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Immersive driving simulation architecture to support gamified eco-driving instructions

David Geoffroy[1], Dominique Gruyer[1], Olivier Orfila[1*], Sébastien Glaser[1], Andry Rakotonirainy[2], Atiyeh Vaezipour[2], Sébastien Demmel[2]

1. IFSTTAR/COSYS/LIVIC, 25 allée des Marronniers, F-78000 France, olivier.orfila@ifsttar.fr

2. Centre for Accident Research Road safety Queensland (CARRS-Q), Queensland University of Technology, Australia

Abstract

Eco-driving is about energy efficient use of vehicles. There are many approaches to improve eco-driving. Eco-driving driving style is hard to learn even with the help of driving assistance systems. This paper presents an immersive driving simulation training tool to support eco-driving training. We address the following questions: (1) How gamification concepts can improve eco-driving evaluation, training and adoption in simulated environments and (2) How to setup such elements in a 3D immersive driving simulator. We present an implementation of gamification concepts in a driving simulator architecture built upon pro-SiVIC software and a 3D Helmet Mounted Display. The gamification functions are then used to motivate drivers to be eco-friendly. We conclude with future work and open issues.

Keywords:

Ecodriving, gamification, virtual reality, simulation

Introduction

Increasing energy efficiency and curtailing activities that consume energy may be our cheapest options for stabilizing CO2 concentrations below a doubling of preindustrial concentrations. Eco-driving falls into such a strategy. However, there is an alarming lack of eco-driving experiments, knowledge and data worldwide. Yet the potential economic and environmental benefits are large. The Swedish National Roads Administration estimate that 1 kg of CO2 costs between 0.1 to 0.3 Euro to society and that eco-driving can reduce fuel consumption by 5 to 15%. Applying these estimates to the 12 million vehicles in Australia that consume approximately 30,000 million litres of fuel per year, leads to potential CO2 savings valued at between $250 and $750 million per year and fuel savings of between $1,800 million and $5,400 million per year. This would greatly reduce the pressure on world oil supplies. While the health benefits of improving fuel consumption, and the resulting lower emissions, are harder to determine, there is a growing consensus that they do exist. Furthermore, legal pressure about CO2 emissions is increasing on car manufacturers as shown by the ICCT [1].

Eco-driving refers to cost effective driving styles that help to reduce fuel consumption and vehicle emissions. Eco-driving research has been growing due to its potential to reduce fossil fuel consumption and particles emission (Nox, CO2). The recent COP21 held in Paris in 2015 has made research in Eco-driving more relevant than ever. A wide range of eco-driving strategies have been designed and studied by traffic psychologists, engineers and traffic simulation researchers for the last 10 years. Despite its popularity, there is poor and inconsistent research evidence regarding the benefits of different eco-driving interventions (e.g. education or ITS intervention) on fuel consumption. Eco-driving instructions are very context sensitive and have different performance in different situations (e.g. weather, road geometry). Rakotonirainy et al [2] demonstrated that standard instructions do not provide the expected 20% fuel consumption reduction on an automatic car in an urban environment.

ITS can be used to train and monitor drivers to adopt eco-driving style. However, there is no clear evidence showing that motivation to adopt eco-driving style could be sustained over a long period of time. Very recently the use of gamification has emerged in the automotive industry, primarily for its motivating and inspiring potential (e.g. Nissan Leaf). Gamification concepts have been used to prevent diminishing motivation when using ITS intervention. There is a growing need to rapidly operationalize and safely test the use of gamification concepts in cars. For example tools need to ensure that the increased motivation, due to gamification, does not compromise safety by diverting attention away from the key driving tasks and that. To our knowledge there is no driving simulator which provides functionalities to facilitate the design and test gamification concepts. This paper presents a driving simulator architecture that enables to design and test the benefits of the use of gamification concepts in the context of eco-driving.

This paper is structured as follows: The next section covers literature review on eco-driving and gamification. Section three presents the gamification conceptual framework we are implementing in the Architecture Section.

Background

Eco-driving

There are a plethora of eco-driving tips (e.g. avoid sharp acceleration). Eco-driving instructions are mostly simple and easy to adopt. There are numerous unverified claims stating that such instructions guaranty an immediate success and bring about safety. Educational campaign related to reducing air pollution is more effective than safety messages in getting drivers to keep to the speed limit (Delhomme et al, 2010, [3]).

