Investigating Spatial Presence in Virtual Reality in Automated Vehicles

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Abstract
Automated vehicles (AV) have the potential to save lives, reduce traffic congestion, and expand mobility, leading to a more sustainable transportation system. They can also enable vehicle occupants to engage in non-driving tasks that are becoming increasingly unrelated to driving. Performing these tasks with engaging and immersive technology such as virtual reality (VR) devices is emerging. As we make these virtual environments (VE) technologically viable, we need to look around the corner and make sure that as the technology's novelty wears off and it becomes an everyday appliance, we are ready to understand and manage the way it affects us, our behavior, and the way we interact with the environment. Hence, we propose studying user's special presence, the sensation of being spatially located in the mediated environment, to assist VR developers to create sustainable applications.

Author Keywords
Automated vehicle; virtual reality; presence; sustainability

CSS Concepts
• **Human-centered computing~ Human computer interaction (HCI)**; •**Applied computing ~** Computers in other domains;

Introduction

Like any other scheme, the effectiveness of automated vehicles (AV) is judged based on its sustainability. Malik [12] categorized the sustainability aspect of AVs into social, environmental, and economic.

The social impact of AVs includes improving the accessibility of different groups who are currently prohibited from getting a driver's license due to age and physical and sensory disabilities [1, 12]. This could also reduce the dependency of these populations to their care givers for transportation. However, AVs can potentially cause negative impacts on those with lower socio-economic status due to being expensive. They will also absorb the investments, negatively impacting the existing transport services including public transit which the poor rely on the most [1, 2].

The automation of vehicles will have environmental effects as well. For instance, there are many factors resulting in less fuel consumption for AVs. Automated acceleration and eco-driving, which is the absence of unnecessary braking, will considerably reduce fuel consumption with the amount varying between 10-20% among various studies [2, 3]. Another contributing factor is platooning of cars, in which the air resistance will be reduced for vehicles following a lead car bearing it [17, 22], resulting in better fuel economy.

Assuming there are enough AVs on the road, each AV can interact with other vehicles and the infrastructure in real-time. This traffic data would then be used avoid congestion and reduce emission [8]. Although it can be argued that this routing efficiency may lead to higher travel times, Zhang et al.[24] believes that the total environmental impact is positive.

Vehicle design is another aspect of AVs that would cause an environmental impact. AVs are safer that non-automated vehicles since they would not fall prey to human mistakes, intoxication, or drowsy driving [7, 14]. Hence, Kopelias et al. [10] claims that the safety equipment in the vehicle would not be necessary anymore, resulting in less weight of AVs. Of course, the amount of safety features present in an AV would be inversely corelated with its automation level; there will be different measures for fully automated vehicles(e.g., SAE Level 5) and semi-automated vehicles(e.g., SAE Levels 2-3) [18].

The social and environmental impact of AVs will have economic significance. Fagnant,et al [4] estimated that "major social AV impacts in the form of crash savings, travel time reduction, fuel efficiency and parking benefits are likely on the order of $2,000 per year per AV, or $3,000 eventually increasing to nearly $5,000 when comprehensive crash costs are accounted for". The economic influence of AVs will also be through non-driving activities performed in the vehicles. A key promise of AVs is that they will, to a greater or lesser extent, allow an occupant to disregard the driving task, and turn their attention to other activities, in an effort to spend their commute time more efficiently and pleasantly [6]. This could result in increased work hours which can help in increasing the GDP of a country. Hence, non-driving activities in AVs are getting increasing attention from researchers [15, 23].

Non-Driving Related Tasks

The vision of automated vehicles is not fully materialized yet, hence it is hard for drivers and passengers to imagine various scenarios demonstrating their full potential. However, activities currently

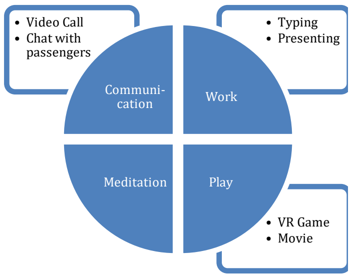

Table 1: Examples of non-driving related tasks

performed in non-automated vehicles can inspire the future activities performed in (semi) automated vehicles. These non-driving activities cover a wide range of tasks including chatting with friends, reading, and even sleeping. Kun et al. [11] categorized these tasks into communication, play, and work tasks, demonstrating the contextual domains of interest for non-active drivers. Higher engagement and performance in the tasks in these categories can be achieved in virtual reality (VR) and/or augmented reality (AR) [16, 20]. It may seem unrealistic to consider VR in the car, but we already see VR being used by vehicle passengers playing games and doing work or education tasks [9]. This is especially the case on longer commutes and road trips. Professional uses of VR in the vehicle has also been proposed, such as firefighters or tactical response units donning VR goggles while en route to a scene, in order to become familiar with the (real) building they are about to enter. And, in addition to the passengers, as the role of the "driver" of an automated vehicle evolves (devolves?) into that of a "regular" (non-driving) passenger, there is a strong likelihood that she will be able to join her vehicle mates in a VR experience.

VR in the Car

It is imperative to know, before it happens, what "VR in the car" will mean, both in the fully automated (e.g., SAE Level 5) and semi-automated (e.g., SAE Levels 2-3) situation. Without careful design, the interactions with immersive technologies in semi-automated vehicles will lower the performance of the occasional hand over and driving, as it would in a non-automated vehicle [19]. Hence, there is a need for more rigorous research to answer the following questions: **(1) What is the effect of being in a car on the VR experience?**; and **(2) What is the effect of being in a VR on the car/travel experience?** In the semi-automated situation, when an occupant may need to take-over the driving task in situations where the automation system reaches its operational limits, these questions are supplemented by: **(3) What is the effect of the VR experience on situation awareness about the vehicle, the automation, the surroundings, traffic, and so on.**

Future Research

To ensure that the users perform VR tasks because of a pleasant and efficient experience and outcomes and not due to the novelty of the device and AV medium, we will study users presence which is their subjective sense of being physically located in the VE [21]. There is evidence that higher levels of presence can lead to higher extents that the task outcomes are achieved and generally more enjoyment in the task [13]. Hence, we are exploring the following research questions: **(RQ1) What level of presence do semi- automated vehicle drivers have in the VR environment? (RQ2) How is this presence level related to the type of VR task they are performing?** This understanding would help us design a VR interface that helps the driver maintain their situational awareness of the driving context. The interface would support efficient take-over in handoff situations from the automation, while sustaining and encouraging high levels of presence in the VR application.

Conclusion

Despite government-issued laws banning the use of smartphones in the vehicles, cell phone distracted driving caused an estimated number of 1.5 million car accidents in 2018 in the US only [5]. The rapid development of automated vehicles has the potential to avert this statistic, but it also will introduce new contexts prone to on-road risks. Use of VR devices for non-driving tasks can be one way to make AVs sustainable but may also emanate risks due to losing situational awareness of real world. The first step to minimize the risk is studying passengers' level of VR presence in semi-automated vehicles and its relation to the VR task. This knowledge can be utilized in the development of VR applications that support the safety and enjoyability of the users.

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