Simulator Sickness and Presence using HMDs: comparing use of a game controller and a position estimation system

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Abstract

Consumer-grade head-mounted displays (HMD) such as the Oculus Rift have become increasingly available for Virtual Reality recently. Their high degree of immersion and presence provokes usually amazement when first used. Nevertheless, HMDs also have been reported to cause adverse reactions such as simulator sickness. As their impact is growing, it is important to understand such side effects. This paper presents the results of a relatively large scale user experiment which compares using a conventional game controller versus positioning in the virtual world based upon the signal of the internal Inertial Measurement Unit (IMU) using Oculus Rift DK1. We show that simulator sickness is significantly reduced when using a position estimation system rather than using the more traditional game controller for navigation. However the sense of presence was not enhanced by the possibility of 'real walking'. We also show the impact of other factors, such as prior experience or motion history, and discuss the results.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism — Virtual Reality; I.3.6 [Computer Graphics]: Methodology and Techniques — Interaction techniques; H.5.2 [Information Interfaces]: User Interfaces — Evaluation/Methodology.

Keywords: Simulator Sickness, Presence, Virtual Reality, Oculus Rift, Locomotion

1 Introduction

Virtual Reality (VR) using head-mounted displays (HMDs) has been used in military training, entertainment and other activities for several years. This exciting technology allows the user to feel a higher degree of presence in the virtual environment (VE) and a true VR experience. However users can experience negative side effects from such immersion. Some resemble those of pure motion sickness, such as disorientation, nausea, headaches and difficulties with vision [Kolasinski 1995]. When caused by virtual simulators these effects are known as cybersickness or simulator sickness (SS). Several studies have shown that SS is a difficult problem to solve in VEs. SS has been studied since the 70s [Reason and Brand 1975] but the recent popularity surge of consumer grade HMDs has made the topic even more relevant to study. One of the most important accepted explanations for SS lies in sensory conflict theory, which relates incoherence between the visual input and the vestibular system with SS. To put in other way, when movement and displacements in the virtual world are not the same as in the real world, SS might be experienced. Previous studies have focused on human factors that influence the virtual immersion experience, such as gender, prior experience and motion sickness history. Females were found to experience more SS in [Reason and Brand 1975; Stanney et al. 2003], while prior experience appeared to have a very strong correlation with SS in [Kolasinski 1995; Stanney et al. 2003]. Another factor studied has been the prior history of motion sickness, and most studies found a positive relationship between SS and this factor [Graeber 2001; Stanney et al. 2003]. Simulator factors impact on SS as well, such as exposure duration, field of view (FOV), interpupillary distance (IPD), position-tracking error, refresh rate, lag, and scene complexity. Factors such as longer exposure, bigger FOV, and incorrect IPD amongst others induce larger SS. Age has been a factor seldom considered. In this paper we analyze and compare two methods of controlling movement in a virtual world, and record the user experience to test which method causes less SS. Previous research on navigational controls [Stanney et al. 2003] showed that the degrees of freedom (DOF) of the navigational control have a positive relation with SS: the more DOF, the larger SS. On the other hand, another important parameter of VR, presence, was found to be higher when subjects' movement in a virtual world was controlled by real walking, rather than using a game controller or other techniques where the user remains static [Usoh et al. 1999]. To decrease SS in VEs during locomotive tasks, a relatively imprecise low-cost position tracking system using Oculus Rift IMU was developed by Llorach et al. [Llorach et al. 2014], with the goal of minimizing sensory conflict. In this paper, we aim to extensively evaluate SS and presence experienced when using this position estimation system and when using a conventional 3-DOF game controller. The comparison between both systems must be made carefully, as the two systems work very differently. The position estimation system is a low-accuracy tracking system which estimates with some error real world movements: some movements are not tracked properly and slow movements are not tracked at all. The game controller offers a 1:1 interaction and subjects are in a seated position during the experiment. Both navigational controls allow movement in the horizontal plane and the head-tracker inside the HMD allows rotation in all directions. 116 subjects took part in the experiment, with two groups only differing in the navigational control. Human factors such as experience, age, gender were also taken into account. SS and presence were measured using widely accepted user questionnaires.

The results in this paper show a higher rate of SS when using the game controller compared to the positional tracking system. The importance of this finding is that the position estimation system is low-cost, because it does not require any extra hardware as it uses

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the Oculus Rift internal IMU; and thus provides a solution for locomotive tasks with low SS effects, rather than using a game controller and experiencing SS. This paper also demonstrates the severity of SS symptoms that users might experience when using game controllers for locomotive tasks in VEs with the Oculus Rift. An unexpected result was that sense of presence should be enhanced by the position estimation system (due to the possibility of 'real walking'), and our results show that subjects judged it to be slightly higher when using the game controller.