Practical training or advanced driving Assistance Systems (ADAS) offer a large variety of means to foster the adoption of correct eco-driving style. We have shown in a large study, that the content and delivery mode of an eco-driving educational intervention is highly correlated to its adoption (RACQ, 2012, [4]). Eco-driving is part of the education of learner drivers in many European countries. Countries such as Finland, Croatia, Greece and Germany have written eco-driving curricula exist, which specifies how to train learner drivers to Eco-drive in theory and practise (ecodrive.org).

The effectiveness of ecodriving depends on the driver baseline. Nevertheless, all studies on this topic showed that a decrease of energy use is generally detected. It is then clear that most of the drivers reduce their energy use when changing their driving habits. The estimated gains are between 3 and 7%, some studies showing impressive figures above 40%. Estimated gains have been determined through Naturalistic Driving Studies (NDS) and studies showing results above 10% are generally realized in specific conditions that does not represent practical conditions, such as en ecodriving challenge.

An important result deals with the capacity of the driver to keep his ecodriving abilities over a long period of time. Results from research studies (Barth, 2009, [5]) show that previous habits may come back very quickly (less than 5 weeks) after an ecodriving training. Another study [5] showed that, even if the driver is assisted with a haptic gas pedal, he gets used to it and finally uses as much fuel as in the beginning.

The third factor to be taken into account is the traffic. It can be thought that a few ecodrivers will force other drivers to ecodrive and that it will decrease the energy use of a whole fleet or city. On the contrary, most studies show that, at best, the decrease in energy use is linear with the percentage of ecodrivers in the population while, at worst, the energy use increases with the number of ecodrivers in specific conditions (Chung, 2011, [6], Orfila, 2011 [7], Samaras, 2014, [8]).

To convince drivers to start ecodriving, some insurance companies propose a “Pay How You Drive” option where the driver behaviour, in terms of ecodriving, is taken into account to estimate the cost of the insurance. This is generally based on a system the user has to install in his car (OBD2 or CAN bus connection) and a website where the driver can check his evolution. Ecodriving is also analysed during the initial training or during the driving license examination in more and more countries (in France, one point is granted if you ecodrive during the exam).

To preserve ecodriving over a long period of time, a wide range of ecodriving assistance systems is proposed. From a smartphone application to a GPS assistant trained to ecodriving, several means have been developed. Drivers should be aware that most of these applications have not been validated and may disturb them while driving. Car manufacturers are also working on active or informative Advanced Driver Assistance Systems that improve your driving skills for a dedicated vehicle.

Gamification

Gamification is the "use of game design elements in non-game contexts" (Deterding, et al, 2011: 1, [9]). Gamification refers to the use of game design, game playing techniques and game mechanisms to engage users and motivate positive behaviour (Seaborn and Fels, 2015, [10], Deterding, Björk, Nacke, Dixon, & Lawley, 2013, [11]; Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011, [12]). More specifically, gamification refers to the use of a particular set of game design elements, namely scoring systems (e.g., points, levels, achievements), and that this focus can have negative effects in particular contexts (Nicholson, 2012, [13]). He also suggest that motivation is the underlying concept of gamification, a focus on the external rewards commonly associated with scoring systems may reduce internal motivation, and in turn the capacity for long-term behaviour change (Deci and Ryan,1985, [14]). As a result, Nicholson (2012) proposes the concept of meaningful gamification, which focuses on the use of play elements instead of scoring. Specifically, the focus is shifted to assisting the user to find meaning in the non-game context through these play elements in an attempt to influence underlying attitudes, beliefs and motivations. Indeed, according to Deci and Ryan (1985:15), “the issue is how to facilitate people's understanding of the importance of the activity to themselves and thus internalizing its regulation so they will be self-motivated to perform it”. Nicholson (2012) argues that this can be achieved through a focus on providing meaningful information to the user, using rewards sparingly or not all, and affording users the ability to set their own goals and create an experience that is most relevant to them.

The term gamification is becoming increasingly more popular in the field of HMI design (Iacovides, 2009, [15]; Van Eck, 2006, [16]). However, the use of gamification in the automotive domain is not without challenges and limitations, most notably that of distraction increasing the likelihood of road crashes (Diewald et al., 2013, [17]).

