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An Exhaust Gas Analysis from Two-Wheeler: A Review

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Abstract **- Urban air pollution from transportation, especially two-wheelers, is a growing concern in metropolitan areas of developing countries such as India. This review, titled An Exhaust Gas Analysis from Two-Wheeler: A Review, synthesizes recent literature on emission measurement techniques, advances in internal combustion engine exhaust gas analyzers, and the role of alternative fuels. It examines conventional and modern emission-measuring devices, including wireless sensor implementations and Internet of Things enabled systems that provide real-time remote monitoring. The review also surveys studies on biodiesel and ethanol blends in two-wheeler engines, assessing their impacts on regulated pollutants and overall exhaust characteristics. Comparative analysis highlights strengths and limitations of existing instruments and identifies gaps where newer sensing technologies and data-access methods can improve accuracy and accessibility. Based on the literature synthesis, the paper defines clear objectives for future research: standardizing measurement protocols, integrating low-cost IoT sensors for urban monitoring, and evaluating biofuel strategies to reduce emissions. The review aims to guide researchers and policymakers toward effective mitigation of transport-related air pollution.**

Keywords **-** Gas Analysis, Carbon Mono-oxide Carbon-Dioxide, Hydrocarbon

1. Introduction

During the 1920s an efficient engine came into the picture. Soon after that, the engines gained enormous popularity because of its less use of volatile inflammable fuel. After World War II there were plenty of changes in financial development, population development, running toward urban development, and prompted to more dependence on individual vehicles for transportation by the closing of some major transit systems. The number of cars and trucks in the United States expanded significantly. One consequence of the quick increment of engine vehicles was air pollution that leads to damage of public health and environment [1].

Interestingly since 1979, surface transportation system has the highest amount of carbon pollution released into the atmosphere in about a span of 12-months than any other sector. Roughly 85 percent of these emissions are identified with the surface transportation systems in federal highways, public roads, and so forth [2]. This happens because of overreliance on the single-occupant vehicle rather than public transportation, carbon emission from single occupant vehicle surpassed any other mode of transportation. A single passenger vehicle per mile produces 50 percent more carbon dioxide than buses. From a report by ICF International says that using public transportation not only save 4800 pounds of carbon dioxide, but it also saves a $6,251 annually which is an average two-persons spent on households. And from a survey conducted by American public transport

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association, the number of trips taken on U.S. Public Transportation in 2014 increased to a record level of 10.8 billion and this was the highest annual ridership in 58 years [3]. Now a new history is created by drastically adopting to public transit buses, this brings up new challenges to control pollution other than carbon dioxide (CO_2) and hydrocarbons (HC) from gasoline engines. These diesel engine buses are now the dominant source of nitrogen oxide (NOx) and particulate matter (PM) emissions. Automotive exhaust emissions are the major source of air pollution. Automobiles are the culprits for the major amount of air pollution in urban areas was identified in California during the 1950s. Prof. Hazen Smith for the first time identified the cause of famous Los Angeles 'Photochemical Smog' which was due to the vehicular emission of HC and NOx that formed a brown haze above the ground level in the Los Angeles area [4].

After an increase in commuters using public transit buses, all the attention is on the air pollution caused by these buses. "In 2004, almost a quarter of carbon dioxide emission is from transport vehicles. Whereas three-quarters of transport-related emissions are from road traffic"[5]. The pollution caused by conventional road transport are reported high in cities which face several traffic congestions. The major pollutants emitted into the atmosphere by these public transport buses are particulate matter of different size fractions (PM10 and PM25), carbon monoxide (CO), nitrogen oxide, carbon dioxide and sulfur dioxide (SO_2). There is no guaranty that all combustion engines produce all the above listed pollutants, but some engines in combustion mode react with other particles in the air and caused a massive drawback of human health[6].