2 Method

This study relied on two experiments. Both had the same simulator conditions, and differed only in the manner of navigational control in the virtual world. In one of them subjects used the IMU-based position estimation system and in the other they used an Xbox game controller with head tracking enabled (rotation). SS and presence were measured with user questionnaires that are widely used in the literature. The study also collected information about human factors such as age, gender, gaming frequency, 3D displays frequency, motion history while travelling and motion history with 3D displays.

2.1 Participants

Participants were assigned randomly to one of the two experiments. The number of participants with the position estimation system was 55 (31 males and 24 females). Their age range was 14 to 31 years (mean = 20.70, SD = 2.423) and IPD ranged from 54.2 to 64 mm (mean = 60.35, SD = 2.48). The number of participants with the game controller was 61 (38 males and 23 females). Their age range was 15 to 37 years (mean = 21.90, SD = 4.19) and IPD ranged from 54.6 to 66.8 mm (mean = 61.12, SD = 2.78). Almost all of the participants were students from the Universitat Pompeu Fabra, mainly from the Polytechnic School, the Faculty of Translation and Interpretation, and the Faculty of Communication. Subjects who suffered the symptoms of flu, cold or amblyopia (lazy eye) were asked not to participate.

2.2 Tasks and Design

During the VR immersion, subjects had to complete several different locomotion based tasks, most of which were based on the VEPAB locomotion tasks [Lampton et al. 1994]. There were 6 different scenarios in the VE (see Figure 1): the straight corridor, figure-of-eight and doorways from VEPAB, a wide museum room, a maze, and an outdoors scenario (Tuscany from the OculusVR SDK). Participants had two minutes to to get used to the control device in the museum room setting. Then, there were three tasks to complete in the straight corridor: first, they had to walk until the end of the corridor; second, walk until then end, make a 180º turn and walk back; and finally walk until the end and then pace backwards (without turning around). For the figure-of-eight scenario, participants had to walk along the curved corridors for one minute. In the doorways scenario they had to walk through six rooms connected by doorways. The maze scenario was set up at night and the virtual character carried a torch. Participants could not "see" very far and had to go to the end of corridors to discover if there was a way out, which involved several 180º turns. The final outdoors scene was a modified scenario from OculusVR SDK (Tuscany), and was the only one where participants were asked if they wanted to stop after a minute or keep going for one minute more. Tasks such as those in the straight corridor and walking through doorways had a time limit and participants were moved to the next task if they took too much time to finish them. The simulation could be paused and restarted, displaying a black screen on the HMD during the pause.

Figure 1: *Images of the VE. From left to right and from top to bottom: museum room, straight corridor, figure-of-eight, doorways, maze and outdoors scenarios.*

2.3 Apparatus

The VE and simulation ran on a 3.2 GHz Dell computer with 6 GB RAM and an NVIDIA GeForce GT 750M with 2GB RAM. The VE was developed with Unity3D. The HMD Oculus Rift DK1 was used for displaying the VE, with a resolution of 640 x 800 per eye (60 Hz refresh rate), 46° horizontal x 53° vertical field of view (110° diagonal), a tracking latency of ~2ms and weighed 380g. Participants wore headphones, through which the instructions for each task were provided. This study used the Simulator Sickness Questionnaire (SSQ) [Kennedy et al. 1993] to assess SS. The SSQ consists of a check-list of 16 symptoms with four degrees of severity for each symptom (none, slight, moderate and severe). It provides three weighted subscales: nausea (SSQ-N), oculomotor disturbances (SSQ-O) and disorientation (SSQ-D); and a final score, total severity (SSQ-TS). Let us remark that previous studies have assumed that a SSQ-TS score of 7.48 or less can be qualified as good health [Stanney et al. 2003] and a SSQ-TS score over 20 that symptoms are a concern [Kennedy et al. 2003]. To assess the level of usability and comfort of the navigational control some of the questions of the Presence Questionnaire (PQ) [Witmer and Singer 1998] were used. Our PQ had 17 questions, mostly focusing on the sense and comfort of moving. In a second, separate questionnaire, four questions were asked to collect information about gaming frequency, 3D displays frequency (3D theaters, 3D game consoles, IMAX etc), motion history while travelling and motion history with 3D displays. The first two had five degrees of frequency (never or rarely, few times a year, once or twice a month, once or twice a week, and every day). The last two questions were based on the Motion History Questionnaire [Kennedy et al. 2001].

