Use of a cognitive simulation model of the driver to support the Virtual Human Centred Design (V-HCD) of ADAS and automated vehicles

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Abstract

This paper presents a research programme jointly implemented by IFSTTAR and ESI group in order to develop an integrative simulation platform able to support the human centred design of future Advanced Driving Aid Systems (ADAS). This 'Virtual Human Centred Design' platform, named V-HCD, is based on a cognitive simulation model of the car driver (named COSMODRIVE) interacting with a Vehicle–Environment simulation platform (named Pro-SiVIC) also able to integrate simulated ADAS. From this integrative simulation approach, it is expected to better take into account end-users needs since the earliest stages of the design process, and then, to reduce the costs of driving aids development, prototyping and test.

Keywords: Driver Model, Virtual Human Centred Design, Simulation, ADAS, Vehicle Automation

1. Introduction: Context, motivations and objectives

With the massive development of Advanced Driving Aid Systems (ADAS), the whole activity of the human driver in modern vehicles is progressively changing. Like the technological progress revolutionized aeronautics at the end of the 1970s (Billings, 1991; Sarter and Woods, 1992), automation is now appearing in cars through new driving aid systems liable to take the control of the vehicle under certain conditions (SAE, 2014). From a driving task totally under the responsibility of the human driver (in terms of road environment perception, decision-making and sensorimotor control), we are now heading towards a co-managed driving task under the joint authority of a complex entity: the "Human-Machine System" (Bellet, Hoc, Boverie and Boy, 2011).

However, past efforts of automation in other areas, like nuclear plants or aviation, revealed a set of potential risks in terms safety introduced by automation (e.g. Bainbridge, 1983; Young, Stanton and Harris, 2007), which may cause new types of human errors, risks and accidents.

Facing to this disruptive evolution, the decision and the way to introduce automation in order to assist, to support, or to replace the human must not only take into account the technological capabilities by themselves, but also the drivers' needs, their own abilities and characteristics, and their acceptance regarding such a technological assistances (Kyriakidis et al, 2017). A Human-Centred Design approach is particularly important in car driving context, according to the heterogeneity of the drivers, the potential risks of the driving task, the variability of the traffic situations and, lastly, the responsibility issues in case of accident. However, integrating end-users' needs is not always easy, especially when one wishes to design totally innovative systems. Ergonomics evaluations with real humans indeed required to develop mock-ups or prototypes which are generally expensive in terms of both money, efforts and time.

To better integrate user's needs during the design process, a Virtual Human Centred Design platform (V-HCD) was jointly developed by IFSTTAR and ESI group. The challenge was to develop a virtual simulation tool able to support Human-Based simulation (i.e. based on a virtual driver model) for virtually assessing accident risks (in case of unassisted drivers) and then the potential benefits of future ADAS. From this approach, it is expected to reduce costs and to increase the efficiency of the design process of future driving assistances, which are more and more complex and thus expensive to develop (Cacciabue and Vollrath, 2011).

Synthetically, this V-HCD integrative platform jointly combines two main components (Bellet et al, 2012):

- A "Virtual driver" based on COSMODRIVE model (for *COgnitive Simulation MOdel of the DRIVEr,*), able to simulate drivers' Situation Awareness (Bellet et al, 2009), decision making (Bornard et al, 2016) and visual scanning of the road scene (from a "virtual eye").
- A Virtual car, equipped with simulated sensors and with a virtual ADAS - simulated with Pro-SiVIC software - able to be piloted by COSMODRIVE virtual driver for dynamically progressing into a 3D road environment.

2. COSMODRIVE virtual driver

COSMODRIVE is a COgnitive Simulation MOdel of the DRIVEr developed at IFSTTAR-LESCOT in order to simulate drivers' mental activities carried out when driving a car, from perception to action (Bellet et al., 2009). At the perceptive level, two complementary processes are implemented in the Perception Module of COSMODRIVE. The first one, named *perceptive integration*, is a "data-driven" process (i.e. bottom-up processing) and simulates the cognitive integration of environmental pieces of information into the Cognition Module, according to their saliencies for the human eyes. The second process is the *perceptive exploration* (referring to Neisser's theory of perceptive cycle; 1976), which is a ''knowledge-driven'' process (i.e. top-down) in charge to dynamically explore the road scene according to drivers' situation awareness, risk assessment, intentions and decisions to be made. From these 2 processes, COSMODRIVE is able to scan the road environment with a "virtual eye" and thus to simulate real drivers' visual strategies. Visual strategies take the form of a set of *fixation points* which are the "outputs" of COSMODRIVE model, in a similar way of empirical data collected from an eye tracking system among real human (as illustrated on the bottom left view of Figure 1).