The standards, which were initially implemented in 2000, were based on European regulations. Since then, increasingly strict standards have been implemented. Following the adoption of the laws, all new automobiles must comply with the rules. Bharat Stage (BS) III regulations have been in effect nationwide since October 2010. Bharat Stage IV emission regulations have been in effect since April 2010 in 13 major cities and from April 2017 throughout the whole nation. The Indian government declared in 2016 that BS VI standards will replace BS V standards completely by 2020. The Supreme Court has ruled that starting on April 1, 2020, no motor vehicles meeting the Bharat Stage IV pollution standard may be sold or registered in the whole nation [7].

The Petroleum Ministry of India agreed to forward the implementation date of BS VI grade car fuels in the National Capital Territory of Delhi with effect from 1 April 2018 rather than 1 April 2020 on November 15, 2017, after consulting with public oil marketing corporations. In reality, OMCs under the Petroleum Ministry were requested to investigate the potential of introducing BS VI vehicle fuels over the whole NCR region as of 1 April 2019. This significant action was made as a result of Delhi's severe air pollution issue, which got worse around 2019. The vehicle firms, who had planned the development in accordance with a roadmap for 2020, reacted angrily to the decision.

The Mashelkar committee's report was adopted by the government of India in 2002. The committee suggested a timeline for India's implementation of emission standards based on the Euro standard. Future rules should be introduced gradually, first in big cities and then spreading to rest of the nation after a certain amount of time [8].

The committee's suggestions led to the formal announcement of the National Auto Fuel Strategy in 2003. The Bharat stage regulations were to be implemented according to a schedule that was set till 2010. The programme also established rules for automobile fuels, reduced emissions from antiquated cars, and research and development for the collection of air quality data and the management of health [7].

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Table 1. Bharat Stage Norms[10]

Sr. No.	Stage	Year	Implementation
1	Mass Emission Norms	1991	For petrol and Diesel vehicles
2	Revision of Mass Emission Norms	1996	Fitment of Catalytic Converter was made mandatory in vehicles sold in metros
3	BS-I	2000	Adopts New norms as per international Euro-I emission norms
4	BS-II	2005	First Implement in three metro city and then apply nationwide
5	BS-III	2010	First Implement in 11 cities and then apply nationwide
6	BS-IV	2017	The Sulphur content in the fuels were brought down by 100 ppm and 300 ppm in petrol and diesel resp.
7	BS-VI	2020	NOx emission brought down by 68% in diesel and 25% in petrol vehicles

Air pollution has become a major problem on a worldwide scale, which has increased interest in environmentally friendly alternative fuels. Alternative energy sources are also increasingly becoming an inescapable option for internal combustion engines as a result of depleting petroleum supplies and rising air pollution. Since the development of the vehicle, alcohol has been advocated as an engine fuel. Alcohols do have significant drawbacks, however, including a difficult manufacturing process and other characteristics that make them unsuitable for engines.

Among the many alcohols, ethanol is widely recognized as a fuel, most suitable for the spark-ignition (SI) engines. A most notable characteristics of ethanol as a fuel for SI engines are its high fast flame, higher thermal efficiency, and octane number because of its increasing compression ratio [11]. Ethanol may be utilised in SI engines either in its pure form or blended with gasoline. While using ethanol in its pure form requires only minor adjustments to the engine design and fuel system, it may be utilised in SI engines at a low concentrations by blending it with gasoline. According to some reports, employing ethanol-gasoline mixes with modest quantities of ethanol might enhance exhaust emissions and engine performance [12].

Due to the gasoline crisis, ethanol was recognised as alternative fuel in the 1970s. However, owing to the engine operation and accessibility of supply, fossil fuel has been the predominant form of transportation since the development of vehicle engines. Compared to alcohol fuels, petroleum fuel has a lower octane number and produces much more harmful emissions. In addition, environmental contamination has been a bigger worry in recent years. As a result, ethanol fuel is becoming more popular as an alternative fuel [13].