2.4 Procedure

Before the virtual exposure, participants were asked to read and sign an informed consent, about eligibility, duration, risks, freedom to withdraw and anonymity. Afterwards, another form with general information (age, gender, gaming frequency, 3D displays frequency, motion history while travelling and with 3D displays) was filled in, as well as a SSQ prior to the virtual immersion. After the questionnaire the IPD was measured with software supplied by OculusVR [OculusVR 2014] and adjusted in the VE accordingly, followed by an explanation of how to use the navigational control.

- *Game controller*: The controller used allowed 3 DOF; movement in the fore-aft directions, sideways and yaw. Subjects could use two joysticks (movement and turnings) and one button to pause and restart. Several tips were suggested such as using the joystick softly to turn around, and trying to combine head movements with the joystick, as it might induce less SS. Subjects were advised to take all the tasks with patience and without hurry. Subjects had the possibility to pause the simulation and rest, without taking the HMD off. The experiments were done in an indoors space in a seated position. Subjects wore the HMD, headphones and had a game controller.

- *Position estimation system*: Subjects were given a verbal explanation and a demonstration of how to move in the VE using the position estimation system. They had to take decisive, separate and marked steps, pausing briefly after each one, as required by our system [Llorach et al. 2014]. The experiments were carried out in an outdoors space. A researcher followed the subject with a game controller to pause the application, and to relocate the subject, if necessary, due to the physical constraints of the outdoors space. Subjects were reminded of the instructions during the simulation if it became clear that they were not being followed. Subjects wore the HMD, headphones and carried a backpack with the laptop inside, as the whole system could run with the battery of the laptop.

We recall that subjects started with the museum room to get accustomed to the VE and to understand how to use the navigational controls. This lasted for two minutes. Then, the VEPAB locomotion tasks were carried out. Afterwards, subjects stayed in the maze until a total time of virtual immersion was reached (10 minutes and 40 seconds). The last task was the outdoors scene (Tuscany). The total time of immersion ranged from 11min 40s to 12min 40s, but the total time of the virtual experience could last longer depending on the number of stops or relocations in the real space . All the tasks had a time limit, set such that all participants would spend a minimal amount of time on each task, with a fixed total immersion time, as [Stanney et al. 2003] showed that SSQ symptoms increase with the immersion time. All the instructions for each task were given through the headphones. Immediately after the virtual immersion a post-exposure SSQ was filled in as well as a Presence Questionnaire.

3 Results

We remind that a total of 116 subjects participated in the study. 55 started the position estimation system experiment and 61 started the game controller experiment. 7 out of 61 (11.5%) of the participants of the game controller experiment abandoned the experiment due SS and were discarded for further statistical analysis, as they could not finish the whole experiment. No subjects abandoned the position estimation system experiment. 4 participants were discarded as they presented extremely considerable pre-exposure SSQ-TS scores. Thus, 51 subjects remained for the game controller experiment and 54 for the position estimation one, a total of 105. As some subjects still presented high initial SSQ-TS scores, only the increase of SSQ symptoms between pre and post-exposure was used for analysis. One of the reasons for this is that some participants were suffering some of the SSQ symptoms at the moment of arrival, such as sweat and fatigue (likely to personal time constraints and/or weather conditions). This study assumes that any reduction in the initial SSQ symptoms is not due the VE exposure but to other conditions of the experiment. Thus, when we refer to post-exposures SSQ scores we are always referring to the increase of SSQ symptoms between initial and final scores. Nonparametric statistics were used for the analyses, as the SSQ scores presented a non-normal distribution.

3.1 Navigational Control

Table 1 shows the means of the SSQ scores, which show "severe and high" SS for the game controller navigational control and "significant" symptoms for the position estimation system according to [Kennedy et al. 2003]. Mann-Whitney non-parametric test showed that the SSQ-TS differs significantly (Z = 2.712, p < .004) between navigational control conditions (game controller and position estimation system). Spearman's correlation showed significant relation (r = .267, p < .004) between the SSQ-TS and the navigational control used.

