Subjective Assessment of Different Locomotion Techniques in Virtual Reality Environments

Sara Vlahović  
University of Zagreb  
Faculty of Electrical Engineering and Computing, Zagreb, Croatia  
sara.vlahovic@fer.hr

Mirko Suznjevic  
University of Zagreb  
Faculty of Electrical Engineering and Computing, Zagreb, Croatia  
mirko.suznjevic@fer.hr

Lea Skorin-Kapov  
University of Zagreb  
Faculty of Electrical Engineering and Computing, Zagreb, Croatia  
lea.skorin-kapov@fer.hr

Abstract— This paper presents the results of a subjective study aimed at assessing different locomotion (may also be referred to as navigation) techniques in virtual reality environments. We implemented a simple virtual environment in which participants were asked to assess the following four techniques using the HTC Vive platform: teleportation, controller movement, controller movement with tunneling vision, and human joystick. A total of 29 participants took part in the study and rated perceived level of immersion, physical discomfort, and overall Quality of Experience for all tested locomotion techniques. Moreover, participants indicated whether they needed a break after a specific test due to physical discomfort. The results indicate that teleportation yields overall highest QoE and lowest discomfort.

Keywords—virtual reality, locomotion methods, immersion, simulator sickness

I. INTRODUCTION

Recent advances in the field of Virtual Reality (VR) have focused on improvements in VR interaction techniques, including support for different locomotion, or navigation, methods. However, as highlighted by the authors in [1], the field of research on VR locomotion is still uncharted, including interaction-related characteristics. One of the interesting open questions is how different locomotion methods in VR applications influence the perception of immersion and the occurrence of simulator (or VR) sickness [2], in particular across individuals with different levels of prior experience in using such applications. Given the limited amount of prior studies empirically comparing different locomotion techniques, and lack of a standardized subjective assessment methodology, we aim to contribute to the research community by providing data for further analysis and sharing our practical experiences. This short paper presents the methodology and results of assessing four different locomotion methods in VR: teleportation, controller movement, controller movement with tunneling vision, and human joystick, as defined in [1]. Similar studies have already been done comparing controller movement with a position estimating system [4].

The four tested locomotion techniques can be characterized as follows. Controller movement consisted of a continuous sliding movement similar to that found in PC or console first-person games: the speed is controlled by a controller, and the direction is controlled by the orientation of the Head-Mounted Display (HMD). Controller movement with tunneling was set up in a similar fashion, the only difference being a smaller field of view while the user was moving (Figure 1.d). We added this method, since previous research has reported that there exists a correlation between field of view and simulator sickness [3]. With the non-continuous locomotion method of teleportation, the user had to use a pointer to select the desired position (Figure 1.c) and the viewport would be instantly transported to that spot in the VR environment with a short blackout of the screen. The user maintains the original orientation when teleported. The chosen method of human joystick based locomotion is characterized by a continuous sliding movement controlled by the user leaning forward or backward with controllers in their hands. The angle between the HMD and the controllers dictates the speed of the movement.

II. METHODOLOGY

A test VR application was created for the HTC Vive platform enabling four different test scenarios. All test scenarios included participants navigating along the same path through the same virtual environment, from sign 1 to sign 3 (Figure 1.a), but using one of the four different locomotion techniques previously described. The application is comprised of a simple village with a number of houses and fences. Participants are instructed to move through the village following the signs to reach three points in the village.

Figure 1 Map of test virtual environment with indicated sign points (a), sample sign (b), teleportation GUI (c), tunneling vision GUI (d)
The areas of navigation are diverse, from a narrow street to a wide-open space, as indicated in Figure 1. We chose this approach to better reflect the more realistic setting in the majority of VR games. Participants were asked to rate the following after each test scenario:

- **Immersion**: perception of being physically present in the virtual world; rated on a 5 pt. Absolute Category Rating (ACR) scale (from 5 – Excellent to 1 – Bad).
- **Overall Quality of Experience (QoE)**: overall perceived quality of locomotion in VR; rated on a 5 pt. ACR scale.
- **Presence of physical discomfort**: users rated their perceived level of physical discomfort, including nausea, headaches, vertigo, etc. Participants indicated one of three options: no discomfort, mild discomfort, and strong discomfort.

The total testing procedure lasted about 15 minutes per participant (5 min for instructions, and 10 min for the tests and ratings). A total of 29 participants took part in the study (8 females, 21 males), between the ages of 22 and 48 (the average 26.7 years). Participants were asked about their previous experience with VR. Nine participants identified themselves as beginners, ten as intermediate, and ten as experienced users.