2. Literature Review

This introduces a focused literature review that surveys technologies and fuel strategies relevant to two-wheeler exhaust analysis. It begins with studies on RFID-based approaches for vehicle identification and data logging, then examines gas sensor technologies used for detecting CO, CO_2, NOx, and hydrocarbons. The review synthesizes advances in exhaust gas analyzers, including portable and IoT-enabled systems that enable real-time, wireless monitoring in urban environments. A dedicated subsection evaluates biodiesel and ethanol blends, summarizing their reported effects on regulated emissions and engine performance. For each topic, the literature is assessed for measurement methods, sensor accuracy, deployment challenges, and applicability to metropolitan monitoring in developing countries. Gaps identified include standardization of protocols, low-cost sensor validation, and integration of identification and sensing platforms. The review frames these findings to define research objectives and guide subsequent experimental design and technology selection for two-wheeler emission assessment. This synthesis informs policy and practical implementation strategies.

A. Literature Survey Based on RFID Technology

Fouletier J. [14] they presented an IoT-based pollution monitoring system for autos in this paper. This device monitors the pollution produced by automobiles on the road in real time. The design of a system for monitoring pollution utilising a sensor, an Arduino, a smart phone, and mobile applications for presenting personalised air pollution information for each car is described in this work. They test the suggested method on real-world data and present some preliminary findings. They demonstrated a real-world experiment utilising sensors and a microcontroller to monitor air pollution on smart IoT devices. They compared our air pollution data to typical air quality values, demonstrating that our recommended strategy is effective.

Momenimovahed et al., [10] the research examined the creation of an IoT-based system for monitoring automobile emissions in support of the green revolution. An architecture of hardware as well as the software implementation are thoroughly detailed. IoT technology is also used to verify the system's performance. The clever intelligent environmental system that was built monitors the pollutants produced by automobiles and alerts vehicle owners to take action to reduce pollution. If a vehicle surpasses the permitted amount of pollution, a message is delivered to the vehicle owner informing them of the car's pollution level as well as the penalty for generating pollution. The data on pollution levels is also sent to a server for further study. Air pollution authorities can examine data and identify car registration numbers that contribute to increased atmospheric pollution. The designed system is easy-to-use, low-cost, and portable in nature. The created system outperforms the old method in terms of accuracy and cost.

Testing new procedures for emissions of exhaust measuring from traveller autos was presented by Vasic & Weilenmann [15]. The goal is to figure out what the true values of emissions are, which aren't usually represented in laboratory emissions levels. Although suitable and precise processes for assessing emissions in real traffic circumstances have not yet been certified, major research centres in Europe are presently analysing suggestions. There are several variations in the ideas, including how road emissions are calculated and research methods for hydrocarbon emission assessment. The findings of emissions testing are compared to the most recent regulation guidelines for passenger cars in this study. The findings are presented in the table below in relation to the measurement technique used: The EMROAD method, also known as the MAW method in the literature, determines the measurement windows and on that basis, determines the RDE test's road emission. During the RDE test, road emissions are assessed using a generalised approach of instantaneous power, often called as a CLEAR i.e. "Classification of Emissions from Automobiles in Real Driving".

Jaikumar et al. [16] offer an affordable nonlinear MPC based approach for integrated exhaust after treatment system and engine control in heavy-duty powertrain. The goals of control approach are also to increase fuel efficiency while remaining compliant with real driving emission rules based on work based window, required for heavy-duty vehicles by Euro VI emission standards. According to simulation data, approach constantly meets real driving emission limits. A nonlinear optimum control issue is designed for minimizing overall diesel fuel usage and AdBlue in order to fulfil real driving emission rules based on work based window. Defined optimum control issue involves limit on NOx emission to guarantee compliance with real driving emission standards, As a result, a mathematical model for forecasting the limit across the prediction horizon is also offered. Finally, in order to come up with real time implementable technique and a computationally efficient, the control problem has been divided into two sub problems. These two sub problems solve original nonlinear optimum control issue iteratively at each sample moment of the E-NMPC-based supervisory controller.

