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Enhancing Road Safety through Fitness-to-Drive Metrics: The NextPerception Project on Driver Behavior Analysis and Gamification

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Abstract

Driving involves numerous factors demanding a driver’s attention. To enhance road safety, there has been a significant increase in the development and implementation of vehicle sensors. These sensors, in conjunction with mobile applications, can assess a driver’s emotional state and focus, providing feedback to enhance their attention. This paper explores the monitoring of driver behavior, emphasizing the effects of distractions and emotions on driving performance. Stemming from the European initiative, NextPerception, this research focuses on advancing perception sensors and refining distributed intelligence models in various domains, including automotive. The initiative aims to develop a

range of sensors, from obstacle detection tools to those monitoring a driver’s eye movements and vital signs. A key goal is to define a “fitness-to-drive” metric, representing the driver’s attentiveness level. The project also seeks to use gamification to emphasize the importance of this metric, increasing drivers’ awareness of their driving skills. The ultimate aim is to create a system that determines fitness-to-drive based on distractions and emotions, integrating this into a prototype simulating sensor data, and introducing a web-based application to display this data for a community of drivers.

Keywords: fitness-to-drive, automotive, safety, gamification

1 Introduction

Driving is a multifaceted task where the driver plays a pivotal role. With the myriad of factors vying for a driver’s attention, there has been a surge in the development of vehicle sensors to bolster road safety. The modern automotive landscape is witnessing an uptick in sensor-equipped vehicles, a trend propelled by legislative mandates and the rise of autonomous driving. In tandem with mobile applications, these sensors can gauge a driver’s emotional state and attentiveness, offering feedback to realign the driver’s focus.

This paper delves into the monitoring and analysis of driver behavior, with a particular emphasis on the ramifications of distractions and emotions on driving performance. It is an offshoot of the European initiative, NextPerception, which is geared towards the advancement of perception sensors and the fine-tuning of distributed intelligence models across healthcare, wellness, and automotive domains. As part of NextPerception, partners are engineering a variety of sensors, ranging from radars and cameras for obstacle detection to in-car sensors that track the driver’s ocular movements and vital metrics. The initiative’s cornerstone is to articulate a “fitness-to-drive” metric, encapsulating the driver’s level of attentiveness. Beyond the mere computation of this metric, this work envisions leveraging gamification to amplify its significance, thereby heightening drivers’ cognizance of their driving aptitude.

The overarching objective is to devise a system that computes the fitness-to-drive based on the drivers’ distractions and emotional states, which will subsequently be integrated into a prototype that simulates sensor data. Complementing this, a web-centric application will be rolled out to showcase this data on a communal platform tailored for drivers, on the basis of human-centric software principles [1].

The structure of this paper is delineated as follows:

In Section 2, we discuss assistance systems, multi-modal feedback mechanisms in vehicles, and mobile applications that bolster drivers. The narrative then segues into the introduction of gamification within the automotive realm.

The Section 3 offers a deep dive into the project’s aims, its synergy with the overarching NextPerception initiative, and an in-depth probe into the fitness-to-drive paradigm. A streamlined formula to compute driving aptitude will be unveiled, succeeded by an overview of the technological arsenal deployed for the project. Then the

implementation of the tools that relies on fitness-to-drive, i.e. the cockpit and infotainment prototype, and the web-based dashboard for activity surveillance, is presented. In Section 4, conclusions are provided.

2 Background

This section provides an overview of the assistance systems and multi-modal feedback in vehicles. It delves into the sensors currently used in vehicles and prototypes, introduces the concept of gamification in the automotive domain.

The aim of this paper is to compute an index providing insights into a driver's fitness while driving, based on data from in-vehicle sensors indicating driver distraction and emotions, which will be discussed in Section 3.

2.1 Sensors in Vehicles and Multi-modal Feedback

Sensors are integral to modern automotive design, with vehicles equipped with a variety of sensors that help manufacturers produce safer, more fuel-efficient, and comfortable vehicles. These sensors monitor everything inside and outside the vehicle, allowing onboard computers to collect data and make informed decisions.

