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A Review on Driving Styles and Fuel Consumption Characterization

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ABSTRACT: Intelligent transportation systems (ITS) rely on connected vehicle applications to address real-world problems. Research is currently being conducted to support safety, mobility and environmental applications. This paper presents the Driving Styles architecture, which adopts data mining techniques and neural networks to analyze and generate a classification of driving styles and fuel consumption based on driver characterization. In particular, we have implemented an algorithm that is able to characterize the degree of aggressiveness of each driver. We have also developed a methodology to calculate, in real-time, the consumption and environmental impact of spark ignition and diesel vehicles from a set of variable obtained from the vehicles electronic control unit (ECU). In this paper, we demonstrate the impact of the driving style on fuel consumption, as well as its relation with the greenhouse gas emissions generated by each vehicle. Overall, our platform is able to assist drivers in correcting their bad driving habits, while offering helpful tips to improve fuel economy and driving safety.

KEY WORDS: Index Terms: Android smartphone, driving habits, driving styles, eco-driving, fuel consumption, greenhouse gas emissions, neural networks, on board diagnostics (OBD-II).

I. INTRODUCTION

INTELLIGENT transportation systems (ITS) introduce advanced applications aimed at providing innovative services, offering traffic management and enabling users to be better informed, including support for safety, mobility, and environmental applications. In parallel to ITS, mobile devices have experienced technological breakthroughs in recent years, evolving towards high performance terminals with multi-core microprocessors.Thesmartphoneisaclearrepresentativeoutcomeofthis trend. In addition, the on board diagnostics (OBD-II) [1] standard, available since 1994, has recently become an enabling technology for in-vehicle applications due to the availability of Bluetooth OBD-II connectors. These connectors enable a transparent connectivity between the mobile device and the vehicle’s electronic control unit (ECU).

When combining high performance smartphones with OBDII connectivity, new and exciting research challenges emerge, promoting the symbiosis between vehicles and mobile devices, and thereby achieving novel intelligent systems. Driving Styles implements a solution based on neural networks, which is capable of characterizing the driving style of each user[2],as well as the fuel consumption [3]. In order to achieve this functionality, the details obtained from the ECU via the OBD-IIBluetoothinterface,includingthespeed,acceleration,revolutionsperminute of the engine, mass flow sensor(MAF) ,many fold absolute pressure (MAP), and intake air temperature (AIT). Currently, this information can be collected and used in applications aimed at improving road safety and promoting eco-driving, thus reducing fuel consumption and greenhouse gas emissions. Specifically we find that, by shifting towards a more efficient driving style, userscansaveupto20%offuelwhileimprovingdrivingsafety, there by reducing greenhouse gases as we detail later on.

This paper is organized as follows: In the next section we present some related works. Section III introduces the Driving Styles architecture (both the Android and the server interface). Models for fuel consumption and CO2 emissions, are described in more detail in Section IV. The tuning of the neural network, along with the obtained results, are presented in Sections V and VI, respectively. Finally, Section VII presents the conclusion of our work.

Technological advancement in the field of mobile telephony are making smartphones very powerful. This high computing power opens new and attractive opportunities for research. When coupled with the eco-driving concept, it has gained great significance in recent years [4]. An example is the prototype of an on board unit developed by

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Hernandezet al. [5]. These driving techniques save fuel consumption, regardless of the technology used inside the vehicle. One of the main problems of eco-driving systems is identifying the factors that affect energy consumption. Ericsson [6] suggests that, in order to save fuel, sudden changes in acceleration and high speed driving should be avoided. Johans sonet al. [7] suggest maintaining low levels of deceleration, minimizing the use of the first and second gears, and putting every effort into using the 5th and 6th gears, while avoiding continuous gear changes. There are several proposals that analyze which variables affect fuel consumption. Kuhler [8] introduced a set of ten variables that are used in laboratories for fuel consumption and vehicle emissions analysis. Other authors such as Andr´e [9] improve these results by increasing and replacing some of the parameters. In previous works such as Leung [10] and COP1229 ERT III [11], different tools were developed to enable real-time collection of engine and vehicle parameters from the OBD connector.

III. BACKGROUND

Our proposed architecture applies data mining techniques to generate a classification of the driving styles of users based on the analysis of their mobility traces. Such classification is generated taking into consideration the characteristics route, such as whether it is urban, suburban, or a highway, and it is then correlated with the fuel consumption and emissions of each driver. To achieve the overall objective, our system comprises four elements:

1. An application for Android, based smartphones. Using an OBD-II Bluetooth interface, the application collects control information (by default every second, configurable by the user) such as speed, acceleration, engine revolutions per minute, throttle position, and the vehicle's geographic position. In addition, we also obtain via OBD-II the mass flow sensor (MAF), the manifold absolute pressure (MAP), and the intake air temperature (AIT) that are used in the calculation of fuel consumption. After gathering the information, the user can upload the collect

2. A data center offering a web interface to collect large data sets sent by different users concurrently, and to graphically display a summary of the most relevant results, like driving styles and route characterization of each route sent. Our solution is based on open source software tools such as Apache, PHP and Joomla.

