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ABSTRACT
This paper presents a preliminary study of the use of Virtual Reality for the simulation of a particular driving task: the control recovery of a semi-autonomous vehicle by a driver engaged in an attention-demanding secondary activity. In this paper the authors describe a fully immersive simulator for semi-autonomous vehicles and present the pilot study that has been conducted for determining the most appropriate interface to interact with the simulator. The interaction with the simulator is not only limited to the actual car control; it also concerns the execution of a secondary activity which aims to put the driver out of the loop by distracting him/her from the main driving task. This study evaluates the role of a realistic interface and a 6-DoF controller-based interaction on objective and subjective measures. Preliminary results suggest that subjective indicators related to comfort, ease of use and adaptation show a significant difference in favor of realistic interfaces. However, task achievement performances do not provide decisive parameters for determining the most adequate interaction modality.

CCS Concepts
• Human-centered computing→Human computer interaction (HCI)→Interaction devices • Human-centered computing → Human computer interaction (HCI) → Virtual Reality

Keywords
Virtual Reality; Driving Simulation; HMD; Interaction devices; Semi-Autonomous vehicles; self-driving cars

1. INTRODUCTION
Autonomous and semi-autonomous vehicles are likely to become a reality in the coming years. Progress toward full self-driving automation has already started with the introduction of systems able to automate some simple driving tasks. In the near future it is likely that systems able to perform a complete journey without human intervention will be introduced [1]. Since autonomous cars will not require constant supervision, the driver will be free to undertake a secondary activity, such as talking to passengers, reading a book, or using a smartphone or tablet. These scenarios therefore require an interface within the vehicle to switch control (Transfer of Control) when the automated driving system notifies to the human driver that s/he should promptly begin or resume performance of the dynamic driving task (Take-Over) [2] or when the human driver wishes to leave the control to the system (driving delegation).

In this context, Virtual Reality technologies can be deeply exploited. VR systems can be used not only as testing and validation environments but also as a training environment for people who are coming in contact with this kind of interface for the first time. The use of VR for this last purpose is the subject of this work. In this paper, we evaluate the use of Light Virtual Reality systems for the acquisition of skills for the Transfer of Control (ToC) between the human driver and the semi-autonomous vehicle. Light refers to VR systems that are easy to setup and manage, not cumbersome and preferably low-cost. In this study, the intention to develop a simulator accessible anywhere for training a large number of people in a fast and reliable way suggests the need for light systems. The system will be used as a training environment where users can become familiar with the novel equipment in the vehicle and can learn how to properly interact to gain or release the driving control in a variety of everyday driving situations.

In this study this system and two simulation interfaces are presented, and the following research topic is addressed: the interaction in Virtual Reality driving environments with a particular focus on the interaction with a semi-autonomous vehicle. For this study an HMD is used as the display device for our Light Virtual Reality system. By wearing the HMD the user loses his/her capability to see the external world. This provides a high sense of immersion, while also preventing the use of traditional interaction devices such as keyboards and conventional joysticks. Considering the need to deploy a light and easy to set up system, it is important to investigate which kind of interaction device is the most adequate to simulate a control recovery task in a highly automated driving scenario.

2. RELATED WORKS
The use of Virtual Reality for driving simulation has been widely addressed by researchers. Several studies have been conducted with the purpose of evaluating the usability [3] and the

physiological responses [4] of a VR driving simulator, as well as the driving differences between the real and the virtual experience [5].

Regarding the simulation of autonomous vehicles, there are only a few ongoing studies about the simulation of critical scenarios [6] and the design of the interface [7, 8] for a complete driving simulation in a fully immersive virtual reality system. Most of the research in this field is aimed at evaluating driver behavior [9, 10] and the cognitive load [11, 12] during the Transfer of Control from the vehicle to the human driver.

Although to date, literature lacks studies on the use of Virtual Reality for training purposes on (semi-)autonomous vehicles, there are a few studies which have addressed the problem of regaining control of a semi-autonomous vehicle for drivers engaged in a secondary task [13, 14]. In [13], the authors evaluated the point in time in which the driver's attention must be directed back to the driving task. In particular, they examined the take-over process of inattentive drivers engaged in an interaction with a tablet computer. Our pilot study is based mainly on this work; however, it differs by two aspects: the type of simulator (full vehicle mockup vs VR headset) and the secondary activity. In [14], the authors investigated reaction times with relation to the duration of autonomous driving before regaining control. They found that the longer the time disengaged from the driving task, the longer the reaction time.