Commonly found sensors include:

- **Radar Sensors:** Crucial for driving, they're often used by ADAS (Advanced Driver Assistant Systems) or ACC (Adaptive cruise-control) to notify or reduce collision risks and detect and navigate around objects for autonomous vehicles. They are efficient and accurate, unaffected by weather conditions, unlike cameras [2].
- **LIDAR Sensors:** Increasingly used with autonomous vehicles, LIDAR uses laser beam return times to reconstruct the vehicle's surroundings. Often combined with radar sensors for a comprehensive environment representation, they're used in ACC, braking assistance, parking sensors, and lane changes [3].
- **Oxygen Sensors:** Located in the emission system, they calculate the optimal fuel-to-air ratio for efficient combustion and optimal catalytic converter operation, controlling emissions [4].
- **Pressure Sensors:** Vital for vehicle safety, they convert pressure measurements into voltage signals. They're used in braking systems, door and window closures, exhaust and engine combustion, steering systems, and airbag deployment impact detection.
- **Image Sensors:** Capture real-time images around the vehicle, allowing drivers to monitor their surroundings. However, their efficiency can be affected by weather conditions.
- **Ultrasonic Sensors:** Used to measure distance from surrounding objects by emitting high-frequency sound pulses. Recently, they've been extensively used for autonomous parking [5].
- **Proximity Sensors:** Measure distance between objects using electromagnetic waves. The sensors transmit signals to the computer, mapping the area near the vehicle [6].

- **Speed Sensors:** Assist the ECU¹ in calculating various functions to ensure appropriate vehicle performance. The computer uses signals from these sensors for anti-skid braking systems, cruise control, and other safety issues.

From the described sensors, other services can be derived. For instance, parking sensors can be implemented using radar, LIDAR, ultrasonic, proximity, and image sensors.

2.2 Multi-modal Systems

As observed, many sensors find their application in ADAS, systems aimed at enhancing driving conditions and promoting safety [7]. ADAS often employ multi-modal feedback, either individually or in combination, to alert the driver of potential issues.

The primary multi-modal feedback mechanisms include:

- Steering wheel vibrations, activated, for instance, when changing lanes without signaling.
- Auditory signals, used to notify critical events like an impending collision.
- Dashboard visual signals, like the classic low-fuel indicator.
- Pulse braking, a recent addition, used to refocus a distracted driver.

Auditory warnings have been found to be more suitable than visual ones for urgent situations due to their faster reaction induction [8]. An alternative is vibration, either on the steering wheel or seat. Some studies suggest that seat vibrations are perceived as more appropriate and less intrusive than auditory signals.

However, multi-modal notification systems must be used judiciously. An overly aggressive, persistent, or sudden signal might momentarily affect driving, leading to accidents in extreme cases. Some studies, like the one conducted by Swan et al. [9], showed that numerous auditory alerts in a vehicle could pose risks, especially if the auditory stimulus coincides with a visual event causing change blindness. Change blindness is an attention-related effect, also studied in the automotive context. It's the inability to consciously notice significant changes in a scene when these coincide with other visual distractions. Moreover, an adaptation of the multi-modal system would provide benefits, with a proper customization, on the basis of the driver's characteristics and behaviours [10].

Currently, an escalation approach for multi-modal feedback is recommended. It starts with a visual signal, followed by a combined auditory or tactile (vibration) signal. If one of the latter two doesn't succeed, both are used [11]. If the driver still doesn't respond, pulse braking is added. Finally, if the driver remains unresponsive, the vehicle pulls over and slows down until it stops [12].

2.3 Application of Gamification in the Automotive Field

Bohyum Kim [13] in the report *The Popularity of Gamification in the Mobile and Social Era* illustrates how the combination of three elements: rapid smartphone adoption, the significant growth of mobile web, and the rise of social media usage, has

¹ECU (Engine Control Unit) is the car's electronic control unit. It regulates mixture formation, combustion, and pollutant emissions containment

led to the unprecedented, ubiquitous, and social application of game elements to real-world activities. Gamification applications span various fields, from education, like the Duolingo app that gamifies language learning, to sports, such as the NikeFuel app that leverages user tendencies to share fitness results on social media, creating challenges among users. The automotive system also finds some gamification applications.

One gamification feature that has become standard in cars is the drowsiness alert feature or driver attention alert, which decrease based on the driver's condition [14]. The level is calculated differently by car manufacturers, but two primary methods can be identified: time-based detection and actual fatigue detection.

