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Keywords: artificial intelligence, sustainability, vehicle retrofitting, OBD-II diagnostics, internet of things, predictive maintenance.

Classification: LCC Code: Q334

Language: English

Great Britain Journals Press

LJP Copyright ID: 975831
Print ISSN: 2514-863X
Online ISSN: 2514-8648

London Journal of Research in Computer Science & Technology

Volume 25 | Issue 3 | Compilation 1.0

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The transportation industry is a major contributor to carbon emissions, with internal combustion engines responsible for over 25% of the total. Despite advances and regulations encouraging the shift to electric vehicles, the transition from diesel engines remains slow, as expected. Many countries have heavily relied on diesel engines, which makes the switch to electric vehicles more difficult due to the higher costs of buying and replacing internal combustion engines with electric ones. Therefore, this report suggests a solution: retrofitting existing ICE vehicles with AI-powered sustainable vehicle monitoring systems. This upgrade involves installing sensors that work with OBD-II diagnostics to monitor emissions, fuel use, and driving habits in real time. Gathering this data aims to develop personalized, eco-friendly driving recommendations that help reduce overall emissions. This method provides a cost-effective, sustainable, and environmentally friendly alternative to high carbon emissions. It is also scalable, even in regions with limited financial resources.

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I. INTRODUCTION

Industrialization, which led to the growth of the transport industry, has led to an increased strain on the environment. This is because internal combustion engines in the transport industry contribute over 25% of the total pollution from carbon emissions. Urban settings primarily use internal combustion engines for transportation. But vehicles can be outfitted with sensors to monitor their status and create ways to limit and reduce their emissions. These suggestions need to monitor driving habits, emissions, and even fuel efficiency. Many regions, including the EU, have pushed for an electric future through the replacement of ICE with electric vehicles. However, not all countries and regions have the financial muscle to execute the transition. As it causes more questions than answers, it introduces more problems instead of solving the existing ones.

As a countermeasure, retrofitting the already existing vehicles with AI-driven and powered sensors and systems offers a more practical, scalable, and affordable solution that will fit all regions. This will involve putting sensors in internal combustion engines (ICE) that use AI and the Internet of Things (IoT) to monitor fuel use, emissions, and driving habits in real time, suggesting eco-friendly solutions that ultimately lower emissions to a manageable level. Strategy will be implemented through the installation of lowcost OBD-II diagnostics, enabling cars to reduce fuel consumption, reduce carbon emissions, and recommend sustainable and eco-friendly driving habits. The solution is, however, limited, as not enough research has been done on older model cars to ascertain that the same technology would present consistent results of reducing emissions even on old diesel engines.

This strategy leaves room for future studies to explore and ensure that credible research supports the approach. Therefore, the main objectives of the study are to develop a modern solution that is compatible with older technology, aiming to reduce carbon emissions, improve fuel efficiency, and enhance overall vehicle longevity by adjusting driving habits.

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II. LITERATURE REVIEW

The application of AI and IoT in internal combustion engines has unlocked new possibilities for sustainability, such as reductions in emissions, fuel monitoring, and intelligent driving systems that reduce both fuel consumption and carbon emissions. While this innovation presents a practical solution compared to the adoption of electric vehicles, which are often too expensive to implement, it still poses challenges regarding compatibility with older technologies in combustion engines [3]. To ensure the relevance and practicality of this technology, future research should be focused on traditional diesel engines to ensure they are all compatible with it, as they significantly contribute to emissions in the first place.

To begin with, OBD-II data collection and analytics have proven to be a cheaper and efficient way to monitor the fuel consumption and vehicle emissions in both theoretical research and practical field applications. OBD scanners and sensors detect anomalies such as engine load and throttle response, and they develop more sustainable fuel consumption strategies that significantly reduce emissions. The scanners can be controlled to ensure they control how fuel is burned inside the engine. When the fuel and air mixture burns rich, it leads to increased fuel consumption and carbon emissions due to the release of unburnt particles. As much as these strategies are effective, it is unfortunate that they are entirely reliant on modern technologies and vehicles that modern ECU systems allow the OBD scanners to interact with [5].

In contrast, AI and IoT operate in nearly identical ways. For instance, accelerometers and GPS data are used to detect driving dynamics such as harsh braking, acceleration, cornering, and even speeding. Such behavior implies that poor driving can significantly contribute to higher fuel consumption and, thus, carbon emissions [9].