Concerning interaction in a virtual environment, the literature includes several examples of work that evaluate the effects of realism on the user. In [15], the authors explore the differences in performance with respect to very high and very low levels of both display and interaction fidelity.

No previous work has attempted to determine the impact of different interaction devices for a Transfer of Control scenario in semi-autonomous vehicles. Therefore, we focus our study on this matter and present a new HMD-based simulator to investigate control recovery in a driving task.

3. USER STUDY

Ten subjects participated in the experiment that took place in our immersive simulator: they were asked to react to a request of control to avoid an obstacle on the road. For each subject, the experimental study consisted of two parts, executed in random order, which differed for the mode of interaction with the virtual environment.

The purpose of the experiment was to determine the most adequate interaction interface to be used in an HMD-based simulator to recover control of a semi-autonomous vehicle for drivers focused on an attention demanding secondary activity.

3.1 Simulator and Virtual Environment

The immersive simulator consists of a system for visually and acoustically for presenting the virtual environment, and several devices for interacting with it. The simulator is able to display the virtual environment on a variety of systems, from simple screens to VR headsets and CAVEs. In this study an HTC Vive, which provides a 90 Hz refresh rate as well as high-frequency and low latency orientation and position tracking, is used as visualization system and headphones are used as the acoustical system for playing 3D spatialized audio. For the driving task the simulator provides different interfaces with different levels of realism. In fact, it is possible to drive using a gaming steering wheel as well as a joystick and smartphone (running an appropriate application).

Fig. 1 - The driver POV

In the proposed experiment, the users wear the HMD while situated inside a virtual environment resembling the interior of a car with which they have to interact [Fig. 1]. The driver is free to move inside the car, and s/he can control the longitudinal and lateral speed. A button on the dashboard allows the user to delegate the vehicle control to the autonomous system.

The simulated vehicle is able to perform simple automated driving tasks such as line-keeping and static and dynamic obstacle avoidance. Additionally, the system provides real-time data collection of relevant vehicle and user data.

The virtual environment is developed in Unity 3D. Graphically, inside the virtual environment, the vehicle is placed on a two-lane dual-carriageway road. Three guardrails delimit the carriageways (two for the outer limits and one in the middle) and props, such as trees, buildings and power-poles populate the roadsides. Moderate fake traffic is simulated in the two directions.

3.2 Secondary activity

Fig. 2 – The secondary activity on the tablet

In order to simulate a non-driving secondary activity, a 9.4 inch virtual tablet computer was placed on the right of the driver. During the autonomous driving phase, the subjects were asked to perform a non-driving activity involving interaction with the virtual tablet: they played some rounds of the memory skill game "Simon" [Fig. 2]. In each round of the game the device lights up one or more colored squares in a random order: the player must then reproduce that order. As the game progresses, the number of buttons that must be pressed increases. To implement the game, the tablet screen was split into 4 colored squares (red, green, yellow and blue), each of which represented one of the 4 buttons game. Simon was chosen as the non-driving activity because the game requires constant attention and fixed gaze in order to advance.

3.3 Interaction interfaces

In this experiment two different modes of interaction with a virtual reality driving environment are compared by evaluating objective and subjective criteria. The interaction consists of both controlling the longitudinal and lateral speed of the car and playing some rounds of the Simon game using a virtual tablet. The following, describes the two interaction modalities chosen in the study: the first modality makes use of a steering wheel and direct user hand manipulation; the second uses the HTC tracked controllers. The choice of this selection was motivated by the following reasons:

- Steering wheel and pedals are the most realistic interfaces for driving tasks. They allow users to perform the driving task as they normally would in real life.
- Controllers are a general purpose device, but they are specifically designed for interaction in HMD-based Virtual Environments.

3.3.1 6-DoF controller-based interaction

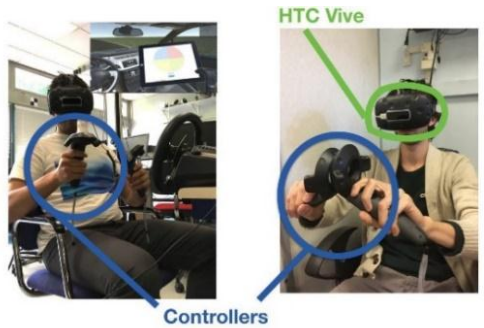

Fig. 3 – 6-DoF controller-based interaction

The first mode of interaction makes use of the two 6-DoF controllers provided by the HTC Vive [Fig. 3]. Inside the Virtual Environment the controllers are tracked in position and orientation via Lighthouse, the HTC Vive's tracking system. The controllers are used both to interact with the virtual tablet and to drive the vehicle in manual mode. To start driving the vehicle, the subject must join the controllers together [Fig. 3]. The longitudinal speed is then controlled with two trigger buttons on the controllers: the right trigger is used to increase the speed, while the left one is used to decrease the speed. The touchpad on the controller is used to interact with the virtual tablet. More precisely, the subject touches the pad to move a pointer on the virtual screen, and s/he clicks the pad to fire a click event at that point.