B. Literature Survey Based on Gas Sensor Technology

Ntziachristos et al. [17], In this system, the hydrocarbon, carbon monoxide, and nitrogen oxide amounts emitted from the exhaust are monitored by mq2, mq7, mq135 sensors mounted at the vehicle exhaust. The analogue value obtained from the sensors is analyzed by the Internet-connected Wi-Fi controller. The value of the sensors is displayed on LCD and cloud on an on-going basis. When the value obtained from the sensor exceeds the threshold limit, the controller alerts the user via the vehicle owner's LCD and database. Io T allows the computer to change the value of the cloud.

Agarwal et al. [18], the proposed system used in this paper consists of a microcontroller and a sensor to measure vehicle emissions in order to alert the government to monitor the AQI and to communicate emission related information through GSM. The proposed prototype system for monitoring and detecting the level of emissions of the individual vehicle and sending information to the Central pollution control board and RTO if the vehicle crosses the threshold limit. The present system capable of detecting nitrogen oxide (NO) and carbon monoxide (CO), Carbon oxide (Cox) by using gas sensors. Due to heat dissipation from exhaust emission, the sensors may be malfunctioned during working so that they placed it in the thermal Isolation Clip. The real-time data get collected in PIC microcontroller and data analyzed using C coding. While comparing data any deviation occurs then with the help of GSM and Information regarding GPS modules is transmitted to the nearest control station also to the driver with the help of LCD display.

Sakthivel et al. [19], the author suggested a vehicle monitoring system (VMS) consisting of different sensors, including O_3,NO_2, CO and PM2.5.The Given system provides data on pollution, smoke, vibrations, and also GPS signals by driving a vehicle(car, bus, etc.) on the street. Using IoT, the various parameters sensed by different sensors are registered and transmitted to a cloud server. The transmitted data is related to GPS location, weather parameters, information about the vehicle, and information about air quality. Based on transmitted data, Government agencies are easily takes decisions on traffic planning and on taking some steps to minimise emissions. For communication purposes, a system called LoRa, which is a transmission protocol, is used in VMS and is regulated by the LoRa Alliance. In this system MQ-131sensor is used to detect ozone, PM 2.5/10 sensor is used to detect particulate matter in exhaust emission of vehicle, MICS-4514 sensor is used to detect carbon monoxide and nitrogen oxide. The Sensor used in this system has a simplified drive circuit and long life, high sensitivity, wide range detection capacity.

C. Biodiesel

Based on the circumstances for utilising pure diesel and biofuel mixes to reduce engine emissions, researchers have utilised several ways to report on the diesel engines emissions. Numerous exhaust gas types, including carbon monoxide, sulphur dioxide, carbon dioxide, hydrocarbons, and nitrogen oxides (NOx) were discovered from a diesel engine. Type of fuel, engine load, cetane number, and engine speed are only a few examples of the variables that affect emissions.

a. Carbon monoxide (CO) emission

According to Chang et al. [20], when this ratio is quite low, the quantity of CO rises because there is less oxygen present to complete the combustion. In contrast, bioethanol and biodiesel with increased oxygen content would produce less carbon dioxide emissions. The oxygen content of biodiesel and bioethanol, respectively, is 12% and 35% greater than that of pure diesel. According to research by Mahesh et al. [21]on the effects of bioethanol and biodiesel on exhaust owing to varied engine functions. The emission of CO was much more correlated with characteristics of fuel than engine operating setups. In the other direction, the fuel content also contributes to gas emissions. For instance, the volume of CO rises as the amount of 1-pentanol and 1-butanol in a biodiesel mix increases because of greater latent heat of vaporisation and poor characteristics of ignition alcohols. Habib et al. [22] high latent heat of vaporisation and the poor ignition led to a fall in cylinder temperature, which in turn produced a loss in combustion characteristics and a rise in CO. Alternately, for a CI engine, fuel versions with various engine loads were studied.