All participants were first familiarized with the course of the testing, the measured parameters, the HTC Vive system, and the controls used for different test scenarios. Each participant was presented with all four test scenarios in a randomized order. The participants were instructed to move along the path marked with numbered signs and move onto the next test scenario once they reached the final sign. One scenario is defined as navigating from the starting position in the virtual environment to the final sign using one type of navigation technique. Between different scenarios, users were asked to rate the subjective parameters of immersion, QoE, and presence of physical discomfort. The test administrator noted the answers and the participant did not need to take the headset off between scenarios. Following each test scenario, participants were asked whether they needed a short break, with the following options available: no break necessary, a short break necessary, complete discontinuation of testing necessary. After completing all four tests, each participant was asked to rank the locomotion techniques from what they considered to be “best” to “worst”.

### III. Results

Participants generally rated traditional controller movement (CM) as being the most immersive (Figure 2), with a Mean Opinion Score (MOS) of 4.03, followed by human joystick (HJ) locomotion with a MOS of 3.97 and teleportation (TP) with MOS 3.90. Controller movement with tunneling vision (CMTV) had the lowest rating, with a MOS of 3.86. Nevertheless, ratings for all locomotion techniques are distributed within a relatively small range (3.85 – 4.03) indicating that there is no significant difference, as is also indicated by the overlapping confidence intervals, and ANOVA test (p=0.7985).

The obtained overall QoE scores are more diverse, with teleportation receiving the highest average rating of 4.31 (Figure 3). Tunneling had the second highest average rating of 3.59, while human joystick and controller movement had an average rating of 3.28 with ANOVA test confirming significant difference (p=0.0001) between locomotion methods for QoE. The teleportation scenario had the lowest occurrence of physical discomfort (Figure 4) with only two participants (6.90%) reporting mild discomfort. After the tunneling scenario, one person (3.45%) reported feeling strong discomfort, while nine participants (31.03%) reported mild discomfort. After the gesture-based locomotion scenario, three participants (10.34%) reported feeling strong discomfort and 15 participants (51.72%) reported feeling mild discomfort. The controller-based locomotion scenario had the highest occurrence of physical discomfort, with three participants (10.34%) reporting strong physical discomfort and 18 participants (62.07%) reporting mild physical discomfort. Although one might assume that participants with no prior VR experience might have the most severe problems with physical discomfort, interestingly it was the advanced users who reported the highest percentage of discomfort in the two categories that had the highest percentage of discomfort overall: 80% of experienced users felt physical discomfort with human joystick locomotion, and as many as 90% of experienced users reported discomfort with the controller movement.
During the teleportation scenario, none of the participants felt the need to take a break. After the tunneling scenario, as well as the human joystick scenario, one person needed a short break. After the traditional first-person locomotion three participants (one beginner, one intermediate and one experienced) needed to take a short break. None of the participants requested a complete discontinuation of testing.

Figure 5 portrays the ranking of different locomotion techniques by test participants. Results clearly show that teleportation received the largest percentage of top ranks, with 16 participants (55.17%), ranking it as the best technique in terms of overall preference. This is likely linked to the fact that the highest percentage of participants reported no physical discomfort while navigating using teleportation. Interestingly, the controller movement technique had the highest number of participants ranking it as the worst, but also a high number of participants ranking it as the best type of navigation. Those ranking it as the best technique were also among those participants that reported no or mild physical discomfort.

IV. CONCLUSION

In this paper we presented how four different locomotion methods (traditional first-person locomotion, teleportation, tunneling, and gesture-based locomotion) influenced the perception of immersion, overall QoE, and the presence of physical discomfort (often referred to in the context of simulator sickness) in a study involving 29 participants with different levels of experience. The participants generally rated controller based as the most immersive, followed by human joystick locomotion, thus showing a preference for continuous movement and non-limited field of view, although the results were relatively evenly spread across different navigation methods. On average, the QoE scores were lower for the locomotion methods which resulted in more physical discomfort (traditional first-person locomotion, gesture-based locomotion) and higher for the more comfortable locomotion methods (teleportation, tunneling). Such a correlation shows that the absence of discomfort is likely a more significant dimension contributing to improving overall QoE than the perception of immersion. Future studies will aim to further investigate the various perceptual dimensions contributing to QoE, with a particular focus on physical discomfort.

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REFERENCES