In the **time-based detection** method, the onboard computer starts measuring time when the engine is turned on. The fatigue detector then periodically (usually every 90/120 minutes) emits an auditory signal and displays a "take a break" message on the cockpit. This recommendation is not trivial, as studies like the one conducted by Müller et al. [15] show that reaction times can increase by up to 50% with prolonged non-stop driving.

The **actual fatigue detector** activates at 65 km/h and relies on sensors that continuously monitor the driver's face, analyzing eyelid movement, potential facial expressions interpreted as yawns, and sensors that monitor vehicle movements. Based on these signals, the system gauges the driver's state, interpreting the received signals and evaluating the fatigue level. The driver is then advised to take a break.

Other interesting examples include Ford's green goddess grows leaves, Ford focus EDFIS, i-cockpit 3D, MBUX, HUD usage, Nissan Crawding, and Nissan Leaf. The first two involve a graphical representation of a natural element, indicating the eco-friendliness of the driving style.

The i-cockpit 3D, Bosch's latest invention for Peugeot 208 and E-208, presents information in a hologram format on different levels based on their importance and urgency [16].

MBUX stands for Mercedes-Benz User eXperience, a system allowing users to interact with the car using voice commands. It also offers fitness programs based on user parameters [17].

HUDs (Head-Up Displays) project essential driving data onto the windshield, allowing drivers to access information without looking away from the road, making driving more interactive [18].

Nissan Crawding [19] introduced by Nissan in its electric car models allows driver performance comparison, awarding bronze, silver, gold, and platinum medals. Similarly, Nissan Leaf evaluates the Co2 Tailpipe Emission Reduction, ranking the best drivers and awarding trophies to the top four daily performers.

Other minor gamification elements include playful interface customization, like GPS icon personalization.

Gamification in the automotive field isn't limited to the car's interior. Several mobile apps aim to enhance driver attention or positively influence driving style, including eco-friendliness. Some of these apps include:

- **EverDrive and Take Your Mobile with You:** EverDrive passively monitors driving habits and provides diagnostics for the car's next review. It encourages drivers to adjust their driving skills to improve their score [20].

- **TrueMotion Family:** This app makes it easy for families to drive together safely. It allows users to view their driving score and distraction level [21].
- **Linear BestDriver:** Detects driving style and rewards attentive and responsible drivers. The best drivers can earn Amazon gift cards [22].
- **Driving Miss Daisy:** Driving performance is evaluated by a virtual passenger (“Miss Daisy”) who reacts based on the driving quality. The app has various difficulty levels that increase based on past performance. Drivers can compare their performance to historical data on the same route, fostering self-competition and public competition [23].
- **Drive Safe:** Records driving behavior, helping drivers improve on the road and be more eco-friendly, while also earning insurance renewal discounts [24].
- **GameECAR:** A European project aiming to develop an innovative and interactive platform that encourages users to adopt an eco-friendly driving style. The platform is divided into two parts: one for data retrieval and processing and one for the gamified environment. The first collects and pre-processes all data related to the vehicle and driver’s state (e.g., fuel consumption, gear shifting, acceleration, braking, heart rate/respiration) and extracts informative indicators, like the eco-score and aggression score. The gamified environment is the actual game that processes all available data to evaluate player scores and rankings. The game’s objectives, achievable within a reasonable time with a reasonable effort, are associated with a sense of development and achievement in case of success or a sense of loss if a goal is missed. The platform also allows users to unlock new content, like avatar outfits, based on their progress [25].

3 The proposed system

This paper delves into a project with three primary objectives: the calculation of a fitness-to-drive index, the development of a web-based application, and the proposal of a cockpit and infotainment prototype.

3.1 Objectives Overview

The primary objective is the calculation of fitness-to-drive. This index aims to determine a driver’s suitability to continue driving when the vehicle is in motion. The driver’s state is monitored using specific sensors inside the vehicle. These sensors, which have been provided by partner companies and universities as part of the European NextPerception project, can detect driver distraction and identify their emotions.

The second objective introduces the development of a web-based application. This application is designed to interact with the driver, employing gamification mechanisms to maintain their driving suitability. The gamification mechanisms have been discussed in a previous section.

