Title:
User Studies in Laboratory Driving Simulations

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Introduction:
User studies have been increasingly conducted in the driving field, in order to increase road safety, improve comfort level, and eventually interact with the decision-making systems in case of automated driving. Three methods are mainly used in nowadays driving behavior studies, namely Computer simulation, Field test, and Laboratory test. Computer simulation mainly focuses on vehicle behavior-related issues, for example, lane-changing and acceleration behaviors [19] and pedal control operations [3]. While, field tests have been mostly used in qualitative researches with questionnaires combined[2, 20]. Laboratory driving simulation is widely used in exploring user's emotions, cognitive and behavioral changes in a specific driving condition because of its precise controllability and fidelity [11]. Along with the rapid growth of automation level in the automobile industry, the laboratory driving simulation is the most promising method of user studies because it is not only applicable to the existing vehicle technologies and also to the ones under development. The aim of this article is to give an overview of how the laboratory driving simulation method is applied in the user studies. A model of the user-vehicle interaction model has been set-up, according to which the user behaviors can be analyzed with a different focus by three categories of automation of the vehicle. From the perspective of measuring driving performance, driving simulators offer a safe, convenient alternative to on-road tests. Fixed-base driving simulators have been widely validated in a series of studies with various research purposes [8]. In this study, a typical set-up of a fixed-based driving simulator and the measurement data collecting tools are introduced in order to provide a comprehensive insight into the topic. And three case studies have been conducted in this driving simulator to verify the methods' effectiveness and availability, focusing on a user behavioral issue of each category of automation correspondingly.

Automation levels in vehicle:
According to the SAE International definition, the automation level of the vehicle is divided into 6 different layers, thus Level 0 - Level 5, from no automation to full automation. In each level, the Dynamic Driving Task (DDT) is completed by both the human driver and the vehicle operating, only the proportion of each element changes. From Level 0 to Level 2, the main DDT falls to the human driver, while in the high levels of automation (Level 3- Level 5), the main role of the human driver and the automated driving system exchanges. From the viewpoint of the driving simulator complexity, Level 2 and Level 3 (partial/conditional automation) have higher requirements respect to other levels because human drivers are expected to regain control when the automated driving system fails, thus an interaction

between the user and the vehicle system should be considered for the falling back of DDT in the design and construction of the driving simulator.

<u>Main focuses of levels</u>
As introduced, the research focus varies among different levels, because of the changes in driving task distribution. Fig. 1 reveals the position of the user in driving tasks in three categories of automation of autonomous vehicles (AVs) has been shown, and the elaboration of these three categories are as follows:

- Level 0–Level 1 (Low automation): most of the control tasks belong to the human driver, so monitoring and helping to maintain the attention level of the driver is important for the road safety[13] , for instance alerting the drowsiness [9], monitoring the fatigue and stress [14];
- Level 2-Level 3 (Semi-automation): part of the control shifts between the automated driving system and the human user, in these levels the issues concerning Take Over Tasks becomes the most critical point, for instance user's response time to the Take-over request and explore the optimal modality to communicate the Take-over requests [10];
- Level 4-Level 5 (Full automation): engagement of the human driver is eliminated, user study focuses on improving trust and comfort[7]. Especially, some user studies have shown that keeping the transparency of the decisions and behaviors of the AVs will be helpful to increase the user's trust and confidence towards the AVs[16][6].

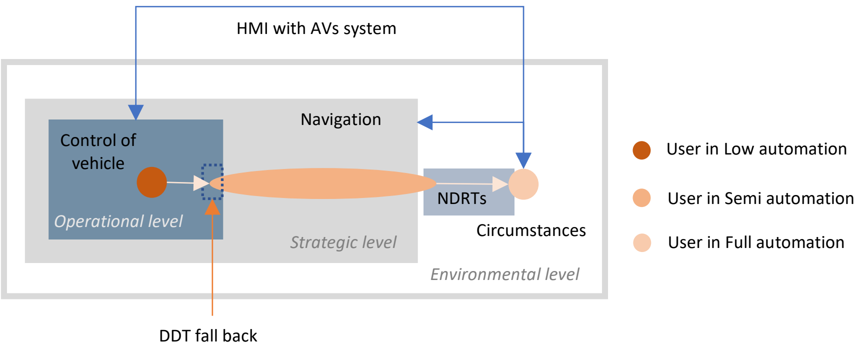

Fig. 1: Model of user studies in different automated driving levels.

<u>Set-up:</u>
As shown in Fig. 2 (a), the main part of the fixed structure driving simulator consists of physical structure including a set of commercial vehicle control such as the steering wheel with force feedback, the gear shift lever with automatic transmission, and the brake and accelerator pedals (Logitech G920, https://www.logitechg.com/en-roeu/products/driving/driving-force-racing-wheel.html). Three 32-inch screens providing 175 degrees field of view show the virtual driving scenario. Two software are used depends on the research purpose, Unity 3D (https://unity.com/) for tests that requires simulation environment fidelity, because of its highly customizability, while IPG CarMaker (https://ipg-automotive.com/products-services/simulation-software/carmaker/) for high vehicle dynamic features simulation because of its possibility of introducing all parameters defining a real numerical model of different vehicles.

ProComp Infinity physiological sensors (http://thoughttechnology.com/index.php/procomp-infiniti-344.html) are for collecting the bio-signal data of user, Pupil Labs (https://pupil-labs.com/) eye tracking glasses for recording users' eye movements and pupillometry information, and cameras for recording the users' movements (Fig. 2(b)). The data generated by the driving simulator are used to explain how the users behave and perform. For instance, the lane position of the car, the steering wheel angle, the throttle pression as well as velocity and acceleration of the vehicle.