Fleet management can leverage the same application in the Internet of Things. Sensors can be used to track real-time information, allowing fleet managers to adjust travel routes and even schedule maintenance based on the mechanical conditions of the vehicles. The gap remains; most of the vehicles that would have significantly benefited from this change are older diesel vehicles that do not support the ECU modifications and specifications required. However, this study still fills the gap in the literature, eliminating the higher cost of electric vehicles by modifying already existing vehicles to be more fuel efficient and carbon emissions-free.

III. SYSTEM ARCHITECTURE AND OVERVIEW

The study proposes a practical, comprehensive approach that considers the economic aspect of the transition. The system involves retrofitting existing internal combustion engines with intelligent sensors to enable real-time data tracking and monitoring of factors such as carbon emissions, fuel consumption, and driving habits. It leverages hardware components from current combustion engines, combined with AI and IoT technology, to collect and interpret data, which can then be used to suggest ways to reduce fuel use and carbon emissions.

3.1 OBD-II Interface

Most, if not all, vehicles from 1996 have the On-Board Diagnostics II port. This port allows real-time data access and interaction with the car when it comes to understanding factors such as engine load, throttle response, emissions, driving habits, and even fuel efficiency. With this live vehicle data, it's easy to identify issues causing higher emissions. A favorable example is when the car is burning more fuel due to an imbalance in the air-fuel mixture; the OBD will detect this error to prompt repair, as unburned fuel will be emitted as exhaust. The data collected can be used to reduce emissions significantly; unfortunately, they only apply to vehicles with modern ECUs, beyond 1996, omitting a significant number of vehicles that still contribute to pollution [7], [1]. To ensure the OBD port option offers credible data, more external sensors are required; these include GPS modules to track routes, elevation, and even travel speed. On top of that, accelerometers and gyroscopes can be used to observe how the car takes corners, rapid accelerations, and even harsh braking, which can all have a significant impact on the overall carbon emissions for the vehicle. Lastly, sensors are also placed in the fuel lines to track how the car consumes fuel [3], [4]. The sensors can also examine pollutants in the fuel line and exhaust to determine how much of the carbon emissions end up in the environment, as modern cars are equipped with technologies that allow them to filter their exhaust gases before they are released into the air.

3.2 Functional Modules

Several modules work together to ensure that the final result is comprehensive and capable of making a real change in the world. For instance, when it comes to emission monitoring, the external sensors placed in exhaust and fuel lines will be able to pick up poor combustion, faulty sensors, and even overdue maintenance. Tracking fuel usage is another important focus, achieved by gathering and studying data on how the throttle responds and the engine's workload to determine the best operating values for the car and identify any problems. Human error and ignorance significantly contribute to pollution, which is why it is important to analyze driver behavior and driving habits. The sensors and machines can detect harsh accelerations, braking, and speeding, which result in fuel wastage and increased carbon emissions. Other functional modules include GPS-based route optimization, which helps drivers take faster and less congested routes that reduce carbon emissions while waiting at traffic jams and intersections [4]. The same principle applies to sensors that detect errors in the engine's optimal performance, identifying issues such as misfiring, faulty sensors, and clogged injectors, which lead to increased fuel consumption and emissions.

IV. METHODOLOGY

4.1 Data Collection

To develop and evaluate the performance and practicality of the proposed solutions, a dataset was collected, sampling 50 retrofit internal combustion engine vehicles of different sizes over a period of 90 days. The vehicles included both petrol and diesel engines, passenger cars, mid-size sedans, and even heavy commercial vehicles for 30 days. The diverse data set is to ensure that nothing is overlooked. Each of the studied vehicles was equipped with an OBD-II dongle, an ESP32 microcontroller, and a suite of external sensors, including a GPS, an accelerometer, and gas sensors. The OBD II scanners recorded RPS, throttle position, engine load, air intake temperature, coolant temperature, and fuel trim. On the other hand, the GPS collected locations, elevation, speed, and route mapping. The IMU collected acceleration, braking, and angular motion [5], [4]. Lastly, the gas sensors approximately measured the levels of CO_2 in the exhaust systems [10]. To ensure that all this data was accurate, manual logs of fuel refilling and service records were also kept to act as a control experiment, especially for service and fuel consumption texts.

4.2 Machine Learning Models and Algorithms

The following machine learning models were developed to extract the raw data and make sense out of it. The assessments are noted in the table below.