Gamification and eco-driving

There are increasing number of research projects focusing on the driver behaviour and means to design in-vehicle HMI to provide eco-driving feedback strategies (ecodriver-project.eu). Driver acceptance and compliance to eco-driving instructions are critical to the success of eco-driving interventions (Vaezipour, Rakotonirainy & Haworth. 2015, [18]). This paper uses gamified feedbacks to optimise driving style for less energy use and consequently lower emissions.

Gamification conceptual framework

This section presents the theoretical framework used in this study to build an architecture incorporating gameplay elements to improve eco driving. An important aspect of gamification, is the design of core gameplay, which can be defined as the “moment-to-moment activity within the game, to meet learning objectives” (Hall, Wyeth & Johnson, 2014: 123, [19]). That is, core gameplay refers to the actions a user makes in order to meet the tasks and demands on the game. Core gameplay not only affects a user's motivation to engage with the play elements, but subsequently the ability for the learning and behavioural objectives of the game to be achieved. Frameworks for core-gameplay typically describe the process as a loop, which shows the interaction between the user and the core mechanics of the game as they progress through the gameplay (Hall et al., 2014). This framework includes such elements as goals, choices, actions, rules, and feedback (see Figure 1).

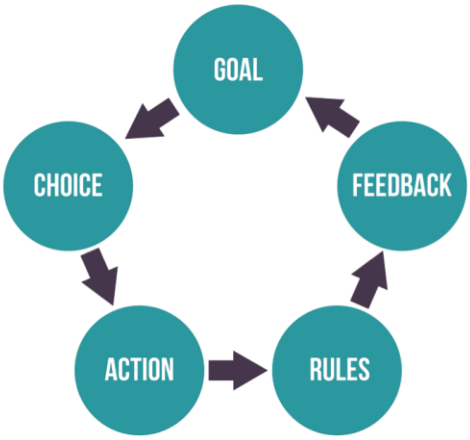

Figure 1 - Core Gameplay Framework

In the context of driving, drivers are challenged to achieve clearly conveyed and reasonably attainable goals (e.g., reduce fuel consumption), and must make choices (e.g., reduce levels of inappropriate acceleration) about what actions (e.g., accelerate more smoothly), or series of actions, will be most appropriate and effective in helping them progress towards this goal. The system must also exhibit rules (e.g., smoother acceleration = improved fuel consumption) that serve to assess the actions of the driver and assess ability to reach (or not) the goal. The system should also provide feedback (e.g., fuel consumption levels) to the driver regarding their success or failure in achieving the goals, as well as suggestions for adjusted goals, choices and actions. That is, the feedback element is a crucial part of the framework. It helps driver to refer to his/her belief in his/her capacity to execute behaviors necessary to reach the goal by lead to new goals (e.g., reduce fuel consumption further) or revisions of choices and actions (e.g., accelerate even more smoothly) if the original goal was not attained.

Gamification to improve eco-driving adoption in simulated environments

Gamification in driving context is defined as using game design in a non-game context in an attempt to accentuate drivers' motivation and commitment to use a new in-vehicle system (Diewald, S., Möller, A., Roalter, L., Stockinger, T., & Kranz, M. (2013)).

The gamification of eco-driving scenarios is of the outmost importance because, apart from motivating users, it provides us means to tell apart experts from beginners. Moreover, as the 3D immersive platform might end up being used in exhibitions to collect driving data or to teach eco-driving. Then, it needs to be appealing to the crowd on first sight and to be enjoyable using it for a long period of time. The gamification process takes advantage of lessons by video games, on which players might spend hours as well as a few minutes depending on the game intrinsic quality, in order to address these aspects.

The cosmetics aspects of the platform will not be developed in this paper, however we will focus on telling apart beginners from experts. Previous studies showed that expertness is an acquired quality (Ericsson & Charness, 1994, [20]) and that the expert's solving process is made of observable sequences of actions (Dreyfus & Dreyfus, 1980, [21]) therefore it is possible to divide this process into small steps. This property allows us to automatically evaluate a driver simply by looking at how many expert's action the driver did during the simulation. As the eco-driving process is not static, it is made of small actions such as "shift gear up between 2000 and 2500 RPM" which allows us to evaluate the driver from the level of completion for each action too. This last kind of evaluation might go too deep to simply discriminate experts from beginners but it is actually really helpful in the learning process.