The third objective presents a cockpit prototype, which was developed during an internship period. This prototype displays the real-time driving suitability index to the driver. It also incorporates some of the previously described gamification techniques, ensuring that these techniques do not negatively impact the driver’s attention.

3.2 Fitness-to-Drive

Driving a vehicle is a demanding task that requires individuals to be mentally and physically fit. The term *Fitness-to-drive* (FTD) is defined as the ability to drive safely without any hindrances caused by physical or mental conditions. This suitability is often assessed only at the time of issuing a driver's license and, depending on the country, may be periodically verified, such as during license renewal.

The FTD this project focuses on is an index that indicates the driver's overall state, including physical, psychological, and emotional aspects. This index is derived from elements like visual and cognitive distractions and the driver's emotional state.

3.3 Calculation of Fitness-to-Drive

The calculation for FTD is based on data regarding driver distractions and emotions, which are collected from in-vehicle sensors. The output data from these sensors can be boolean (for distractions) or decimal (for emotions). Given the different data types, separate formulas are used to calculate their influence on FTD. The formula also factors in the vehicle's speed.

The FTD calculation formula is:

$$FTD = 1 - (DCi + DVi + Ei)$$

Where:

- DCi represents cognitive distraction.
- DVi represents visual distraction.
- Ei represents the emotion index.

3.4 Software Application for Fitness-to-Drive Calculation

As outlined in the objectives that this paper aims to achieve, the core of the project revolves around the calculation of the fitness-to-drive index. To implement this calculation, in agreement with the universities and companies participating in the NextPerception project, the MQTT protocol was chosen to send and receive messages in JSON format concerning the data.

The message exchange process, starts with the vehicle's ignition, during which a connection to the broker is established. The broker's name and port are retrieved from the configuration file. Once connected, the needed topics are subscribed to, containing messages for distraction (both visual and cognitive) and emotions, respectively. A blocking loop then begins, during which messages are received and processed at a frequency of 20Hz. This loop only stops when the vehicle is turned off.

Upon entering the loop, each incoming message's topic is checked. Once the sender is identified, the respective data and any necessary counters are decoded, extracted, and updated. Then, the actual index calculation is performed.

The JSON messages differ based on their topic.

Once all data (distraction, emotions, and current speed) is obtained and the resulting fitness-to-drive is calculated using the formula, a JSON file containing the final FTD value is created and sent via publish on the related topic.

Only after sending the message, the fitness-to-drive and the data contributing to its calculation are saved to the database using an appropriate query.

This query, in addition to the data used for the fitness-to-drive calculation, also stores the car's ID on which the FTD is calculated and the potential identifier for the daily activity carried out by the driver (discussed in the following).

3.5 Cockpit and Infotainment Prototype

The second objective, as mentioned, concerns a cockpit and infotainment prototype that leverages the implemented MQTT client for initial fitness-to-drive calculation tests and proposes a potential idea for integrating the representation of fitness-to-drive within the vehicle.

Based on preliminary studies, the decision was made to have only minimal gamification mechanisms during driving to avoid further distracting the driver. A summary of the data is only displayed when the vehicle is turned off.



Fig. 1 Designed cockpit with gauge

Upon starting the vehicle, the user is prompted to choose how to save the data: either only on the vehicle or also on the driver's personal profile, allowing each driver to monitor their driving suitability during all their journeys. After choosing the saving method, the cockpit is displayed (Fig. 1).

Inside the simulator, in addition to the classic representation using gauges for current speed, engine RPM, and fuel level, gamified elements have been added for the representation of fitness-to-drive. From in-depth studies on gamification, it emerged that users might want different representations of the same element, such as those who prefer raw technical data and those who prefer more playful and processed data. Therefore, the decision was made to allow drivers to choose the type of visualization [26, 27]. This choice was also supported by the idea of the car manufacturer Ford,