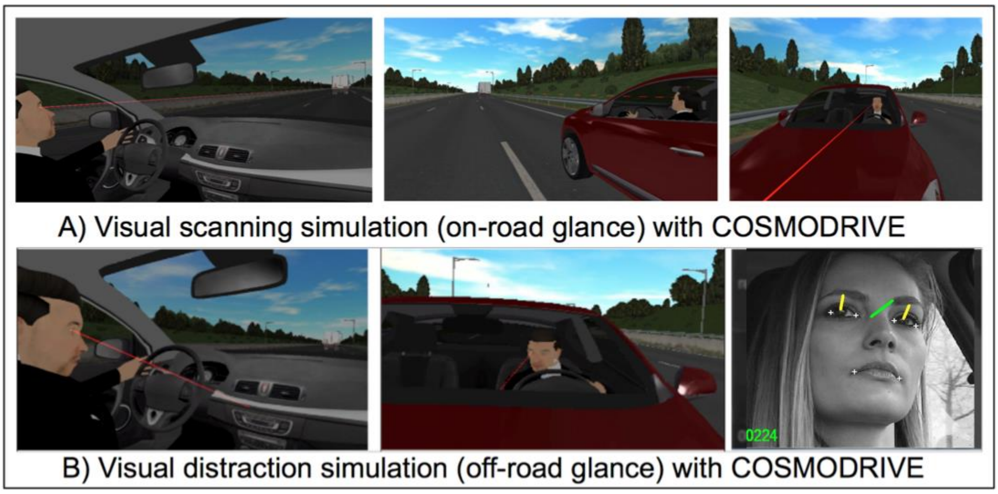

Figure 1: Simulation of Drivers' visual Scanning with COSMODRIVE

Perceptive data collected by the virtual eye and processed by the Perception Module are then integrated in the Cognition Module of COSMODRIVE. The key-component of this Cognition module are "Mental Representations" (Bellet et al., 2009), corresponding to the driver's Situation Awareness according to Endsley's definition of this concept (1995): *the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*. Mental representations, as mental models of the traffic situation, are dynamically formulated in working memory through a matching process between (i) information perceived in the external environment and (ii) pre-existing driving knowledge, that are modelling in COSMODRIVE as “Driving Schemas” and “Envelop Zones” (Bellet et al., 2009, 2012). These mental representations provide ego-centred and a goal-oriented understanding of the traffic situations. They take the form of a Four-Dimensional mental models (temporal and spatial) of the road environment, liable to be mentally “deployed” by the driver, in order to support anticipation through cognitive simulations, and thus providing expectations about future situational states.

This cognitive process of anticipation based on a “mental deployment” is illustrated in Figure 2. In this situation, the driver/model is following a truck that is suddenly braking. Facing to this unexpected event, the virtual driver has to make the decision between braking versus implementing an overtaking manoeuvre. To support this decision-making process, the virtual driver (like real human) mentally explores alternative driving behaviours in order to assess their respective feasibility and levels of risk (for instance, by immediately implementing a Lane Change manoeuvre with the current speed, versus after a braking aiming to reduce the car velocity). From the results of these mental deployments, COSMODRIVE will make its decision by selecting the most appropriate manoeuvre and/or the less critical behaviour. Then, this planned behaviour is provided to the Action Module in order to be effectively implemented by the virtual driver (through actions on vehicle commands).