Lesson learnt from video games such as Mario (platform game) or Euro Truck Simulator (truck driving simulator), a classic progression of difficulty consist of leaning a game mechanic, using it in increasingly complex situations and then adding a new mechanic which will be used aside the first one in increasingly complex situation. In the end, the player learnt how the various mechanics work together and is able to use all of them in extremely complex scenarios.

To help setting up a learning process, which should offer an adjusted difficulty level at each and every one of its step in order to keep the driver driving, the previously observed methodology will be used. By identification, the game mechanics evocated will be the expert's set of action. These actions will be ordered by ease of access and then we will organise the simulation in order to teach those steps gradually and keep track of the driver's progression in mastering them.

Architecture

The aforementioned conceptual framework helped us to design a dedicated architecture. This architecture implements the five key concepts described in Figure 1 into a platform call eco-SIVIC. The main goal of the eco-SiVIC platform was to educate users about problems associated with eco-driving style and to prove them that with a specific driving behavior and with the respect of specific rules, a driver could reduce significantly the energy consumption.

Add-on architecture in SiVIC

The extension we made into pro-SiVIC "research" platform [22] consists of a new set of functions which facilitate the creation of driving scenario which incorporate gameplay elements to improve eco-driving. The extension was guided by the conceptual framework illustrated in Figure 1 as follows:

- **Goal**: Drivers are challenged to achieve clearly conveyed and reasonably attainable goals. A simple and realistic driving scenario in which the driver is asked to travel as far as possible with 1.5 litres in the tank was implemented.
- **Feedback**: Instantaneous fuel consumption and remaining fuel is displayed, score is given at the end of the journey
- **Rules**: Eco-driving instructions to reduce fuel consumption are given verbally to participants at the beginning of the experiments. Participants comply to road rules as well as road markings or signs in the virtual environment. Road exit penalizes the driver and limit his speed to 10 m / s.
- **Choice**: Participants make a series of choice related to longitudinal and lateral movements. They can decide to perform hard or smooth acceleration to reach the speed limit or cut corners on curves to reduce distance travelled. Choices are guided by the instructions and feedback they have received.
- **Action**: Action results from a choice where the driver decides the most appropriate and effective manoeuvre to progress towards the goal.

The scene takes place on the Satory's test track in Versailles - France (see figure 2). To obtain a high quality 3D immersion for the real drivers in the virtual environment, a realistic 3D reproduction of the real track was produced by LIVIC. Figure 2 shows the similarity of this simulation in comparison with the same perspective on the real track. In this figure, the first line provides virtual renderings and the second line gives the real pictures from the same point of view.

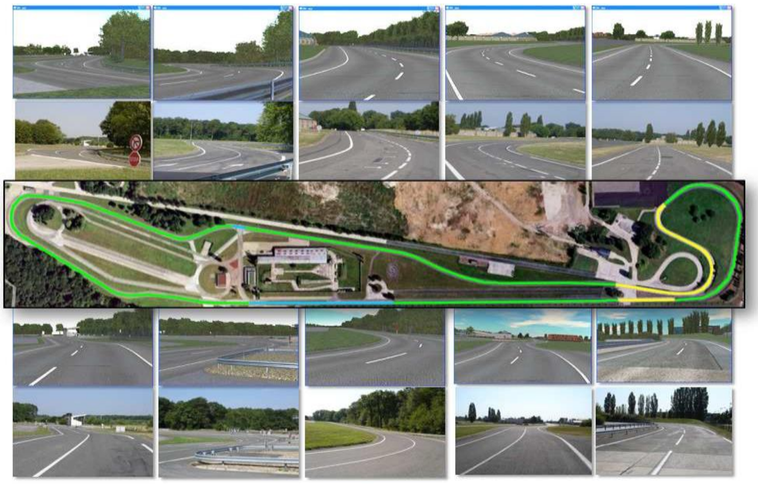

Figure 2 - Modelling and simulation of the Satory's test track in the SiVIC platform.