3. A neural network, which has been trained using the most representative route traces in order to correctly identify, for each path segment, the driving style of the driver, as well as the segment profile: Urban, suburban or highway. We use the back propagation algorithm [13],which has proven to provide good results in classification problems such as the one associated to this project.

4. Integration of the tuned neural networks both within the mobile device itself, and in the data-center platform. The goal is to use . neural networks to dynamically and automatically analyze user data, reporting to the drivers in real time and allowing them to find out their driver profile, thus promoting a less aggressive and more ecological driving. data to the remote data center for analysis.

The basic layer in the Android device is the Linux kernel, which contains all the essential hardware drivers to interact with the OBD-II device via Bluetooth. The top layer includes both Android's native libraries and our own libraries. Specifically, we developed the OBD-II communications module, along with the libraries for graphical data representation, at this layer. The next level up is the Application Framework; this layer manages the basic functions of the mobile device, and the communications with the developed libraries. Finally, at the application layer, we developed the different modules of the Driving Styles architecture, such as the fuel consumption and CO_2 emissions estimators, the neural networks behavior, GPS routes, and graphics. Also, the application provides real-time feedback from the device to the user such that, when it detects high levels of aggressiveness (above a certain threshold), the device automatically generates an acoustic signal to alert the driver.

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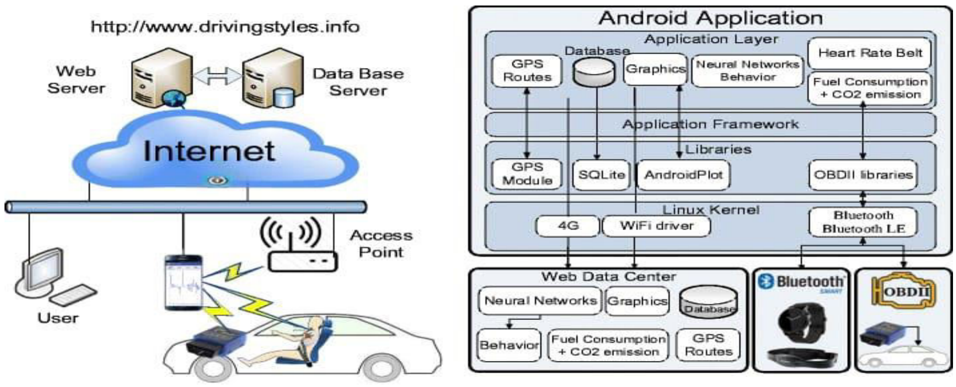

(a) Overview of the architecture (b) Block diagram of the architecture

IV. METHODOLOGY

A. Driving Styles Android Interface :

The first step for a user is to register at http://www. Driving styles. Info and to download the free Android application. After installing the Android application in the mobile device, and after connecting to the Bluetooth ELM327 interface inside the car (this connector is mandatory on all vehicles since 2001), the data acquisition process will start (see Fig.1(a)). The Android application is a key element of our system, proving connectivity to the vehicle and to the Driving Styles web platform. Currently, it can be downloaded for free from the DrivingStyleswebsite1,or from Google Play 2. Once the mobile application is installed and configured, the user must pair the mobile device with the ELM327 (OBD-II Bluetooth device) to start getting data. The data obtained from the different variables such as acceleration, engine revolutions per minute (RPM), speed, mass flow sensor (MAF), manifold absolute pressure (MAP), and intake air temperature (IAT) are analyzed by the application, showing users the characteristics related to their driving, fuel consumption ,and CO2 emissions. In order to adjust the application functionality, it offers several configuration options.

B. Driving Styles Server Interface:

The second main component of our architecture corresponds to the data center and its web interface. To implement this component, we have selected open source software such as Apache HTTP, and as the content management system (CMS). We have used a CMS, combined with the use of are source wrapper, which detaches our system from the presentation layer, thus focusing on the driving styles characterization problem. This module can be found in http://www.drivingstyles. info. Basically the server receives data sent from the Android application of each user, and it provides functionality to work with User, Routes, and Statistics. Once the user is logged in, he is asked to record a number of important data, especially for future data mining studies. The most relevant items are sex, age, and other details concerning the vehicle used: car manufacturer, model, fuel type, and the theoretical0–100 acceleration level(important to normalize the user behavior in our study). In the Routes' section, users can access all the routes they have uploaded. When selecting car/body sensors, the system displays nine graphs for the different sensors obtained from the OBD-II (direct and indirect variables), as well as the route and driver behavior(seeFig.3). Next, we present our fuel consumption estimation approach relating it with the driver style as captured by the Driving Styles platform.

FUEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS CALCULATION:

Fuel Consumption : Fuel consumption is usually represented as the ratio of fuel consumed per distance travelled, being measured in terms of liters per 100km (or alternatively as MPG – miles per gallon). In this work, we focus on gasoline and diesel engines. Although the basic designs of gasoline and diesel engines are similar, the mechanics are different. A gasoline engine compresses its fuel and air charge and then initiates combustion by the use of a spark plug. A diesel engine just compresses air until the combustion chamber reaches a temperature for self-ignition to occur. So, at a given speed in kilo meters per hour, instantaneous fuel consumption can be calculated as follows:

Inst. Fuel Consump.[l/km] =Fuel Flow [l] /Speed [km]

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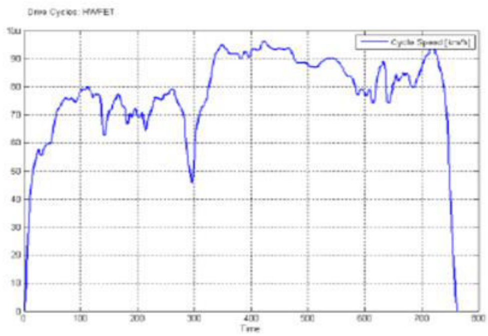
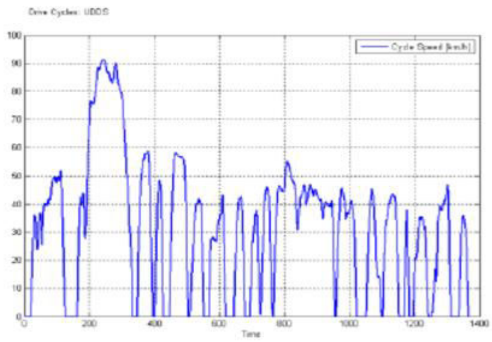
1. By combining the Engine Fuel Rate (PID 015E),also known as Fuel Flow (liters/hour), and Speed (PID 010D), it is easy to calculate instantaneous fuel consumption. However, while speed is mandatorily available, fuel rate is not. In fact, it was unavailable in all vehicles we used to carry out our tests. This can be due to two reasons: (i) The manufacturer chooses not to make it available, or (ii) there is no sensor inserted in the fuel line between the fuel tank and the engine carburetor to measure liters per hour.

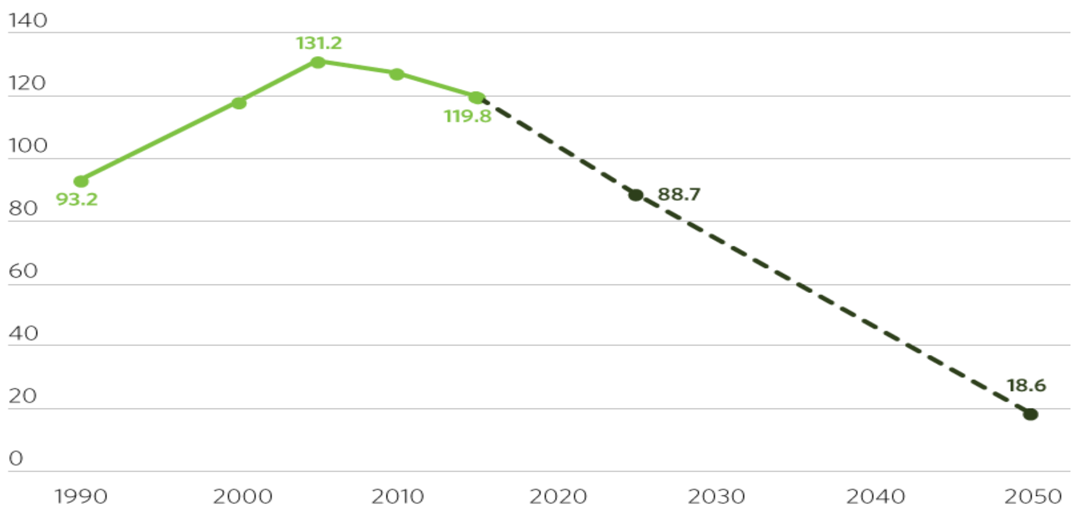




2. If the MAF PID is available, but the Engine Fuel Rate is not, we can calculate fuel rate as Fuel Flow (liter/hour) by dividing the Mass Air Flow (PID 0110) × 3,600 s. by the product of air-to-fuel ratio and Fuel Density (using a fuel density equal to 820 g/dm3forgasolineand 720g/dm3for diesel).