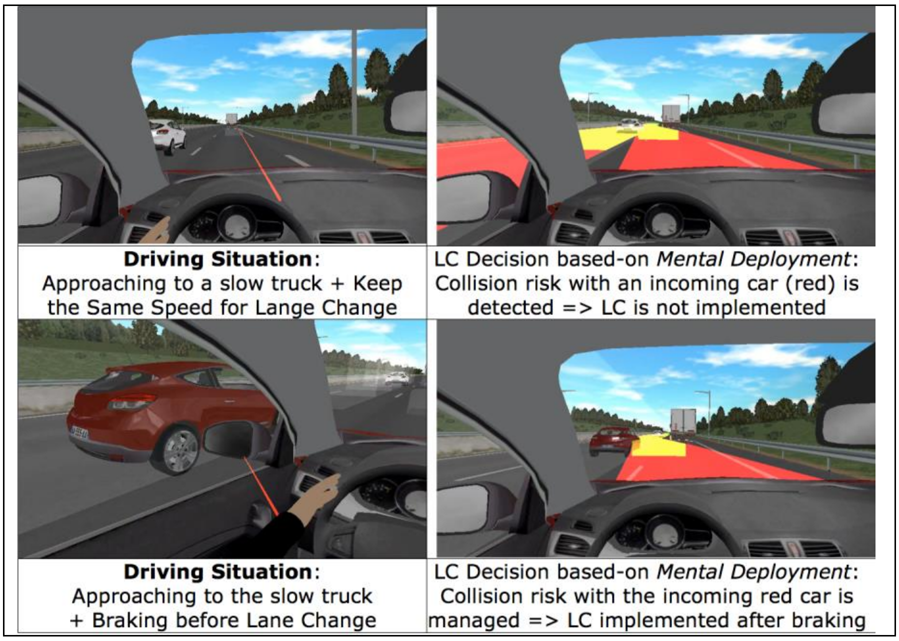

Figure 2: simulation of decision making processes based on mental deployments

When driving, human drivers continuously update their Situational Awareness (SA) as and when they dynamically progress on the road. SA contents depend on the aims the drivers pursue, their short-term intentions (i.e. tactical goals, such as changing of lane for overtaking), the attentional resources they allocate to the driving task and their visual scanning of the road environment. In case of a visual distraction, the mental model updating may be negatively impacted, more particularly in case of too long off-road glance and/or if an unexpected event is occurring in the driving environment.

Figure 3 presents a typical example of erroneous Situation Awareness of the driver due to visual distraction, as simulated with COSMODRIVE. In this situation, the followed truck is braking when the driver is visually distracted (fixation point of the virtual eye on the car radio; as presented in the central view of the figure). Consequently, the mental model of the driver (right view of the figure) is not correctly updated: the front truck is still far in the mental model compared to reality (left view of Figure 3).

Figure 3: Erroneous updating of Driver's SA due to visual distraction

3. Pro-SIVIC simulation software

Pro-SIVIC software of ESI group is a Vehicle–Environment–Sensors simulation platform initially developed by IFSTTAR-LIVIC (Gruyer, et al., 2006) for the virtual design, prototyping and test of virtual sensors for embedded systems, with respect to their physical capabilities. The aim of this software is to support real-time simulations of environmental changes including weather conditions, moving objects, infrastructures, or others dynamic events. Indeed, the design and the development of driving assistance systems generally requires to collect a lot of data through vehicles equipped with an embedded architecture of perception and control/command systems. From simulation, Pro-SiVIC may replace real-life data collection by simulated data. In order to be able to reproduce a coherent situation with the reality and to be able to generate the data coming from real sensors embedded in a vehicle, a set of sensors were modelled with a high fidelity in this software. The main sensors models currently available are video cameras, radars, laser scanners, odometers, inertial navigation system, GPS and ultrasonic sensors. Pro-SiVIC can be used for the virtual prototyping and test of perceptive functions and control algorithms associated with a set of simulated perception sensors. By changing parameters of the environment (e.g. weather conditions like fog, rain or snow, sun position or light effects, night driving, etc) it is possible to evaluate the robustness of these algorithms in a systematic way and under extrems driving conditions.

