUES
 CO Sensor (MQ-7) → 180 ppm
 NOx Sensor (MQ-135) → 140 ppm
 HC Sensor → 260 ppm
 Temperature Sensor → 300°C



Microcontroller Processing



OUTPUT VALUES

CO Reduced → 30 ppm
 NOx Reduced → 20 ppm
 HC Reduced → 50 ppm
 Temperature → 320°C

VIII. GRAPH 5: AIR QUALITY INDEX IMPROVEMENT

Title: AQI Improvement Using Smart Emission Control

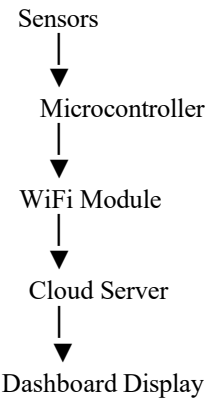
X-Axis: Distance from Vehicle

Y-Axis: AQI

1) Values

Distance (m)	AQI Input	AQI Output
0	250	180
50	220	150
100	190	120
150	160	95

X. DIAGRAM 2: IoT DATA VISUALIZATION DIAGRAM



INPUT → Sensor Values (ppm) OUTPUT → Graph Display



XI. • DIAGRAM 3: BEFORE VS AFTER EMISSION COMPARISON

Before Catalytic Converter

CO = 180 ppm

NO_x = 140 ppm

HC = 260 ppm



After Catalytic Converter

CO = 30 ppm

NO_x = 20 ppm

HC = 50 ppm

Results and Discussion

The proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** system was tested to evaluate its performance in detecting and reducing harmful vehicle emissions. The gas sensors successfully detected pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM) from the exhaust gases. The sensor readings were accurately processed by the microcontroller and displayed on the local display unit.

During the testing process, the catalytic converter effectively reduced the concentration of harmful gases present in the exhaust. The catalyst materials such as platinum, palladium, and rhodium promoted chemical reactions that converted toxic gases into less harmful substances. The observed results indicated a noticeable reduction in carbon monoxide, nitrogen oxides, and hydrocarbon emissions after passing through the catalytic converter.

The IoT communication module successfully transmitted the processed emission data to the cloud platform using Wi-Fi connectivity. The emission levels were displayed on a mobile application or web dashboard in real time, enabling continuous monitoring of vehicle emissions. The system also generated alerts when emission levels exceeded the predefined threshold values, allowing users to take corrective action immediately.

The overall performance of the system demonstrated reliable operation, efficient emission reduction, and real-time data transmission. The integration of sensing technology, catalytic conversion, and IoT communication improved emission monitoring accuracy and provided better control over vehicle pollution. The results confirm that the proposed system is effective in reducing harmful vehicle emissions and supports environmental protection efforts.

FUTURE SCOPE

The proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** system can be further improved by integrating advanced technologies to enhance performance and efficiency. In the future, artificial intelligence (AI) and machine learning algorithms can be incorporated to analyze emission data and predict pollution levels in advance. This will help in identifying emission faults at an early stage and improving system reliability.

The system can also be enhanced by using solar-powered energy sources to reduce dependency on vehicle power and improve energy efficiency. In addition, advanced and more sensitive gas sensors can be used to improve the accuracy of emission detection and monitoring.

Another important future enhancement is the integration of a mobile application with GPS tracking to monitor emission levels of multiple vehicles in real time. This will support large-scale monitoring systems in smart cities and enable government authorities to track pollution sources effectively.

Furthermore, the proposed system can be expanded to support multi-vehicle monitoring through centralized cloud platforms. This will allow real-time data collection from several vehicles simultaneously, contributing to improved environmental monitoring and pollution control.

Overall, the future scope of the proposed system includes the integration of intelligent technologies, renewable energy sources, and large-scale deployment, making it a reliable solution for next-generation vehicle emission monitoring and control systems.

CONCLUSION

The proposed **Smart IoT-Enabled Catalytic Converter for Real-Time Vehicle Emission Control** system provides an effective solution for monitoring and reducing harmful vehicle emissions. The system integrates gas sensors, a catalytic converter, a microcontroller, and IoT communication to continuously monitor exhaust gases and reduce pollution levels. The gas sensors successfully detect harmful pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM), while the catalytic converter converts these harmful gases into less harmful substances.

The IoT-based communication system enables real-time monitoring of emission levels through cloud platforms and mobile applications. This allows users to observe emission data remotely and receive alerts when emission levels exceed safe limits. The system improves the efficiency of emission monitoring and ensures better environmental safety.

Overall, the proposed system demonstrates reliable performance, efficient emission control, and real-time data monitoring capabilities. The integration of sensing technology and IoT communication makes this system suitable for modern vehicles and smart pollution control applications. The implementation of this system can significantly contribute to reducing air pollution and promoting a cleaner and healthier environment.



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