Exploring Locomotion Techniques for Seated Virtual Reality

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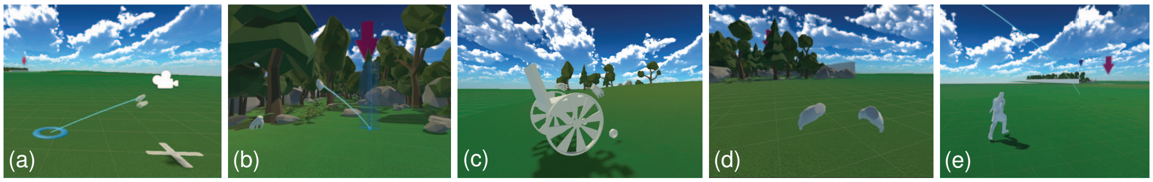

Figure 1: We compare different locomotion techniques in a pilot study in a custom-made evaluation environment: the widely used *Standard Teleport* (a), a teleport adaptation we call *Volumetric Teleport* (b), a virtual *Wheelchair* (c), *Grab&Pull* (d), and the multi-perspective locomotion technique *Outstanding* (e).

Abstract

Virtual reality often only uses locomotion techniques that require users to stand or walk around in physical spaces. We explore the feasibility of selected promising locomotion techniques for a seated stationary VR setting, as it might better support lengthy sessions and small physical spaces, and has the potential to include people with limited mobility. Therefore, we present our evaluation approach and preliminary user study to evaluate these factors. Our results suggest that it is feasible to adapt common locomotion techniques, like teleportation, for this purpose, while more physically demanding techniques may exhibit problems, including motion sickness and usability issues.

Index Terms: Human-centered computing—Virtual reality; Human-centered computing—Empirical studies in accessibility; Human-centered computing—User studies

1 Introduction

Modern virtual environments (VEs) give users the possibility to explore potentially infinitely large spaces from their own homes. To move through a VE, many virtual reality (VR) applications provide locomotion techniques (LTs) that expect the user to stand and be able to walk around or take a few steps in a limited physical space. However, there are cases where a seated stationary VR setting might be more beneficial: long VR sessions that require users to stand can become tiring, many people might not have enough space in their own homes for room-scale virtual environments, and they exclude people with limited mobility.

According to the World Health Organization, about 1 billion people ($\sim$ 15% of the world's population) are living with a disability [5], and 70 million people rely on wheelchairs as mobility aid [4]. Since a significant part of the population is affected by limited mobility, giving all people an accessible way of using emerging technologies, such as VR is of societal relevance. However, many LTs that are designed for people with limited mobility rely on additional hardware, which can be expensive or unpractical, and is rarely supported by common VR applications. For most of the commonly used LTs, it is unclear if they are accessible because there has been hardly any research done on this topic so far. We hypothesize that LTs which are feasible in seated stationary VR settings have the potential to be accessible LTs for people with limited lower-body mobility. Hence, as a first step towards more inclusive LTs in VR, we need to find feasible LTs which do not require additional hardware and enable locomotion where users can remain seated and stationary while in VR. Due to these restrictions, the employed techniques have to provide metaphors for translation and users' rotation while sitting. To investigate the feasibility of such LTs, we propose a concept for an evaluation environment and task design and use it to test five LTs in a pilot study with 15 participants. To the best of our knowledge, the feasibility of LTs for seated stationary VR without additional hardware equipment has not been explored in depth yet. Therefore, our pilot study tries to take a first step in this direction and make different locomotion metaphors comparable in such a setting. Not every LT is adequate for people with limited lower-body mobility, or seated VR in general, and this paper gives an outlook on which metaphors might have potential for this use case.

With this work, we make three contributions. First, we selected five potentially suitable LTs, based on a literature review, and present **adjusted versions of these LTs** for seated stationary VR. Next, we discuss our developed **evaluation environment and task design** to explore the feasibility of the chosen LTs. Finally, we present the preliminary results of our **pilot user study** with 15 participants.

2 Locomotion Techniques

Our goal was to include LTs with different archetypes in our pilot study. We conducted a literature review, looking for LTs that (1) rely only on upper-body movement, (2) provide a holistic virtual movement by allow translation and rotation in a stationary real-world setting, and (3) don't require additional hardware, therefore avoiding additional costs. We selected the following LTs:

Grab&Pull allows users to grab the air in front of them and pull or push themselves continuously forward within the VE (see Fig. 1, d). Our implementation is based on Commer et al. [2]. As this is a rather slow but precise form of movement, we added a multiplier of 2.0 to overcome greater distances, but without adding noticeable jitter. To include full 3D movement, the LT was extended to support altitude changes and continuous rotation via joystick.

Outstanding is a continuous multi-perspective LT where the user can control an avatar (see Fig. 1, e) via selecting target points [1]. As is common for VR applications, the user views the scene through a first-person view but can switch to a third-person view to move their avatar over large distances. We adapted the first-person camera

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for height differences in the VE and included a continuous rotation so the user can adjust their viewing direction.