3.3.2 Realistic interaction

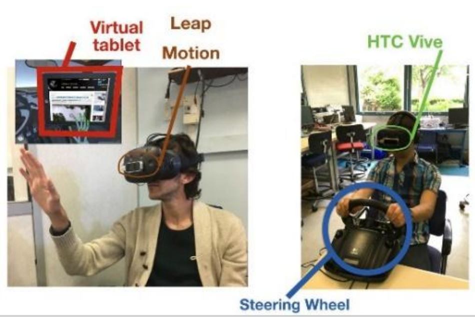

Fig. 4 – Realistic interaction

In the second mode, the participants use their hands, a gaming steering wheel and pedals to interact with the environment [Fig. 4]. During the manual driving phase the steering wheel is used to control the lateral speed of the vehicle, and the throttle and brake pedals are used to adjust the longitudinal speed. The real and the virtual steering wheel have the same size and position with respect to the user. In addition, the angle of the virtual steering wheel matches the angle of the real one. For the secondary task execution, we use a Leap Motion controller placed on the front face of the HMD to retrieve the relative position and orientation of the user's hands as well display a graphical representation. The contact between the index fingers of the user hands and the virtual tablet screen fires a click event in the contact point.

3.4 Take Over Request

Fig. 5 – Take Over Request displayed on the HUD

To communicate the Take Over Request (TOR), the automation system alerts the user with a sound and a visual message. The sound consists of a looped "beep" emitted through the vehicle speakers, while the visual message "TAKE OVER" [Fig. 5] is displayed on an HUD in front of the user with a ten second countdown; as soon as the driver takes back control, the TOR ends and the HUD displays the message "MANUAL". If after this period the user has not yet taken the control of the vehicle, the system employs an emergency brake.

3.5 Design and variables

In a within-subject design we chose to study the impact of the interaction interface on the following sets of variables:

- Objective measures:
  - Response time: time needed to take back control of the vehicle after the alert notification.
  - Driving stability after regain of control in terms of number of steering turns while avoiding the obstacle on the road.
- Subjective measures:
  A post-experience questionnaire designed to assess physical realism and comfort as well as ease of use and adaptation.

3.6 Participants

Ten subjects aged between 22 and 37 (mean = 27,6) years old participated in the experiment. All participants had normal or corrected-to-normal vision, and all the subjects except one, had a valid driving license with 2 to 18 (mean = 8,22) years of driving experience.

Seven participants are used to playing video games, and

- three participants did not have any previous virtual reality experience

- seven participants had previous virtual reality experiences (one, had more than 10 experiences).

3.7 Procedures

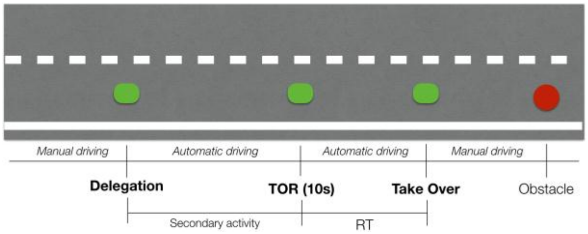

Fig. 6 – Experiment timeline

The experiment contains 5 parts: (1) the pre-experience questionnaire to collect demographic data and information about driving skills and habits and previous experiences in Virtual Reality; (2, 4) two simulator sessions, one for each interaction mode, executed in random order; (3, 5) the post-experience questionnaire after each session to collect information about physical comfort, realism and acceptability.
For this particular experiment, the maximum speed for the car was set to 80km/h for the autonomous mode and 130 km/h during the manual driving.
After an acclimatization phase in which the subjects became familiar with the simulator, the virtual environment and the given interaction interface, they were asked to perform the following sequence of steps three times [Fig. 6]:

- *Delegate control*: the subjects press the button on the dashboard to delegate control of the vehicle to the autonomous system. The vehicle starts the autonomous journey with a maximum speed of 80 km/h.
- *Perform the secondary activity*: the subjects interact with the virtual tablet to perform the secondary activity, the Simon game.
- *Regain control*: the subjects continue the secondary activity until the TOR alerted him after 4, 5 or 6 completed rounds. The subjects react to the TOR, stopping the execution of the secondary activity and taking back the control of the vehicle.
- *Avoid obstacle*: the subjects change the line, adjusting longitudinal speed in case, in order to avoid the obstacle on the road. After doing this they returned on the right line.