Table 1: OBD-II Interface

Use Case	Model Type	Input Features	Output	Performance
Emission Anomaly Detection	Random Forest Classifier	Engine load, RPM, fuel trim, gas sensor readings	Normal/ Anomalous	Accuracy: 92.7%
Fuel Efficiency Forecasting	Gradient Boosted Trees	Throttle %, speed, distance, elevation, fuel input	Fuel usage (L/100km)	RMSE: 0.47

Driver Behavior Classification	CNNRNN Hybrid	IMU + GPS time-series data	Aggressive/ Normal	F1-Score: 0.88
Maintenance Prediction	LSTM	Sensor trends over time (temp, RPM, DTCs)	Maintenance alert (Yes/No)	Precision: 90%

The study trained the models on about 70% of the dataset, with the remaining 30% used for validation to balance data among vehicle types based on their driving patterns. These models offered actionable recommendations from the collected data that can be applied at both personal and commercial levels, including fleet management, to reduce carbon emissions and improve drivers' behaviors that lead to higher fuel use and more pollution.

V. RESULTS AND DISCUSSION

5.1 Quantitative Results

The study included 50 vehicles that were retrofitted over 90 days. The vehicles had to be powered by internal combustion engines and operate in an urban environment. The AI-based monitoring systems installed in the vehicles provided measurable suggestions and strategies for increasing fuel efficiency and reducing carbon emissions. They also address the issue of poor driving habits, which contribute to increased pollution. The table below summarizes the study's findings.

Table 2: Findings

Metric	Baseline (PreRetrofit)	Post-Retrofit	Improvement
Avg. Fuel Efficiency	11.5	13.8	20.00%
CO_2 Emissions	170	138	-18.82%
Aggressive Driving Events	8.6	2.3	-73.26%
Maintenance Interventions	2.8	1.1	-60.71%

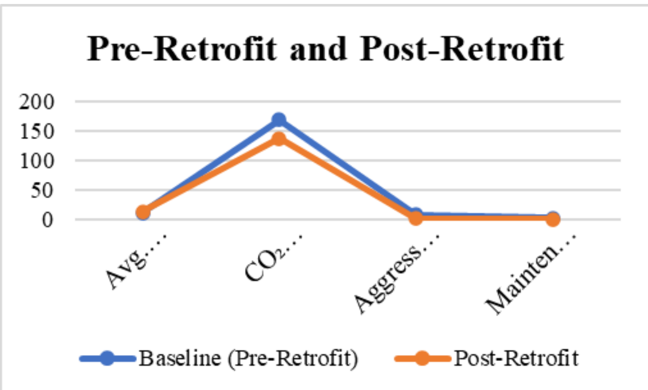

Figure 1: Pre-Retrofit and Post-Retrofit The data collection and analysis yielded the following results, which we discuss below: All of the tested vehicles saw a fuel efficiency increase of at least 20%, as represented in the calculations below: Fuel efficiency

$$\text{Fuel efficiency} = \frac{\text{old fuel usage} - \text{new fuel usage}}{\text{old fuel usage}} \times 100\%$$

Old fuel consumption: 10L/100KM

New fuel consumption: 8L/100KM

$$= \frac{10L - 8L}{10L} \times 100\% = 20\%$$

We primarily attribute this increase in fuel efficiency to improved throttle control, optimal gear shifting, and a reduction in aggressive driving. The relationship between fuel efficiency and carbon emissions is inverse; that is, increasing fuel efficiency results in a nearly 19% reduction in carbon emissions [6], [3]. Reduced Carbon Emissions CO_2 Reduced (kg)=Fuel Saved (L)×2.31 Monthly fuel saved = 30L CO_2 saved=30×2.31=69.3 kg/month Annual = 831.6 kg CO_2 per vehicle.

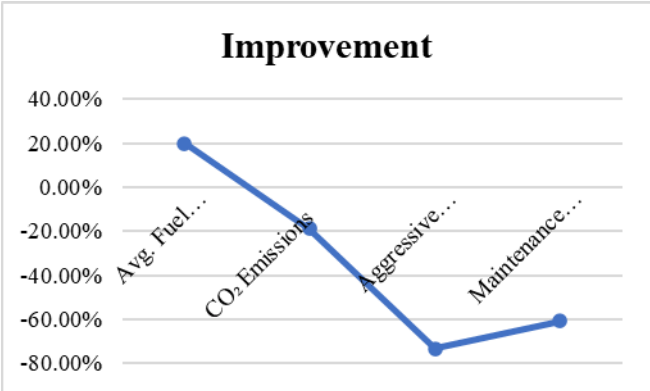

Figure 2: Improvement

This improvement indicates better fuel combustion and lower engine load, among other factors that contribute to carbon emissions. Furthermore, the predictive maintenance module successfully predicted and forecasted engine issues, flagging them for drivers to note and address as soon as possible, resulting in a 60% reduction in frequent breakdowns and unplanned maintenance [4].