Greenhouse Gas Emissions Calculation: The most significant green house gases are generated from direct combustion of carbon dioxide CO_2, Methane (CH_4), and Nitrous oxide (N_2O), among others. CO_2 is always generated when burning fuel that contains carbon. Since the carbon in the fuel is combined with the oxygen in the air: $C + O_2 \rightarrow CO_2$, the amount of CO_2 can be calculated by the atomic masses of carbon and oxygen, and the carbon content of the fuel. The atomic mass of carbon is 12U and oxygen is 16U, meaning that $CO_2 = 12\ U + 2\times 16U = 44\ U$. Burning 1kg of carbon produces $44/12 \approx 3.67$ kg of CO_2 in complete combustion, and so the CO_2 emission of combustion is $3.67 \cdot Cc \cdot m$ fuel where Cc = fuel carbon content(mass basis). Considering at the carbon content of diesel fuel is 85.7% the CO_2 emission when burning1 kg (m fuel =1kg)of diesel fuel is:

$mCO_2 = 3.67 \cdot Cc \cdot m$ fuel, $mCO_2 = 3.67 \cdot 0.857 \cdot 1$[kg]=3 .15 [kg/1kg fuel] Density of diesel fuel is 0.84 [kg/l], (3) $mCO_2 = 3.15 \cdot$[kg] $\cdot$ 0.84 = 2 .64 [kg/1l fuel]. Driving in a fuel-efficient manner can save fuel, money, and reduce greenhouse gas emissions. Among the factors that can affect fuel consumption, such as: Vehicle age and condition, outside temperature, weather, and traffic conditions, we consider that driver behavior can be one of the most relevant parameter. Next, we provide detailed information about the neural network we proposed for characterizing driver styles.



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V. RESULTS

In our project, we focus on characterizing the driving style of different drivers, and then measuring the associated fuel consumption variations. In order to achieve this objective, we rely on the collaboration of 534 drivers from around the world using our platform, including countries like India, Brazil, Central America, and Europe. In this particular study, we analyzed the behavior of 75 representative routes (each divided into 10 s periods) using the neural network described earlier. For each section, the neural network returns the corresponding driver behavior, and we combine this data with the fuel consumption data corresponding to that route.

We carried out several types of tests to validate our proposals. Fig. 6 shows the fuel consumption and CO2 emissions reported by different drivers classified according to their driving style. The results of this test show that a more aggressive driving behavior causes fuel consumption to increase significantly, while also increasing the generation of CO2. To gain further in sight into these core relations, Fig. 7 displays the differences between quiet, normal, and aggressive driving behavior in terms of fuel consumption; aggressive drivers provoke fast starts and quick accelerations, driving at high engine revolutions, and causing sudden speed changes. Conversely, a quiet driving behavior would be smooth, with out sudden speed changes or continuous gear shifts. It is clear that fuel consumption increases when the driver behavior becomes more aggressive, with average differences of up to 1.5 liters per 100 km. In our experiments, an aggressive driver uses an average of 8 liters per 100 km, and a quiet driver only 6.6 liters per 100 km, meaning that the difference in terms of fuel consumption is not negligible, as the former may consume up to 20% more fuel depending on the driving style. Regarding CO2 emissions, they may increase by50%, goingfrom10 to15 kg/100km, depending on whether drivers are quiet or aggressive.

VI. CONCLUSION

This paper presents our Driving Styles platform, which integrates mobile devices with data obtained from the vehicle's engine ECU to characterize driver habits, as well as the associated fuel consumption and emissions. Our platform helps to promote a more ecological driving style by emphasizing on the relationship between driving style and fuel consumption, which has a clear and direct impact on the environment. It has been also demonstratedthatthedrivingstyleisdirectlyrelatedtofuelconsumption. Specifically, adopting an efficient driving style allows achieving fuel savings ranging from 15 to 20%. An aggressive driving style always results in energy consumption and more CO2 emissions, whereas smooth driving ends up providing a greater energy efficiency and reduced gas emissions. The application, which is available for free download in the Driving Style's website and Google Play Store, achieved more than 5,800 downloads from different countries in just a few months. This emphasizes the great interest about research on this topic. As future work, we intend to extend this platform by providing route recommendations based on real-time feedback about the congestion state of different alternative routes, as well as providing estimated green house emissions for different routes.

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