In order to develop this simulation architecture dedicated for eco-mobility studies, several functions, methods, and tools were necessary. The figure 3 shows these functions and tools shared between the actual world (involving the driver, the bench, the actuators, and the immersive mechanisms) and the simulated world. Moreover, the different interfaces and data flows are represented.

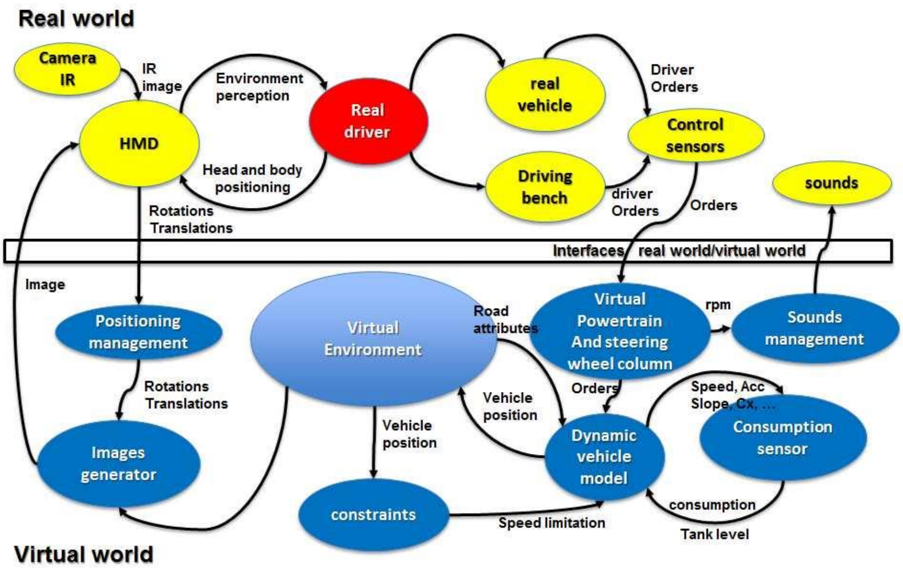

Figure 3 - Functional diagram of the eco-SiVIC platform

The rules and feedback stages will be addressed in the next section are dedicated to the proof of concept prototype and the presentation of some first results about the technical parts needed in order to allow to get a full and functional platform (action stage).

Proof of concept prototype

Methodology

The proof of concept has been tested during the Paris Motor Show in 2014. The idea was to collect the maximum amount of data from the event visitors. Then, data were collected throughout an eco-driving virtual challenge where participants driving performance were recorded and scored according to distance travelled with a fixed amount of fuel. All challengers were conducted in the same test conditions. Data collection was performed over 17 days of the Paris Motor Show event. More than 1,900 participants participated. Data were pre-processed and 1,211 participants were validated, as the others being not exploitable (wrong data registering, participants doing their best not to follow guidelines...). The experimentation was performed in 3 steps.

- The first step is familiarisation with the simulator, the instruments, indicators, and constraints associated with the experiment. Figure 4 shows the hardware and software platform we used.
- The second step consists in providing advice to the current driver to make them aware of their driving habits. Then, they were advised to adapt their speed on curves, to adjust their speed in straight roads, or to limit the accelerations and braking.

- The third step consists in informing and instructing the driver to do the following task:
  - The fuel tank is almost empty (only 0.15 litres of gasoline) and the participant is asked to travel to the longest distance with this amount of fuel.
  - The speed limit in the simulation is 25 m/s.
  - The eco-driving instructions are:
    - maintain a constant speed (an optimal speed is given about 50 kph)
    - avoid sharp acceleration and deceleration
    - anticipate curves

The driver should drive on the paved road. If the driver drives out of the road, a speed limitation mechanism is applied in order to limit the speed at 2.7 m/s (10 km/h). In this case, the manoeuvres made in order to join the road area and the bad efficiency of the engine at low speed will increase significantly the fuel consumption and will lower the final score.

Each participant’s performance is scored based on the distance travelled.