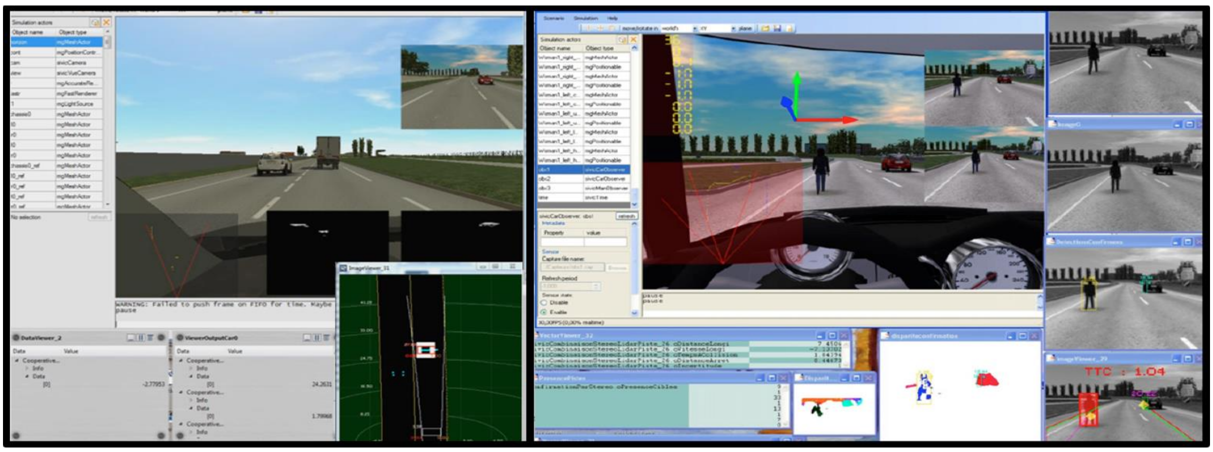

Figure 4: Examples of Pro-SiVIC use for virtual sensors and ADAS simulation

Figure 4 presents two examples of applications related to fully autonomous car design (left view) and pedestrian detections (right view). These advanced driving aid systems were virtually prototyped by IFSTTAR-LIVIC with Pro-SIVIC, and then effectively embedded in a real car (e.g. Gruyer, et al., 2006, 2010). Several demonstrations of ADAS and autonomous car applications based on Pro-SIVIC are available at http://www.civitec.com/applications/.

4. The V-HCD integrative platform: a simulation tool to support the Virtual Human Centred Design of future ADAS

In order to support the Virtual Human Centred Design (V-HCD) of future ADAS and vehicle automation, and integrative simulation platform combining COSMODRIVE and Pro-SIVIC has been jointly developed by IFSTTAR and ESI group.

The functional architecture of this V-HCD platform is presented in Figure 5. The version of the COSMODRIVE model interfaced with Pro-SiVIC in the V-HCD is composed of three main modules: a *Perception Module* (in charge to simulate human perceptive information processing from a "virtual eye" implemented from a pro-SIVIC virtual camera), a *Cognition Module* (in charge to simulate Situation Awareness, anticipation and decision-making processes), and an *Action Module* (in charge to simulate executive functions and to act on the commands of a Pro-SIVIC vehicle). When working together, these 3 modules are able to jointly simulate all the perceptive and cognitive activities required fot car driving.