High (above 80%), medium (40%-80%), and Small (0%-40%), were the three engine loadings. The analysis of the results reveals that the maximum quantity of CO emission from diesel fuel was found for medium and small loads. Due to high amount of oxygen concentration, the biofuel mix was shown to have lower CO emissions than diesel fuel at low and medium loads. Choudhary & Gokhale [23] one another research based on CO emissions from pure diesel, Fuel A (5% butanol, 5% ethanol, 30% biodiesel, and 60% diesel) and Fuel B (5% butanol, 5% ethanol, 50% biodiesel, and 40% diesel) was tested at full load.

It is obvious that Fuels A and B achieved reduced CO emissions compared to diesel emission. The finding is ascribed to Fuels A and B having greater oxygen concentrations than diesel, which supports the earlier debate on quick and complete combustion made by Maurya et al., [24].

Oxygenated fuel enhances fuel combustion and lowers diesel engine discharge, albeit this discharge is depending on engine load. When utilising oxygenated gasoline, however, carbon oxides are often reduced due to enhanced combustion discharge of thick gases. An emissions and accumulates inside the engine wall, rendering it inefficient and causing premature wear. Both fuel quality and engine design have an impact on CO2 emissions. The CO2 emissions of a DI engine operating at a full load, constant angle, and constant speed of 1500 rpm of diesel emissions reduced as volumetric fraction of ethanol fuel increases. When compared to diesel-ethanol blends, biodiesel-ethanol blends yielded reduced CO2 emissions [25]. Some critical qualities of a gasoline mix, such as lubricity, viscosity and pour point, are determined by density. The density of the fuel type utilised is linked to the warming quality and cetane number. The density of a certain mixture affects the atomisation of fuel and burning properties. The yield energy of a DI engine, as well as its burning quality, changes with the density of the mixture.

b. Emission of carbon dioxide (CO2)

Engine configuration and fuel quality both affect CO2 emissions in different ways. When biodiesel-ethanol (BE) and diesel-ethanol (DE) were used as fuel in a DI engine operating at the same 1500 rpm, constant angle of diesel injection and full load. The emission of CO2 showed that it reduced with increasing volumetric percentage for both fuels. Compared to ethanol-diesel, the ethanol-biodiesel blends generated less CO2 emissions, according to Barth & Boriboonsomsin,[26].

While the molecules of oxygenated ethanol-biodiesel fuel contain more H2O and less carbon, ethanol emits less carbon dioxide as a consequence. It confirms once further that BE gasoline emits less CO2 emissions than DE fuel. To determine the emission characteristics, a fuel mixture made up of 84% (by volume) diesel, 4.75% anhydrous ethanol, 11% biodiesel and 0.25% hydrous ethanol, was evaluated in a heavy-duty DI engine. The engine's particle exhaust demonstrates that the diesel-biodiesel mix generated less carbon dioxide (CO2) than standard diesel because the combustion process was improved by the greater oxygen content of the fuel, according to Tang et al. [27].

c. Emission of nitrogen oxides (NOx)

One of the primary pollutants from DI diesel engine is nitrogen oxides. This emission is a byproduct of the engine's combustion process, which involves the interaction of oxygen and nitrogen gases. The environment might be seriously impacted by this pollution. As a result, several studies have been conducted to determine how utilising biofuels might affect the reduction of this emission. The impact was examined using fuel blends that were a combination of fish oil-biodiesel and diesel at a 40–20% concentration. Additionally, 1% and 0.5% of ethanol by volume were added to two of these gasoline blends to raise their cetane numbers. The various fuel mixtures utilised in a DI engine running at a steady 1500 rpm with various engine loads. The findings demonstrate that as the amount of ethanol in the blends increased, the NOx emission trended downward. The reduction in ignition delay and combustion temperature brought about by the increase in ethanol content contributed to a reduction in NOx emissions. According to Vasa et al., [28] the NOx emission was found to drop by 4.5% and 3.7% when the ethanol volume increased in blends by 1% and 0.5%, respectively.