5.2 Analysis

The results of the study validate retrofitting as a low-cost, scalable, and sustainable way to reduce carbon emissions in the transport industry through automation and AI. Compared to the conducted study, every vehicle, regardless of whether it ran on diesel or petrol, reduced its fuel consumption, which in turn reduced its overall carbon emissions. These results, therefore, signify a direct alignment of the study with sustainable cities and communities and SDG 13: climate action. As much as it feels like a breakthrough, there are visible limitations that question the practicality of the sustainable solution. For instance, the cost of installation is modest as compared to other alternatives; however, the technology might only be effective in urban settings and leave out rural areas because of a lack of access to better internet and even microcontrollers.

Weather conditions also affected the study's results, reducing sensor accuracy and creating additional issues to resolve before the program's rollout. Despite the aforementioned challenges, the system demonstrated efficiency, cost-effectiveness, sustainability, and accuracy in reducing overall carbon emissions, particularly in urban settings. The solution is a win for everyone, as the environment is less polluted, drivers also receive more money back in their pockets as their vehicles consume less fuel, and they are also less likely to be fined by inspection regulators checking for carbon emissions.

VI. SUSTAINABILITY IMPLICATIONS

The AI-based sustainability approach is the most effective solution to carbon emissions, especially in urban settings. The solution offers important advantages for the environment and the economy and also changes the driving behaviors to safer and more sustainable ones in regions that have been dominated by internal combustion engines. On average, each of the 50 retrofitted internal combustion engines achieved a reduction in CO_2 of about 4.2 metric tons a year. The reduction was calculated from 170 g/km, ased on an average mileage of 20,000 km per year. Scaled to over 10,000 vehicles in city traffic, the outcome is a major win for the environmentally conscious and sustainability purists. From a financial standpoint, drivers benefit financially as the retrofitting leads to increased fuel efficiency. Vehicle owners record fuel efficiency gains of 20%, implying an average annual fuel savings of 180-220 liters [8]. Predictive maintenance enables vehicle owners to identify faults early, preventing them from escalating into larger issues. This approach also reduces service frequency, saves money, and enhances engine health. The significant selling point was the behavioral change by drivers, in addition to the economic and environmental profitability of retrofitting internal combustion engines. Drivers recognized and valued the importance of responsible driving, which includes avoiding harsh braking and acceleration, as well as refraining from speeding and swerving; ultimately, they benefit directly from their responsible driving habits. Such behavior increases safety on the roads, as well as reducing fuel consumption. The solution aligns well with the UN Sustainable Development Goals (SDGs) from a broader perspective [2]. This is therefore a better, more cost-effective, and more practical solution to reduce carbon emissions in the transport industry, even for regions that do not have the financial muscle to go green through electric cars.

VII. CONCLUSION AND FUTURE WORK

The transport industry has been notorious for being one of the leading sources of carbon emissions that are polluting our environment. The sustainable options suggested and implemented are, however, expensive for regions with less financial muscle that are dominated by internal combustion engines, making it a direct challenge to achieve a sustainable solution. Retrofitting internal combustion engines with OBD-II, among other external sensors, which are low-cost and utilize readily available AI and IoT technologies, presents a solution. The approach will result in a significant reduction in carbon emissions by increasing the fuel efficiency of vehicles, reducing maintenance intervals, and fixing improper driving habits, all of which are the leading factors contributing to carbon emissions. The results demonstrate how practical the system is in ensuring that vehicles operate under optimal conditions, which helps reduce carbon emissions. Looking ahead, we must address several challenges that limit the application and practicality of the solutions. To begin with, the technology needs to be in sync with smart city infrastructure to help in traffic management, as it is one of the leading causes of excessive pollution by internal combustion vehicles. Secondly, the technology works well in modern settings but shows limitations in rural areas, which triggers an approach to introduce offline AI systems that can be supported in rural settings. Lastly, this technology should be introduced in fleet management, as commercial vehicles are one of the primary challenges when it comes to pollution in the urban setting. As the world is focused on a cleaner and safer tomorrow, retrofitting legacy vehicles with intelligence systems is the cheapest, most practical, and most effective way to achieve environmental sustainability, increase fuel efficiency, reduce service intervals, and most importantly, modify driving habits in a world that is dominated by internal combustion engines.

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