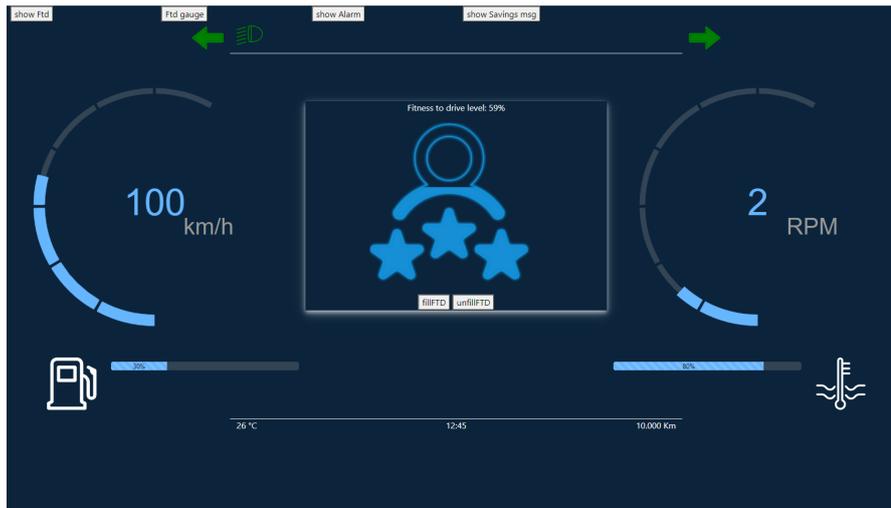


Fig. 2 Designed cockpit with icon

which believes in a cockpit that displays information in a way that drivers can best understand.

Specifically, a gauge was considered for those who feel more sporty and serious and want a clear image of the index they are observing. In contrast, a more playful representation, with an image colored based on the suitability level, was considered for those who want an alternative visualization (Fig. 2).

Major car manufacturers, like Ford, have found that with instant fuel-saving information at hand, drivers can learn to drive more efficiently. Based on this discovery, it was thought to allow the driver to select one of the two representations, and once chosen, it remains displayed until the driver decides to view other information, such as a drowsiness alert or vehicle consumption.

Regarding the FTD notification, an alarm message is displayed when the fitness-to-drive index is too low. In addition to the alarm message, other methods, such as steering wheel vibration or an acoustic signal, were considered to bring the driver's attention back to the primary task. These mechanisms were not directly implemented but will be used later when user tests are conducted.

All data collected during driving is then displayed, once the vehicle is turned off, in the statistics section of the infotainment. Specifically, the statistics section (Fig.3), using data visualization mechanisms, will provide the driver with the fitness-to-drive results from the last ten days through a tabular and graphical representation, indicating how and how much distractions and emotions have influenced the suitability index.

3.6 Web App

The last objective is a web application designed for drivers to monitor their long-term FTD. The app uses gamification techniques, such as challenges and leaderboards, to engage users. It caters to user types identified by Richard Bartle [28], including:

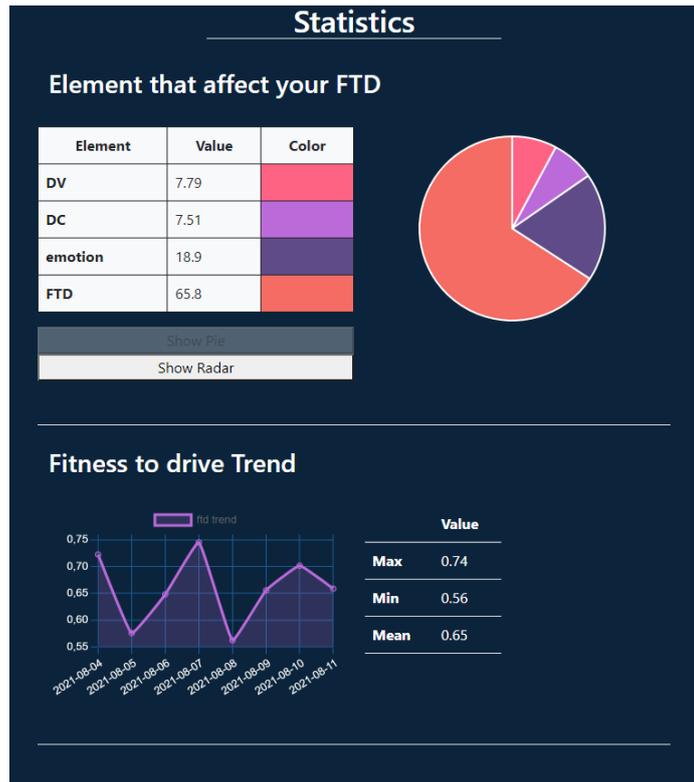


Fig. 3 Representation of the designed infotainment

- *Achievers*: System assigning a level based on fitness-to-drive.
- *Explorers*: Navigate and explore user profiles.
- *Killers*: Global and individual challenge leaderboards.
- *Socializers*: Interact by following and liking activities.