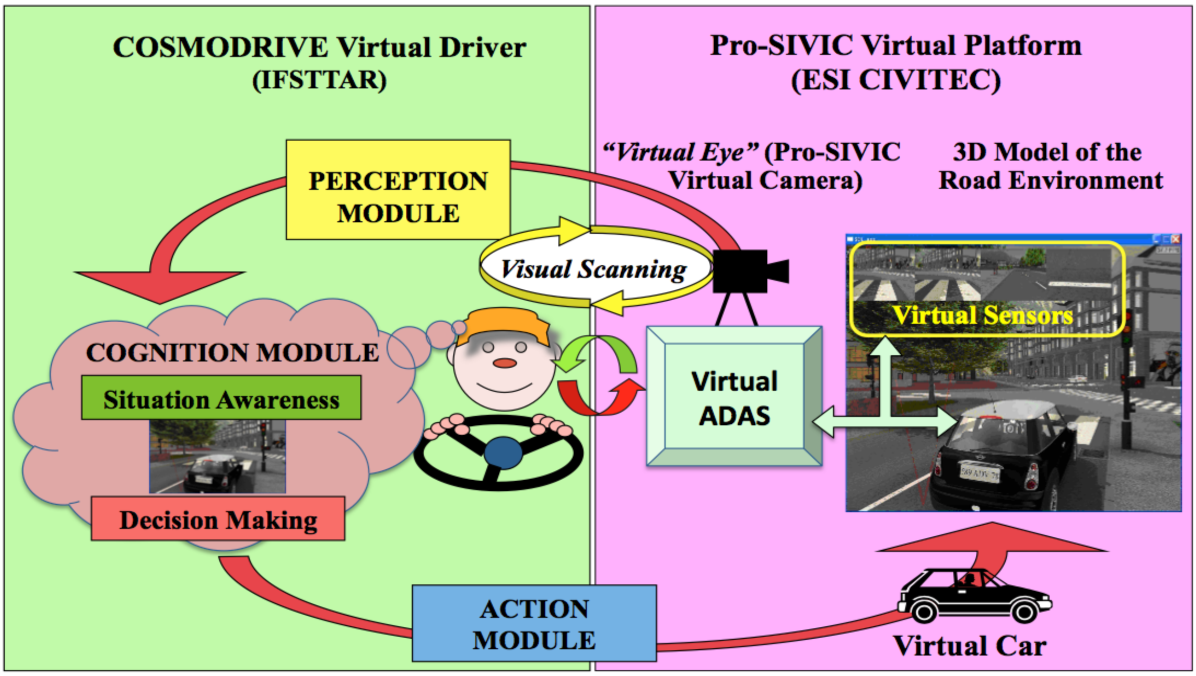

Figure 5: The V-HCD platform, interfacing COSMODRIVE and Pro-SIVIC

From this V-HCD integrative platform, it is possible to generate dynamic simulations of drivers' behaviours when interacting with a virtual vehicle liable to be equipped of virtual ADAS. Such a type of simulations, based on a virtual driver model, may be used at different levels of the V cycle of the design process of future driving aid systems, as summarized in the following Figure 6.

In comparison with the traditional method implemented to design ADAS, the human centred method based on the V-HCD platform presents several advantages. Indeed, from a "User Centred Design" point of view, it is crucial to take care of end-users' needs during the design process. Unfortunately, it is generally very difficult for Human Factor experts to interact with engineering designers at some steps of the development cycle. In addition, it is not aways possible to obtain Mock-Ups and/or prototypes of the ADAS liable to be evaluated with end-users during the initial stages of the V design process and, if possible, it is generally very costly in terms of time, effort and money to perform evaluations with real humans.