Table 1. *Statics of SSQ Symptoms by Navigational Control*

	Game Controller		**Position estimation**	
SSQ Symptoms	*Mean*	*SD*	*Mean*	*SD*
Total Severity	32.27	29.26	15.93	14.81
Nausea	38.85	36.49	15.37	17.16
Oculomotor	15.16	15.16	9.97	10.60
Disorientation	38.48	36.00	18.56	22.25

Participants in the game controller experiment paused their movements for an average for 13.79 seconds. Participants in the position estimation experiment paused for an average of 118.88 seconds – however this delay was caused by participants relocation due to space restrictions. During the position estimation system experiments, some subjects lost balance for a moment one or several times. Usually this happened when the movements were vague and not done as instructed. Some subjects started walking normally, without stopping after each step, in the fourth phase, having done all the previous movements correctly. They answered that they felt so immersed that forgot about the restrictions of the system. In the game controller experiments some subjects started sweating profusely and went pale. Exposure aftereffects were not measured but some subjects reported SS several hours after finishing the game controller experiment.

3.2 Initial pre-exposure SSQ scores

Spearman's correlation results for the game controller experiment (n = 51) showed that initial pre-exposure SSQ scores had significant effect on SSQ-TS final scores (r = .390, p < .003). Thus, subjects that had initial symptoms were prone to report a higher increment of SS during the exposure than ones that had less initial SS. On the contrary, the results for the position estimation experiment (n = 55) showed a weaker correlation between the initial SSQ score and the final scores (r = .165, p = .121).

3.3 Human Factors

No significant differences in SSQ symptoms between genders (64 males and 43 females) were found. The age range is too small to be considered for analysis in this study (mean = 21.33, SD = 3.56, range = 14-37). Spearman's correlation results have shown no correlations between the SSQ scores and the initial questions with the position estimation system experiments. On the contrary, stronger correlation has been found for 3D displays frequency (r = -.355, p = .006), motion history while travelling as a passenger (r = .299, p = .019) and motion history with 3D displays (r = .410, p = .002) using the game controller, while no correlation has been found with user gaming frequency.

3.4 Presence

Only some of the questions of the PQ have been considered, as there was no interaction, only locomotion. This study focuses on questions related with the mechanism of control and the sense of moving. When measuring presence, we found very little difference between the two navigation control methods. Figure 2 illustrates mean responses for those questions which differed the most in their answers. Spearman's correlation showed that the SSQ-TS scores had a significant negative relation with "How compelling was your sense of moving around inside the virtual world" question (r = -.387, p < 0.001) and "How proficient in moving in the VE did you feel at the end of the experience" question (r = -.347, p < 0.001).

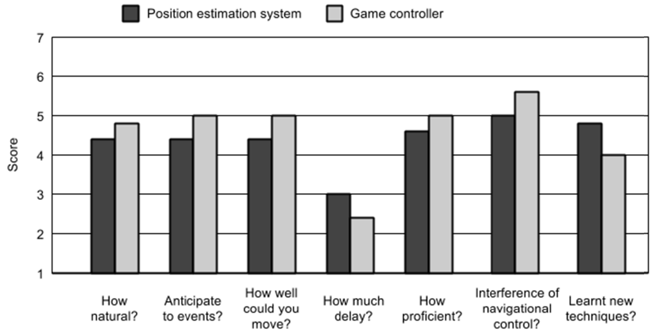

Figure 2: *PQ answers on navigational control*

4 Discussion and Future Work

Differences found in post-exposure SSQ scores are high enough to conclude that the position estimation system (low sensory conflict) induces less SS than the game controller (high sensory conflict), thus confirming the sensory conflict theory. This is reinforced by the fact that 7 of the participants had to drop out during the game controller experiment, while none left the other (although these navigational controls are very different from each other and the comparison between them should be done carefully). Locomotion tasks were executed much faster with the game controller, which meant spending much more time in the maze, as previous tasks (walking through a straight corridor and doorways) were carried out faster than with the position estimation system. Fast turns in the game controller experiment might be one of the main factors that induce SS. Reducing the maximum speed of turning was considered, but initial experiments showed that subjects complained about this limitation and the navigation presets from the OculusVR SDK for Unity3D were used. Presence was not enhanced by the position estimation system, probably due to the low accuracy tracking and the number of stops due to enforced relocation. In this study the correlation between the real movement and the virtual movement was not measured, but we believe that it had a considerable effect on presence and the SSQ scores. As the results seem to support that position sensing greatly reduces SS, even with a relatively clumsy system, the emergence of low cost affordable more precise systems would make them extremely usable. These systems could be used for professional use, such as simulating architectural designs, planning visual effects in cinema.

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