Effects on User Perception of a 'Modified' Speed Experience Through In-Vehicle Virtual Reality

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Abstract
In order to make the experience of traveling in automated vehicles more enjoyable, Virtual Reality (VR) experiences based on the real-world journey have been proposed. Presenting users with VR content synched to the car's actual movement decreases the motion sickness, but it also sharply limits the possible range of VR content. In this paper, we investigate whether the user's subjective perception of speed can be 'modified' by presenting VR content at a different speed than the actual speed of the vehicle, and whether users feel this experience is strange. Study participants viewed VR content occurring at a faster or slower speed than their actual travel speed in an electric wheelchair. Our results show that the participants were able to do this without experiencing a feeling of "strangeness". However, the participants did report higher "strangeness" scores when the speed in the VR content was slower than their actual speed.

Author Keywords
Entertainment in cars; virtual reality; self-driving cars; vection.

CCS Concepts
•Human-centered computing → User studies; •Computing methodologies → Virtual reality;

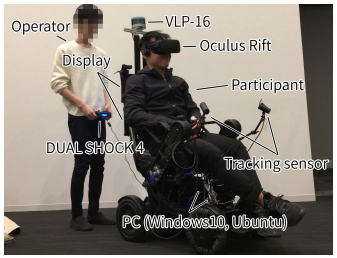

Figure 1: Hardware setup for our experiment using an electric wheelchair.

Figure 2: VR content presented to participants through the head-mounted display.

Introduction

What are the possibilities for passengers when autonomous driving is fully realized? How will they pass their time when they are no longer responsible for directing the vehicle? In the meantime, how can they be kept engaged in the journey when they are responsible for emergency back-up of the automated system? Autonomous driving technology is rapidly improving, so it is expected that autonomous vehicles will begin appearing on roads in the near future. On-road testing of self-driving taxi services such as Waymo One by Alphabet is already taking place, for example. Taxis without human drivers will have a huge impact on transportation businesses, but most automotive user interfaces are designed to be driver-focused. We should begin considering novel forms of service which focus more on passenger-car interaction.

Some companies have recently introduced the concept of in-car Virtual Reality (VR) systems, and demonstrations have been presented at trade shows [4, 6]. A study conducted by Holoride [4] showed that their vehicle motion-synched VR system evoked a strong feeling of immersion in users, and was less likely to cause motion sickness, as a result of syncing the VR content on the headset screen with the actual movement of the car [1]. In the case of Holoride, the representation of VR content is limited by the actual characteristics of the car's motion. For instance, a user might feel strange if the VR content moved too fast (such as in a car chase scene) in relation to the actual speed of the vehicle. How much the dynamics of the VR action can differ from those of the actual motion of the car before it feels unpleasant is an interesting research question, which if answered would allow developers to create content that is not only entertaining but also natural, or at least not unsettling. In this paper, we first focus on vehicle speed, and investigate whether users' subjective perception of speed can be altered by viewing VR scenes occurring at various speeds. We conduct an experiment in which study participants view VR content with a headset while traveling at a fixed speed in an electric wheelchair.

Related Work

It has been reported that when a large region of the visual field is stimulated by consistent motion, observers perceive they are moving even when they are not actually moving [2, 7]. This illusory feeling of motion is referred to as "vection". Although researchers had been using large screens to evoke vection in observers, Seno et al. reported that vection could also be evoked in VR environments conveyed using head-mounted displays (HMD) [8]. It was also reported that the strength of the vection effect was actually stronger in the HMD environment. Therefore, we thought it might be possible to alter the user's subjective feeling of speed (speeding it up or slowing it down) in relation to the actual reality of the user by applying an immersive VR environment in a traveling vehicle.

Evaluation Method

Setup

Taking the safety of our participants into account, an electric wheelchair (WHILL Inc., Model CR), remotely controlled by an operator, was used in this preliminary experiment (as shown in Fig. 1) rather than an automobile. The experiment was conducted within a flat space of about $8\,\mathrm{m} \times 8\,\mathrm{m}$ in an indoor, carpeted room. To present an immersive, VR environment, we used the Oculus Rift Development Kit 2 as our head-mounted VR display, and placed an infrared motion tracker on the wheelchair. We created a virtual forest environment using Unreal Engine 4 (as shown in Fig. 2), and presented this environment to our participants through the VR system. The position of the wheelchair was estimated using a Light Detection and Ranging sensor (VLP-16) and

the Normal Distributions Transform algorithm [10] which is implemented in Autoware [5], an autonomous driving software. This position information was then sent to the VR system using a modified version of ROSBridge [3]. The VR images were rendered at 10 Hz based on the estimated position, and extrapolated at 60 Hz, based on the vehicle's location history, in order to reduce motion sickness. In order to evaluate whether the user's sense of speed could be altered by presenting a VR environment in which motion was displayed at a different speed, we developed a method of scaling the speed in the VR environment at any ratio in relation to the actual speed of the wheelchair.

Participants, Task & Procedure
We recruited 10 participants (8 male and 2 female) to take part in our experiment. Their ages ranged from 20 to 30.

First, each participant sat in the electric wheelchair without a VR HMD, and traveled 3 m forward at $0.5\,\mathrm{m/s}$. Then participants repeated the trip while wearing the HMD and VR images were presented showing forward motion at the same speed as the actual motion of the wheelchair. These two runs were defined as the "standard stimulus" and the operator who was remotely controlling the wheelchair informed the participants that the speed of travel was $0.5\,\mathrm{m/s}$.