Another investigation into the maximum rotation and torque in different fuels (biodiesel-ethanol, biodiesel, diesel, and mixtures) in a Diesel engine reveals a thorough characteristic of emission. The mixes had ethanol content of 5%, 10%, and 15%, respectively. The results show that emission of NOx for diesel fuel rises with increasing engine load. Hexanol was thus added as a fuel additive to a fuel mix containing 45%, 35%, 25%, and 20% ethanol[29].

Other researchers carried out a separate investigation to look into the NOx emissions. It is clear that the diesel fuel's NOx emission is greater than that of the butanol blends. Due to the presence of extra oxygen in the blends, it was discovered that the NOx emission had reduced as the percentage of butanol rose. This finding is consistent with the previous research mentioned earlier, which found that adding more oxygen to biofuel blends improves combustion and lowers NOx emissions assist lower the combustion temperature since it has strong cooling properties [30].

d. Emission of hydrocarbon (HC)

Due to the many negative effects that HC emissions have on the environment, several research projects have been conducted to determine how utilising biofuels may help to lower these emissions. With an emphasis on the biodiesel's oxidation properties. Kuhns et al. [31] the outcome shown that the oxygen concentration in fuel mixes enhanced fuel oxidation, which led to a decrease in the quantity of HC emission. Furthermore, the high cetane number in biodiesel blends led to a shorter ignition delay and less hydrocarbon exhaust [32]. When using biodiesel mixes instead of pure diesel fuel, the results clearly demonstrate an improvement.

The quantity of cetane number grows together with the biodiesel volume in the blends, which has a good effect on lowering the emission of HC [32]. In a diesel blend containing 20% and 10% by volume of n-butanol, the lower cetane number caused a delay in ignition, which made the combustion unstable and increased the quantity of HC emission. This research establishes that the quantity of cetane number in the blends affects HC emission, with a higher cetane number enhancing engine ignition and reducing HC emission. A fuel mixture consisting of 10% surfactant, 40% ethanol, and 50% diesel had a similar outcome.

Another strategy included blending organic substances with biodiesel and testing the results using diesel fuel. One such method included adding diglyme to the biodiesel blends; as a consequence, it was discovered that the BTE was raised owing to the blends' higher oxygen content, which improved combustion. Diglyme is said to have increased the Cetane number and improved engine performance while lowering the temperature of the exhaust gas, even if it was still lower than that of pure diesel. The premixed combustion phase and ignition time were enhanced by this addition. As a result, the engine used less gasoline to provide the specified output and released less HC and CO; on the other hand, an increase in oxygen content caused an increase in NOx emissions.

3. Conclusions

This review synthesizes current knowledge on two-wheeler exhaust analysis, highlighting technological approaches, fuel strategies, and measurement challenges.

Key findings show that RFID and identification systems can streamline vehicle-level data collection, while modern gas sensor technologies especially when integrated with IoT enable low-cost, real-time monitoring of CO, CO_2, NOx, and HC. Advances in portable exhaust gas analyzers improve field applicability, but sensor accuracy and calibration remain critical constraints for reliable urban deployment. The assessment of biodiesel and ethanol blends indicates consistent reductions in hydrocarbon and carbon monoxide emissions, with mixed effects on carbon dioxide and a tendency for increased NOx under certain operating conditions. These trade-offs underscore the need for fuel specific calibration of measurement systems and for engine tuning strategies that minimize adverse NOx formation while preserving reductions in other pollutants. Practical implications include prioritizing standardized measurement protocols, validating low-cost sensors against reference analyzers, and combining identification (RFID) with sensing networks to map emissions spatially across metropolitan areas. Policymakers and urban planners can leverage IoT enabled monitoring to target hotspots and evaluate the real-world impact of biofuel adoption. Limitations of the reviewed literature include heterogeneous experimental conditions, limited long term field studies on two wheelers, and sparse data from many developing country urban contexts. To address these gaps, future research should focus on multi-site validation campaigns, lifecycle assessments of biofuels in two-wheeler fleets, and development of integrated platforms that fuse identification, sensing, and cloud analytics. In conclusion, combining robust sensor technology, standardized protocols, and targeted biofuel strategies offers a viable pathway to reduce two-wheeler emissions and improve urban air quality. Coordinated research, technology validation, and policy support are essential to translate these findings into measurable public health benefits.