3.8 Results

To evaluate the impact of the interaction interface on the driving task, relevant data such as position and orientation of the vehicle in the lane, and its longitudinal speed and steering angle were collected in real time during the experiment.

Based on this data we defined the following set of variables to describe the quality of control regain recovery:

- Reaction time: time between the notification of the TOR and the actual regain of control.
- Number of steering oscillations: how many times the steering angle changes sign.

Tab. 1 shows the results.

Tab. 1 – Objective measures results

Variable	6-DoF	Realistic
Reaction time (mean, [s])	2.17	2.67
Num. of steering turns (median)	8.5	5

The reaction time is better when the user interacts with the simulator using the 6-DoF controllers. However, since the number of steering turns is lower in the realistic condition, it appears that the subjects were able to control the vehicle in a more stable way using steering wheel and pedals.
The trajectories followed by the user are shown in Fig. 6 (Steering Wheel) and Fig. 7 (Controllers).

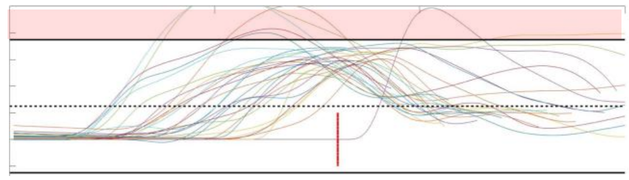

Fig. 7 – Steering wheel and pedals trajectories

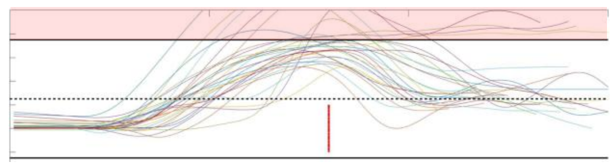

Fig. 8 – 6-DoF controllers trajectories

These images provide a qualitative representation of the concept of stability. In fact, we can observe from the trajectories that the use of the controllers to regain control produce a higher number of lane departures (pink zone) with respect to the use of steering wheel and pedals.

With respect to the subjective measures, the participants expressed a preference for the realistic interface according to all the indicators. Fig. 9 shows the results of the post-experience questionnaire.

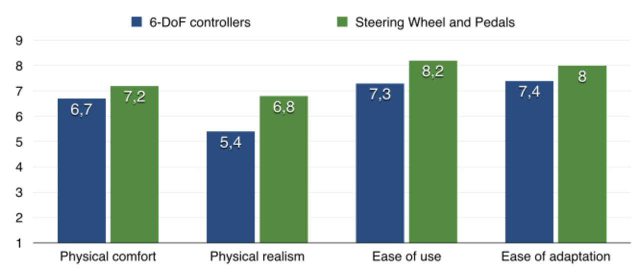

Fig. 9 – Subjective measures results

Considering the objective performance criterion, it is not possible to determine which of the two interaction modalities is the most adequate. This is because even if we have a lower reaction time with 6-DoF controllers, the stability of control recovery is better with the realistic interface. On the other hand, the indicators related to comfort and ease of use and adaptation provide us a clear predilection for the realistic interface.

4. CONCLUSION AND FUTURE WORK

This paper presents an high immersive HMD-based simulator for semi-autonomous vehicles and a pilot study to evaluate the most adequate interface to drive and perform a secondary activity during autonomous driving. The task proposed to the subjects was to recover control of the vehicle from the autonomous driving while they were focused on a non-driving activity.

This paper analyzed two different interaction modalities. The first was based on a realistic interface and uses a steering wheel and pedals for driving and a finger-tracking device for performing the secondary activity (Simon game). The second interaction modality uses two hand-held 6-DoF controllers for the driving task and the embedded touchpad for the game activity. The subjective criteria, such as physical comfort and ease of use and adaptation, show that the subjects prefer the realistic way of interaction. With respect to objective measures, it's observed that realistic interaction elicits more stable trajectories, but controller-based interfaces provides better reaction times.

Future work will aim at addressing the question of semi-autonomous driving skills acquisition by end users. On the basis of this study, we will implement our Virtual Reality learning environment using realistic interfaces.

5. ACKNOWLEDGMENTS

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