During the next 17 runs, the speeds simulated in the VR space were *x0.2, x0.3 ... x1.8* in comparison with the actual speed of the wheelchair. The wheelchair always traveled at the same speed of $0.5\,\mathrm{m/s}$. The images presented to the participants in the VR space simulated speeds randomly chosen from among the 17 available altered speeds (*x0.2, x0.3 ... x1.8*). When the participant felt that they had finished traveling 3 m, i.e., the same distance as the travel distance during the standard stimulus, they pushed a button held in their left hand and the operator stopped the wheelchair. The same series of actions was performed for all of the simulated travel speeds, with the order of the simulated speeds being determined randomly. Each iteration of this procedure was defined as the "test stimulus".

After each test stimulus, i.e., each trip in the wheelchair at a VR altered speed, the participants were asked to complete a questionnaire asking them to assess their subjective feeling about the normality of their journey, and to estimate the difference between their perceived speed in VR environment and the actual travel speed of the wheelchair.

Questionnaire
Data on two subjective topics was collected via a questionnaire during this experiment. (1) Estimated speed: the participant's subjective estimate of their real-world speed of travel in $\mathrm{m/s}$. (2) Level of strangeness: the participants' subjective feeling about the 'strangeness' of their journey, due to the difference between the speeds in the real and VR environments. The participants were asked to rate, on a Likert scale of five, the level of strangeness they felt as a result of the VR stimulus from 0: not strange at all, to 4: extremely strange.

Results
Fig. 3(a) shows the relationship between the participants' subjectively perceived speed and the ratio of the participants' speed in VR environment (v_{VR}) to the wheelchair's actual speed (v_{actual}). Fig. 3(b) shows the relationship between the participants' 'strangeness' scores and the speed ratios. We used Steel's many-one rank test [9] to determine if there was a significant difference in the 'perceived strangeness vs. speed ratio' measure between the control group (traveling at the same speed as in the VR scene, i.e., the "standard stimulus": $v_{\mathrm{VR}}/v_{\mathrm{actual}} = 1$), and each of the test groups (traveling at a different speed than in the VR scene, i.e., the "test stimulus": $v_{\mathrm{VR}}/v_{\mathrm{actual}} \neq 1$). The pairs

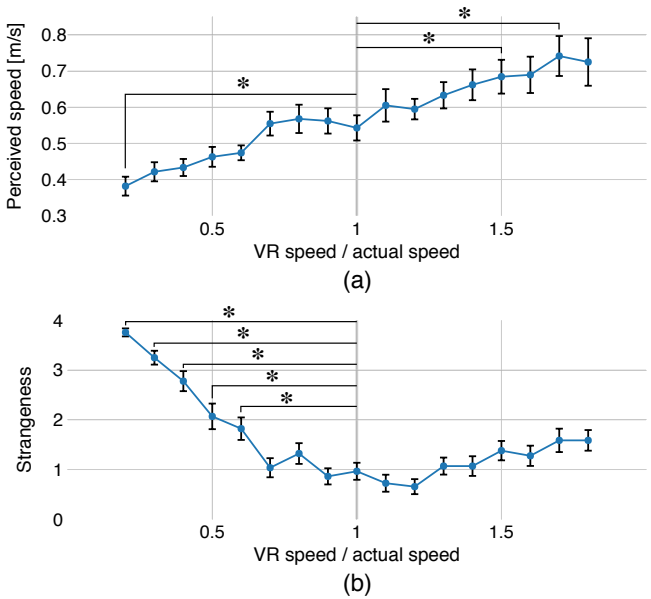

Figure 3: Relationship between the ratio of the user's speed in VR environment to the wheelchair's actual speed and (a) the participants' subjectively perceived speed or (b) the participants' 'strangeness' score. The markers and the error bars indicate the average values of the estimated speeds and the standard error, respectively. The pairs with a $*$ above them indicate the measures between the control group ($v_{\mathrm{VR}}/v_{\mathrm{actual}} = 1$) and the test group ($v_{\mathrm{VR}}/v_{\mathrm{actual}} \neq 1$) differed significantly ($P < 0.05$).

with a $*$ above them in Fig. 3(a) and Fig. 3(b) indicate that the measures differed significantly ($P < 0.05$) between the control group and the test group.

Discussion

When the speed in the VR environment was faster than the actual speed ($v_{\mathrm{VR}}/v_{\mathrm{actual}} > 1$), the subjective feeling of speed differed significantly when $v_{\mathrm{VR}}/v_{\mathrm{actual}} = 1.5$ and 1.7, while there was no significant difference in the feeling of "strangeness" felt by the participants during these scenarios in comparison with the control group. This indicates that the user's subjective feeling of speed can be speeded up by presenting a faster VR environment, without the user feeling it is "strange". Participants did report significantly higher "strangeness" scores in comparison to the control group when $v_{\mathrm{VR}}/v_{\mathrm{actual}} = 0.2$ to 0.6, however. This indicates that it is more difficult to slow down the user's subjective feeling of speed without making the user feel "strange" than it is to speed it up.

Conclusion & Future Work

In this paper we have investigated whether the user's subjective perception of speed can be altered by presenting speeded up or slowed down VR images to the user. The results of this preliminary study using an electric wheelchair confirm that presenting a speeded-up VR environment to the user can change the user's subjective perception of speed without making the user feel it is "strange". However, users had a tendency to feel it was "strange" when a slowed down VR environment was presented.

In a future study, we would like to conduct a similar experiment using an actual car, to investigate whether users report similar tendencies as when using an electric wheelchair. In this paper we focused only on simulating different speeds in a straight, forward direction, therefore it is still necessary to investigate the effects of presenting users with a VR environment that differs from their perception of the vehicle's actual motion, such as when taking curves, accelerating or decelerating, stopping, etc.

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