REFERENCES

[1] P. Trefz *et al.*, "Continuous real time breath gas monitoring in the clinical environment by proton-transfer-reaction-time-of-flight-mass spectrometry," *Anal. Chem.*, vol. 85, no. 21, pp. 10321–10329, 2013.

[2] D. J. Butcher, "The real-time analysis of gases by direct sampling–mass spectrometry: elemental and molecular applications," *Microchem. J.*, vol. 66, no. 1–3, pp. 55–72, 2000.

[3] A. J. Ward *et al.*, "Real time monitoring of a biogas digester with gas chromatography, near-infrared spectroscopy, and membrane-inlet mass spectrometry," *Bioresour. Technol.*, vol. 102, no. 5, pp. 4098–4103, 2011.

[4] R. S. Pilling *et al.*, "Quantifying gas sensor and delivery system response time using GC/MS," *Sensors Actuators B Chem.*, vol. 96, no. 1–2, pp. 200–214, 2003.

[5] H. Kopetz, *Real-time systems: design principles for distributed embedded applications*. Springer, 1997.

[6] M. Kumar *et al.*, "Healthcare Internet of Things (H-IoT): Current Trends, Future Prospects, Applications, Challenges, and Security Issues," 2023. doi: 10.3390/electronics12092050.

[7] R. Kitchin, "The real-time city? Big data and smart urbanism," *GeoJournal*, vol. 79, no. 1, pp. 1–14, 2014.

[8] M. Vajedi, A. Taghavipour, N. L. Azad, and J. McPhee, "A comparative analysis of route-based power management strategies for real-time application in plug-in hybrid electric vehicles," in *2014 American Control Conference*, IEEE, 2014, pp. 2612–2617.

[9] S. C. Terry, J. H. Jerman, and J. B. Angell, "A gas chromatographic air analyzer fabricated on a silicon wafer," *IEEE Trans. Electron Devices*, vol. 26, no. 12, pp. 1880–1886, 1979.

[10] A. Momenimovahed *et al.*, "Real-time driving cycle measurements of ultrafine particle emissions from two wheelers and comparison with passenger cars," *Int. J. Automot. Technol.*, vol. 15, no. 7, pp. 1053–1061, 2014.

[11] K. B. Ariyur and M. Krstic, *Real-time optimization by extremum-seeking control*. John Wiley & Sons, 2003.

[12] G. C. Walsh, H. Ye, and L. G. Bushnell, "Stability analysis of networked control systems," *IEEE Trans. Control Syst. Technol.*, vol. 10, no. 3, pp. 438–446, 2002.

[13] A. Fuentes, S. Yoon, S. C. Kim, and D. S. Park, "A robust deep-learning-based detector for real-time tomato plant diseases and pests recognition," *Sensors*, vol. 17, no. 9, p. 2022, 2017.

[14] J. Fouletier, "Gas analysis with potentiometric sensors. A review," *Sensors and Actuators*, vol. 3, pp. 295–314, 1982.

[15] A.-M. Vasic and M. Weilenmann, "Comparison of real-world emissions from two-wheelers and passenger cars," *Environ. Sci. Technol.*, vol. 40, no. 1, pp. 149–154, 2006.

[16] R. Jaikumar, S. M. S. Nagendra, and R. Sivanandan, "Modal analysis of real-time, real world vehicular exhaust emissions under heterogeneous traffic conditions," *Transp. Res. Part D Transp. Environ.*, vol. 54, pp. 397–409, 2017.