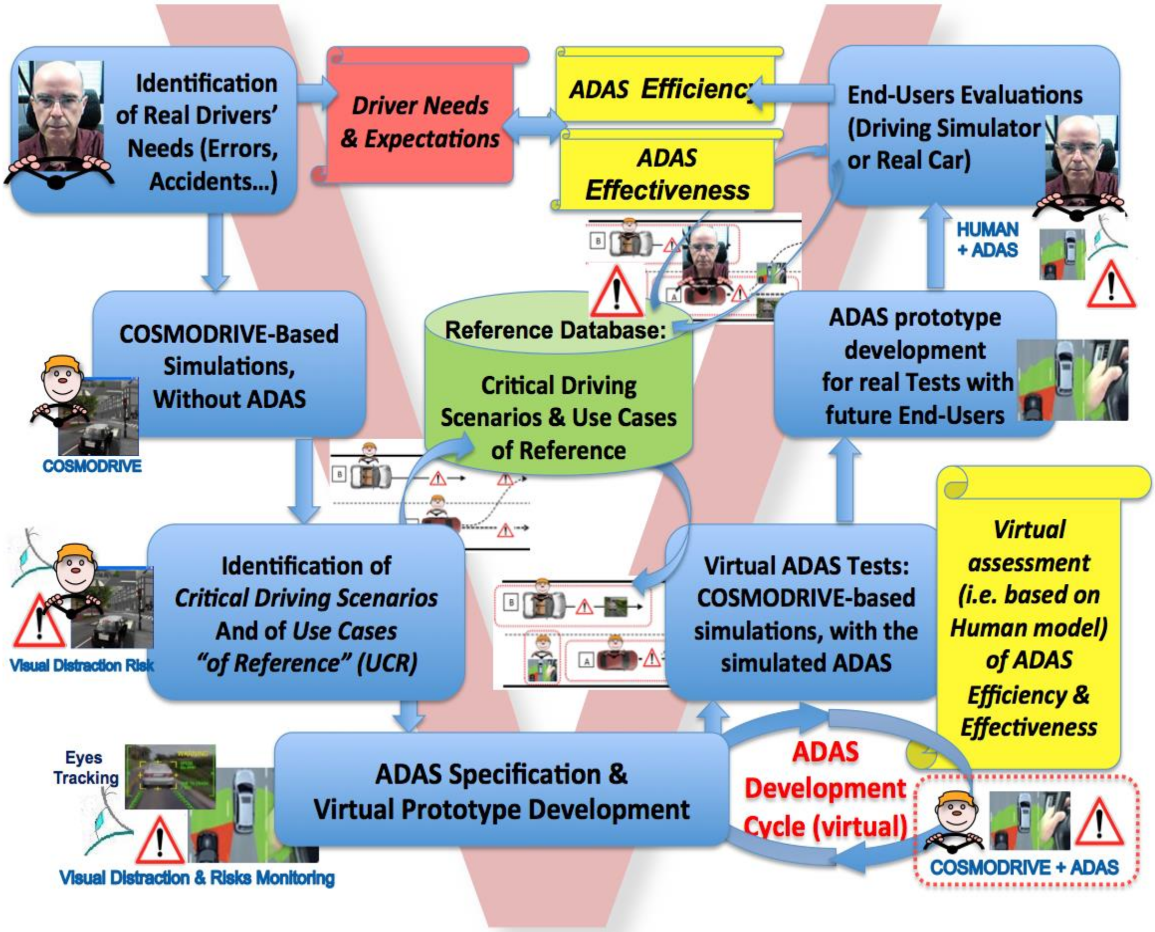

Figure 6: The Virtual Human Centred Design Cycle, as supporter by COSMODRIVE and Pro-SIVIC simulations

The main objective of the virtual design and prototyping method introduced by the V-HCD is the possibility of using a "virtual model of future end-users" at all the stages of the design process. During the initial phases of the development cycle, COSMODRIVE-based simulations may assist the designer to:

- Simulate human drivers' performances, errors and potential accident risks, in case of an unassisted driving,
- Identify the most critical driving scenarios and specify accordingly the future ADAS to be developed to manage them in a safe way;
- Provide accordingly a set of Use Cases to be used as Requirements, Functional and Technical Specifications of this future ADAS.

The results of such simulations may be then stored as "*Use Cases of Reference*" and re-use as "test-scenarios" to support the ADAS development. Indeed, during the progressive development of ADAS prototypes, dynamic simulations supported by COSMODRIVE virtual driver may be implemented to anticipate the future uses of this ADAS by real humans and to evaluate their interests from the end-user point of view.

From this virtual design approach, the objective is to:

- Test and improve ADAS Effectiveness, by using initial “Use Cases of reference” for evaluating if this system is able to effectively assist end users by avoiding accidents
- Evaluate ADAS Efficiency in accordance with end-users’ characteristics and limits (by also using “Use Cases of References” as “requirements” at the technical levels)
- Evaluate and validate ADAS efficiency and effectiveness for highly critical scenarios ethically impossible to test in real driving conditions among human drivers.

At this implementation and evaluation levels, one of the main advantages of this approach is the allow the designers to assess the respective benefits versus the potential risks on road safety of different versions of a driving aids systems, under different driving conditions, as supported by Pro-SIVIC software functionalities (e.g. night driving, bad weather conditions like fog, etc).