Users can register via Google accounts. Upon login, they receive a driving tip and can then access the app's features. The home page offers an overview of user activities, with details like likes, FTD indicators, and graphical summaries of driving emotions and distractions (Fig. 4).

Clicking on a nickname leads to the user's profile, displaying personal data, fitness level, and sub-pages for main card, statistics, and activities. The main card showcases the best FTD result and challenge progress. The statistics page visualizes the last 10 days of FTD, distractions, and emotions. The activities page summarizes personal activities.

Users participate in challenges against other app users. A dedicated page lists challenges and progress. A separate global leaderboard encourages competition to enhance overall user FTD.

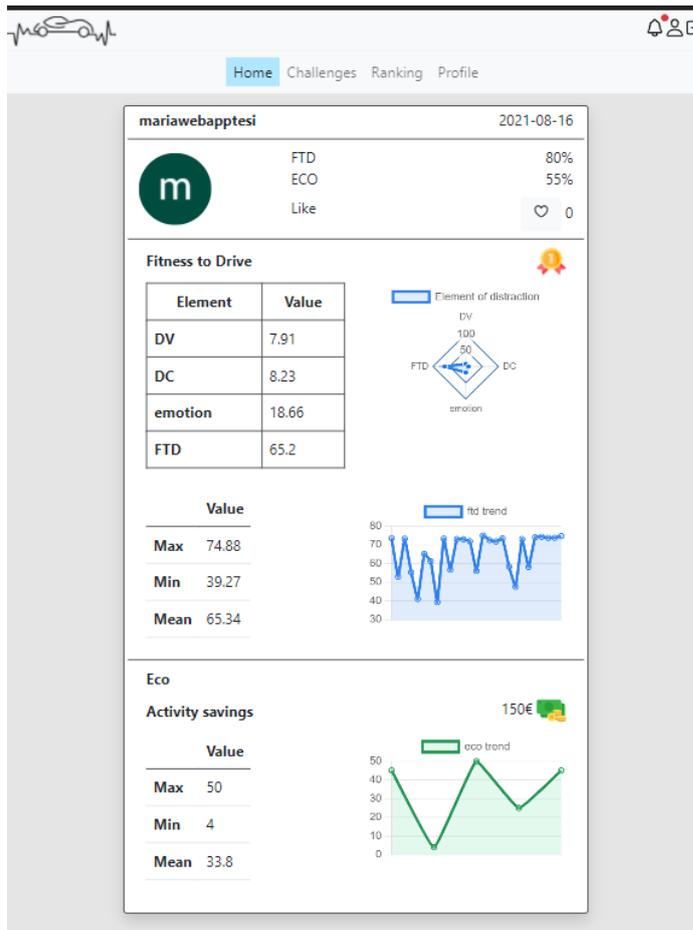


Fig. 4 Activity details - tablet mode

The app notifies users about new challenges, likes, and welcome messages. An admin section allows challenge management. The app also hints at future eco-sustainable driving features, though they're currently not implemented.

4 Conclusions

This research aimed to define a formula for assessing driving fitness and to showcase its practical application, contributing to the European NextPerception project.

Initial studies focused on driver support technologies and the impact of visual/cognitive distractions and emotions on driving. Distractions, both visual (diverting gaze from the road) and cognitive (mind wandering), were identified as major factors affecting driving fitness. Among emotions, anger and happiness were found to be the most detrimental to driving.

A formula was developed to calculate a fitness-to-drive index, considering penalties for cognitive and visual distractions (based on vehicle speed) and the influence of emotions.

To demonstrate the real-world application of this index, a cockpit prototype and a web application were developed in Python. These tools incorporated the fitness-to-drive index and gamification techniques, encouraging drivers to monitor their driving fitness both during and after trips.

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