Figure 4 - Eco-Sivic driving simulator experiments during the French science festival, Cité des sciences (Right) and Paris and Motor show (Left), Paris 2014

Results

Consumption was calculated along each trip using a fuel consumption model developed in [23]. Figure 5 left illustrates the cumulated fuel consumption for all drivers on the first 600 meters of the virtual scenario. It shows that drivers had highest consumption during the first 100m where they start to move the car. In red are presented all optimal fuel use profiles according to the Pareto definition of optimality. In this study, total travel time and total fuel use were considered as optimal objectives. Then, a profile is considered optimal if there is no other profile with a lower travel time and a lower fuel use. It can be notice that there is no optimal solution associated to a low fuel consumption in the first 100 meters of the scenario.

The speed profile of participants varied considerably as illustrated in Figure 5 right. Most of the participants drove less than 3,400 metres. The average distance covered by a driver with

0.15 liter of fuel is 3,142 meters. The standard deviation is 385 meters. Each driver went through a temporary high fuel consumption. Once this speed limit is reached, drivers maintain their speed and the consumption remains almost constant. At 3,400 meters, the fuel tank is emptied and the speed goes down due to the resistive forces applied to the vehicle. The maximum distance travelled is 3,500 metres where the vehicle stops. The best driver (in green), who drove the furthest, used a strong acceleration in order to reach quickly the desired speed. Such result is counter intuitive as most of eco-driving instructions advice drivers to avoid sharp acceleration.

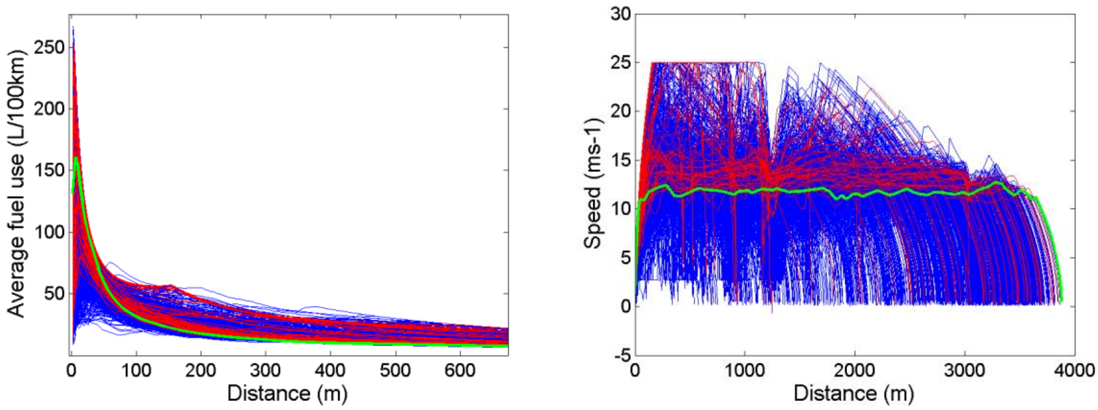

Figure 5 – Left: Cumulated fuel consumption; Right: Speed profiles for all drivers during the Paris Motor Show Paris. Blue: All profiles; Red: Optimal profiles (Pareto definition); Green: Best profile

Conclusion and future work

This paper presented a gamification methodology and proof of concept to encourage drivers to change their driving habits. The principle is to use a fuel consumption challenge, in virtual reality, where the drivers need to drive as far as possible with a limited quantity of fuel. This challenge, relying on this specific scenario has then be demonstrated in the Paris Motor Show in 2014 where more than 1200 participants drove on a virtual road.

It has been noticed that participants were ready to change their habits, in an innovative way, without training. This is mainly due to the gamification that increased their motivation to win the challenge and to test new technologies and sensations.

A first perspective of this work is to include more adaptive driving scenarios that will automatically increase the difficulty level according to the participant performances.

A second application, more theoretical is in progress in order to test the capabilities of SiVIC to self-control a virtual vehicle in order to compute different acceleration profiles (Normal acceleration, strong acceleration and low acceleration). Moreover this new experimentation is really necessary to evaluate the impact of current vehicle characteristics on its consumption. For instance, what would be the impact of the tire grip level, the impact of acceleration and braking capacities on the car consumption?

Finally, we have started the integration into Eco-SiVIC of electric motors modelling. With both, a combustion engine and an electric motors modelling, specific driving behaviours could be studied and highlighted. The expected results could allow the development of adaptive driving strategies for car consumption optimization depending on the driving mode (hybrid vehicle).

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