Standard and Volumetric Teleport. A teleport allows users to select a target point within a designated area and discontinuously move (jump) there. When using this LT in a seated setting, the lowered viewpoint could lead to occlusions in the VEs while aiming. To evaluate this effect, we use two versions of teleport, differing only in the target point indicator. The "*Standard Teleport*" uses a flat circle, while the "*Volumetric Teleport*" uses a volumetric, translucent cross as indicator (Fig. 1, a and b respectively). To support rotation, we added snap-rotations–discontinuous 45° rotations–via joystick.

Wheelchair is similar to the continuous VR wheelchair of Majetich's [3]. To move within the VE, the user has a virtual mechanical wheelchair model (see Fig. 1 c) where they can grab the wheels to push themselves around. The velocity of the grabbing controller is translated into the force moving the wheelchair, which we increased in our implementation to ease movement.

3 Evaluation Environment and Task Design

To explore different LTs for seated stationary VR, we designed a custom-made VE with three different tasks (*T1, T2, T3*) as test cases. For *T1*, users must climb a hill to test how well they can reach positions at **different altitudes**. In *T2*, we test LT performance over **long distances** and for *T3*, users must navigate through a **winding path around obstacles** to investigate how well LTs deal with precise positioning and obstacle avoidance.

In each task, the goal is to move through the VE towards a target (marked with a large pink arrow floating above) that consists of a black pillar with a *task-button* which has to be pushed to complete a task. The three different tasks, their starting point, and targets are placed in different corners of a quadratic plane. The symmetry of the ground plane allows us to create a continuous path for all three consecutive tasks in random order by connecting three replicas of this ground plane (each displaying only one task) in such a way that the new starting position lies exactly underneath the last target.

4 Pilot Study

The goal of this study was an initial feasibility test of our selected LTs for seated stationary VR in general. While we did not yet make a distinction during the study on whether participants had lower-body mobility disabilities or not, in the future we plan to also evaluate LTs with this target group. In total, 15 people (7 female, 8 male) took part in our pilot study with ages ranging from 26 to 55 ($mean = 33.5$, $SD = 4.7$). One user never used a VR system before, four tried it once, seven multiple times and three are regular VR users. The study consisted of a demographics questionnaire, an experiment with five conditions (the five LTs), where each condition was experienced by each participant (using a within-subject design) and involved the completion of three tasks, the virtual reality sickness questionnaire (VRSQ), a subset of the system usability scale (SUS) questionnaire, and additional questions regarding the users' preference. We also tracked the task completion time, user inputs, collisions, and positions. Not all participants could complete all tasks, either due to exhaustion or motion sickness. Therefore, the number of included data sets per evaluated parameter or task differs. Our exploratory experiments showed a shorter **task completion time** for the discontinuous LTs (*Standard Teleport* and *Volumetric Teleport*). The percentage of **wrong user input** was 0% in most cases. This also applies to the recorded **collisions** per LT (expect *Outstanding*, as it cannot produce collisions). In the **VRSQ**, *Wheelchair* and *Grab&Pull* showed lower scores than the *Teleport* variations or *Outstanding*. Our subset of the **SUS** showed promising results for every LT except *Grab&Pull* and *Wheelchair*, which received lower scores. As seen in Fig. 2, most participants **enjoyed** the *Teleport* variations more than the other LTs while, similar to the SUS results, *Grab&Pull* had unfavorable ratings, and *Wheelchair* received the lowest ratings. (Note that these preliminary results have to be validated again in future work.)

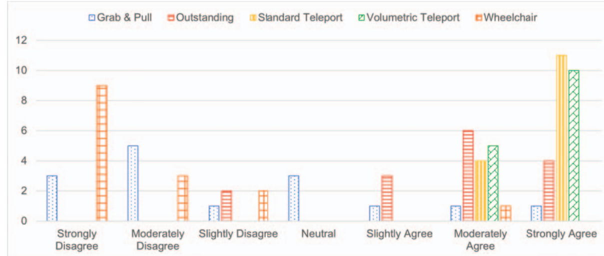

Figure 2: Participants' responses to the question "Did you like/enjoy this Locomotion Technique?".

5 Conclusion and Future Work

There exists a large number of LTs, but their viability for seated stationary VR settings has previously not been explored in depth. We identified a number of existing LTs that are potentially viable for people with limited mobility. In our pilot study, we explored the feasibility of *Grab&Pull*, *Outstanding*, *Standard Teleport*, *Volumetric Teleport*, and *Wheelchair* for seated stationary VR, using our proposed evaluation environment and task design. The *Teleport* variations surpassed all other LTs in efficiency, usability, and user preference. We would recommend the *Volumetric Teleport* for environments with a lot of obstacles and the *Standard Teleport* for large, open settings with fewer occlusions. *Outstanding* received the best ratings among the continuous LTs and presented some unique advantages due to its switching between first- and third-person view. Our versions of *Grab&Pull* and *Wheelchair* showed problems due to exhaustion, motion sickness, and low usability. *Grab&Pull* still showed potential for small, precise movements for a short period of time. In the future, we would like to improve our *Wheelchair* LT, and investigate if it could be an intuitive LT for people familiar with mechanical wheelchairs, and which LT has the best usability for people with limited mobility.

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