Finally, user study methods in the field of design has been used to assess parameters which are difficult or even impossible to be measured quantitatively. The methods include interviews, questionnaires, usability studies, such as the questionnaire on user's acceptance [12], Self-Assessment Manikin (SAM test) [5], and User Experience Questionnaire (UEQ) [17].

Fig. 2: Set-up of the fixed-base driving simulator: (a) participant wearing the physiological sensors and eye-tracker during a driving task; (b) monitoring and data recording systems besides the simulator.

<u>Case studies:</u>

Low automation scenario

Due to the fact of DDT mostly falls onto the human otherwise the vehicle control system, in low-level AVs (L0-L1), how to maintain the attention level of the driver is the most focused issue for improving the road safety. 15 participants had been involved in a study on the effectiveness of olfactory signals in keeping the driver's attention, comparing to the conventional auditory signal. In this study, an olfactory display was implemented into the driving simulator and releasing olfactory signals in the olfactory-track of test replacing the auditory signals in the auditory-track. The drivers' Electrodermal activities (EDA) were recorded and analyzed to investigate the driver's parasympathetic activities, therefore the cognitive arousal could be identified, and it has been verified that olfactory signals are useful and more efficient in keeping driver's attention respect to the conventional in-car alarm signals [4]. Another study involved both the physiological sensors and the eye-tracker to investigate drivers' behavior changes in different levels of detail (LODs) in the driving simulation, which would help researchers to understand the impacts of LODs onto the users' behavior both from the mental perspective and eye-movements in the low automation scenarios.

Semi-automation scenario

For semi-AVs (L2-L3), the control shifting between the human driver and the AVs system is one of the most critical scenarios in the roadmap of AVs development. An investigation of the correlation of the drivers' performance and their reaction time to the take-over request in semi-autonomous driving has been done in the driving simulator. By driving in a virtual scenario simulating take-over tasks, three participants' behavioral profile has been defined by analyzing key metrics collected by the simulator, namely lateral position, steering wheel angle, throttle time, brake time, speed, and the take-over time. In addition, heart rate and electrodermal changes have been considered as physiological indicators to assess cognitive workload and reactivity [18]. Eyes-on-road reaction time, steer initiation time and steer turn time were the variables taken into consideration in a study of 101 participants focusing on the take-over scenario from the drivers' behavior aspect, and a usefulness and satisfaction questionnaire was introduced as a subjective assessment of the take-over request modality [15].

Full automation scenario

The bursting development of self-driving technology (L4-L5) leads us to face the challenge of providing an optimal user experience in the 'third living space' from the perspective of human factors. Due to the algorithm used in the AVs system, the performance of the vehicle differs from one to another. This case study gave an insight into the impact of AVs driving styles onto the human user from a human factors point of view under a Non-driving-related tasks (NDRTs) scenario. Two AVs systems based on two algorithms (REINFORCE and DDPG) with different characteristics are utilized to generate the two driving styles of the AVs, which are implemented into a driving simulator in order to create an autonomous driving experience. 8 user's skin conductance data, which enables the evaluation of the user's cognitive workload and mental stress were recorded and analyzed. Subjective measures were applied by filling out Swedish occupational fatigue inventory (SOFI-20)[1] to get a user's self-reporting perspective view of their behavior changes along with the experiments. The results showed that human's states were affected by the driving styles of different autonomous systems, especially in the period of speed variation. By analyzing users' self-assessment data, a correlation was observed between the user "Sleepiness" and the driving style of the AVs.

The summary of the methods used in different levels of automation user studies are listed in Fig. 3.

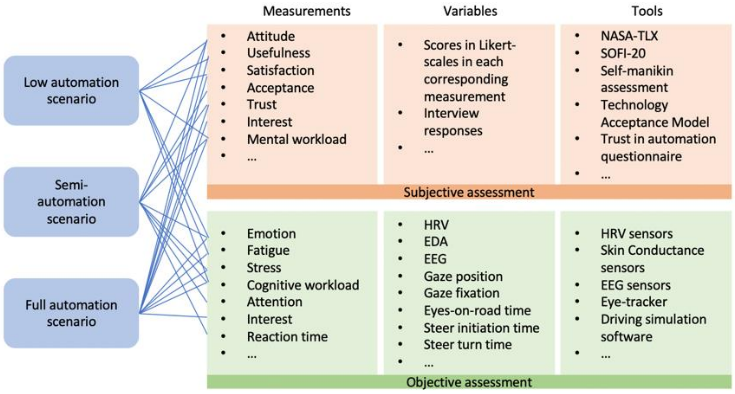

Fig. 3: Measurements, variables, and tools involved in the user studies of three levels of automation.

Conclusion:

In the transition period of stepping into autonomous driving, a user study platform that can support researches in multiple levels of automation is energy-saving and high-efficient. In this article, a model of user interaction in different AVs automation has been introduced, according to which the potential issues in each automation level could be allocated, and a typical driving simulator which widely used in laboratory tests has been implemented. According to the categorization of SAE International, there are six automation levels in the automobile industry and can be divided into three groups according to their main concerns from the viewpoint of human factors, namely low automation, semi-automation, and full automation. The case studies of each level have been presented following the proposed method and the measurements and tools are summarized.

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