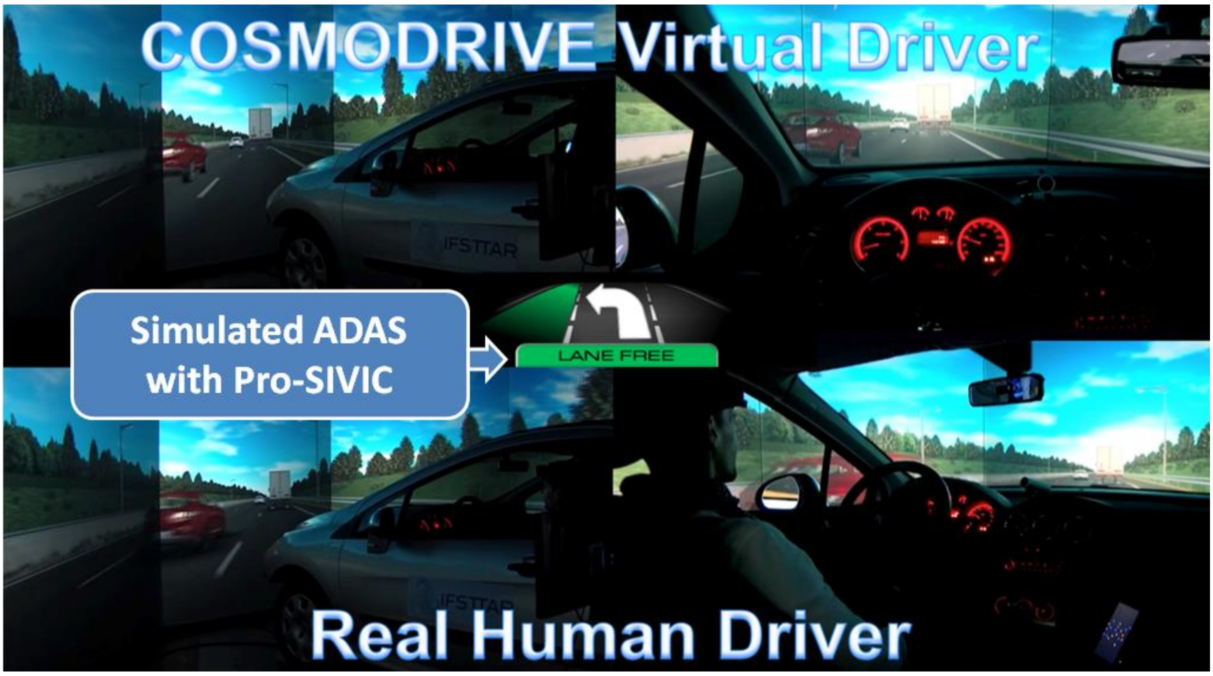

Figure 7: comparative evaluation of ADAS (with virtual vs real drivers) on the V-HCD platform, interfaced with IFSTTAR driving simulator

Because based-on a Human Driver Model, such types of virtual HCD evaluations may be easily implemented at each phase of the V design cycle. Nevertheless, when the ADAS validation is achieved in a virtual way, real evaluations with end users are still required for the final validation of the prototype in terms of adequacy to drivers’ needs, road safety and acceptance. To support this last stage of the evaluation process, the V-HCD platform has been interfaced with the IFSTTAR driving simulator (Figure 7) in order to support immersive experiments among real humans.

According to that, it is additionally possible to compare virtual testing results based on COSMODRIVE simulations with real drivers’ performances, and thus to support further development and validation of this model to progressively increase its validity for the future development of new ADAS.

4. Conclusion and perspectives

With the recent emerging of advanced driving aid systems based on high levels of automation, there is a new set of challenges regarding their technical design, testing, certification and then validation. In addition, with the increasing of the new ADAS complexity, such design and evaluation processes become more and more complicated and expensive for the car industry.

Moreover, technical validation is only one side of the coin. The other one concerns the future human users of these ADAS systems (Kyriakidis et al, 2017). One way to anticipate their future use by humans is by performing virtual simulation based on human models, as well as driving simulations with the "human-in-the-loop". Indeed, even if a system based on vehicle automation is technically validated, a remaining challenge is to understand how this system will be used (or misused) by human beings, and what types of interaction will take place with other vehicles as well as with humans inside or outside the vehicle in question.

In this context, as mentioned in the recent FERSI position paper (Lindström A. et al 2018), a new generation of virtual testing methods supported by a new type of integrative simulation platforms, including both the simulated ADAS and human model(s) of the future users, need to be used before introducing real systems on the public road. They are essential in predicting potential risks for end users, to increase effectiveness and benefit of future ADAS, and finally to avoid new types of accident likely to occur, much as was the case when automated systems were introduced in aviation. The V-HCD integrative platform presented in this paper has been specifically designed to achieve these objectives. It is currently used in the frame of VI-DAS European project (H2020) to support the virtual design and prototyping of an advanced adaptive and cooperative HMI dedicated to future automated vehicles.

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