[17] L. Ntziachristos, A. Mamakos, Z. Samaras, A. Xanthopoulos, and E. Iakovou, "Emission control options for power two wheelers in Europe," *Atmos. Environ.*, vol. 40, no. 24, pp. 4547–4561, 2006.

[18] A. K. Agarwal, P. Bothra, T. Gupta, and P. C. Shukla, "An evaluation of the emission profile for two-wheelers at a traffic junction," *Particuology*, vol. 18, pp. 112–119, 2015.

[19] B. Sakthivel, R. Sridhar, S. Ansh, B. Srinivasan, and J. S. Kumar, "Development of cost effective smart engine management system for two wheeler application," *SAE Int. J. Engines*, vol. 10, no. 2017-26–0138, pp. 95–103, 2017.

[20] X. Chang, B. Y. Chen, Q. Li, X. Cui, L. Tang, and C. Liu, "Estimating real-time traffic carbon dioxide emissions based on intelligent transportation system technologies," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 469–479, 2012.

[21] S. Mahesh, G. Ramadurai, and S. M. S. Nagendra, "Real-world emissions of gaseous pollutants from diesel passenger cars using portable emission measurement systems," *Sustain. Cities Soc.*, vol. 41, pp. 104–113, 2018.

[22] G. Habib, A. Kumar, A. Sharma, and M. Haider, "On-road emissions of CO, CO2 and NOX from four wheeler and emission estimates for Delhi," *J. Environ. Sci.*, vol. 53, pp. 39–47, 2017.

[23] A. Choudhary and S. Gokhale, "Urban real-world driving traffic emissions during interruption and congestion," *Transp. Res. Part D Transp. Environ.*, vol. 43, pp. 59–70, 2016.

[24] K. Maurya, M. Singh, and N. Jain, "Real time vehicle tracking system using GSM and GPS technology-an anti-theft tracking system," *Int. J. Electron. Comput. Sci. Eng.*, vol. 1, no. 3, pp. 1103–1107, 2012.

[25] L. M. Bergasa, J. Nuevo, M. A. Sotelo, R. Barea, and M. E. Lopez, "Real-time system for monitoring driver vigilance," *IEEE Trans. Intell. Transp. Syst.*, vol. 7, no. 1, pp. 63–77, 2006.

[26] M. Barth and K. Boriboonsomsin, "Energy and emissions impacts of a freeway-based dynamic eco-driving system," *Transp. Res. Part D Transp. Environ.*, vol. 14, no. 6, pp. 400–410, 2009.

[27] J. Tang *et al.*, "Carbon nanodots featuring efficient FRET for real-time monitoring of drug delivery and two-photon imaging," *Adv. Mater.*, vol. 25, no. 45, pp. 6569–6574, 2013.

[28] P. Vasa *et al.*, "Real-time observation of ultrafast Rabi oscillations between excitons and plasmons in metal nanostructures with J-aggregates," *Nat. Photonics*, vol. 7, no. 2, pp. 128–132, 2013.

[29] T. Logenthiran, D. Srinivasan, A. M. Khambadkone, and H. N. Aung, "Multiagent system for real-time operation of a microgrid in real-time digital simulator," *IEEE Trans. Smart Grid*, vol. 3, no. 2, pp. 925–933, 2012.

[30] J. Teizer, B. S. Allread, C. E. Fullerton, and J. Hinze, "Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system," *Autom. Constr.*, vol. 19, no. 5, pp. 630–640, 2010.

[31] H. Kuhns, V. Etyemezian, D. Landwehr, C. MacDougall, M. Pitchford, and M. Green, "Testing re-entrained aerosol kinetic emissions from roads: A new approach to infer silt loading on roadways," *Atmos. Environ.*, vol. 35, no. 16, pp. 2815–2825, 2001.

[32] M.-J. E. Salami, I. B. Tijani, and A. U. Jibia, "Development of real-time software interface for multicomponent transient signal analysis using Labview and Matlab," in *2011 4th International Conference on Mechatronics (ICOM)*, IEEE, 2011, pp. 1–5.