Developing a Study Design on the Effects of Different Motion Tracking Approaches on the User Embodiment in Virtual Reality

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ABSTRACT

Body tracking systems often are used to capture body movements of users and to realistically animate humanoid figures in virtual reality (VR). Such systems are based on different techniques, e.g. marker-based and markerless tracking, and consequently have different advantages and disadvantages. In this paper, we highlight different quality aspects such as the reconstruction accuracy and invasiveness of tracking systems for embodied virtual reality. By a direct comparison of the systems through objective measurements and a user study we plan to investigate the effects of different motion tracking approaches. Based on objective and subjective measurements we want to reveal which parameters can influence the user experience and embodiment in a VE.

KEYWORDS

User embodiment, motion tracking, virtual reality

1 INTRODUCTION

As in the physical reality, a virtual body in virtual reality (VR) tends to immediately and continuously provide information about our physical and mental state [1]. Benford et al. [1] define user embodiment as providing a physical representation of a user in cooperative situations. Spanlang et al. [11] use the term virtual embodiment to describe the process in which VR hard- and software is used to reflect the body as a virtual one in a virtual environment (VE). Embodiment can potentially create the subjective illusions of body ownership and agency [11] and can affect the user's self-perception, e.g., negative stereotyping [13]. This can cause an Illusion of Virtual Body Ownership (IVBO), where the users perceive a virtual body or its parts to be their own [8]. Related to this sense of body ownership, the sense of agency describes that users see themselves as the cause and control of actions of the body [6]. The virtual body often aims to reflect the body movements as we expect them from the physical reality [6]. To generate the perception of these both senses the visuomotor synchrony between real and virtual movements is crucial [7]. To achieve this, the real movements must be captured.

From the technical point of view, body tracking can be used to transfer body movements into a VE [11]. Optical body tracking solutions can either be marker-based or markerless [11]. Marker-based solutions commonly combine infrared radiation (IR) signals and small retro-reflective markers or wireless trackers attached to the user's body [5]. Due to the need of a marker placement on the body, these systems can be considered as very accurate regarding the reconstruction, but also invasive. In this context, the term invasiveness describes the extent of the attachment of (technical) objects to the body. A highly invasive tracking system can lead to a change of one's body schema and identity [10], which can be described as the Cyborg's Dilemma [2]. In contrast to marker-based tracking, the markerless tracking is less accurate and has a higher latency. But it is less invasive with no need to attach markers on the user's body. This technology estimates a human shape and its motions from the input of an RGB-D camera [3, 4].

In this paper we want to determine the influence of the invasiveness of the tracking technology and its precision on embodiment and user experience. We are especially interested in the user preferences for the different technologies and the influence on user embodiment. Our findings on the effects of reconstruction accuracy and invasiveness of tracking systems could contribute to gain further knowledge about the emergence of embodiment in VR. Different tracking technologies could have different effects on the embodiment and user experience. Through a direct comparison we want to find out if there is an effect between different tracking approaches. This shall provide useful information about which quality aspects of different tracking systems can affect the user embodiment in VR.

2 RELATED WORK

Each tracking system has its own characteristics in terms of temporal and spatial resolution. These characteristics come with different advantages and disadvantages. A marker-based tracking solution can be realized with a full body marker set to track every related joint or bone position. A smaller marker set can reconstruct the body by skeletal pose estimation based on inverse kinematics (IK)

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calculations [4]. IK approximates the joint angles and bone positions by considering end-effector positions (i.e., hands, feet) and the degrees of freedom (DOF) at each joint [10].

Roth et al. [9] compared the body-tracking performance of a full body marker set with a reduced rigid body marker set with the Optitrack system. Optitrack is a marker-based motion capture system with a reliable tracking quality and low latency. On the downside, it is highly invasive due to tight tracking suits and the need of marker placement. Also it often comes with high costs and a lack of portability. The simplified IK-based approach with the reduced marker set resulted in lower latency and task load [9]. Another marker-based and IK-based solution with a lower level of invasiveness is the Vive with additional trackers. This simple setup with low initial costs offers a high accuracy and low latency [5]. Due to the fact that IK is calculated with limited DOFs, it can result in diverging body movements.

A Kinect sensor provides a markerless bodytracking solution with low invasiveness and preparation time. But it has disadvantages such as a low frame rate and high end-to-end latency [12]. However, researchers often use this markerless and inexpensive technology to develop for example exergames [4]. An IK-based approach as well as a markerless solution also have the disadvantage that they can be severely affected by occlusion.

Due to the different system characteristics, a mere comparison of the systems is difficult. They differ in more than one dimension, especially at the temporal resolution, but also at the spatial resolution and invasiveness. However, we want to make a first markup and leave the systems as they are today, because in some cases they cannot be adjusted to each other. To the best of our knowledge, our approach will be the first to compare these three different tracking systems for embodied virtual reality.

3 METHODOLOGY

With our investigation we aim to gain insights on the impact of quality aspects of tracking approaches on embodiment and user experience. We compare three tracking systems within an embodied VE to identify and analyze parameters that could possibly influence the user experience and embodiment.

Experimental Design. Our investigation will be two-fold: (1) we will analyze the systems regarding objective factors, e.g., reconstruction accuracy. (2) We will compare the three systems in a counterbalanced within-subjects experiment with the senses of embodiment and the user experience as dependent variables. With this design we want to inspect the following hypotheses: (1) The Optitrack system has a better overall reconstruction accuracy. (2) A less invasive system like an IK-based approach or a Kinect depth camera provides better results at the user experience. As for the embodiment, it is difficult to predict which system will perform better.

Technical Setup. Due to a lack of system comparisons mentioned by Caserman et al. [4] we want to implement marker-based as well as markerless tracking systems into an embodied VR application. The used tracking systems are the OptiTrack motion capture system, Vive trackers combined with an IK approach and the Azure Kinect sensor with an associated body tracking software. The different levels of invasiveness can be seen in Figure 1. The OptiTrack motion

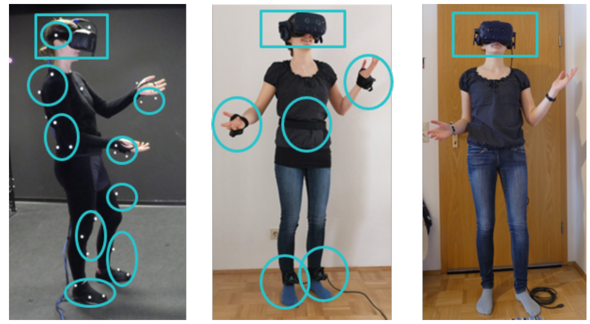

Figure 1: Levels of invasiveness of the Optitrack (left), Vive (middle) and Kinect (right) system.

capturing setup consists of 18 infrared cameras and a full body marker set with 37 markers. The Vive headset is combined with five additional Vive trackers to reconstruct the virtual body with an IK approach. The most current Kinect sensor, called Azure KinectDK takes over the part as markerless solution.

Task and Measures. The evaluation will consist of objective and subjective measurements. For the objective part, technical measurements on latency, performance, and accuracy will be included. The measurements on accuracy will be taken by gathering positional data of end-effectors and values of joint angles. These data will be compared with previously selected ground truths to determine a reconstruction accuracy. The participants are represented by a human-like avatar in a VE. To develop a sense of embodiment and virtual body ownership they will perform different tasks like observing themselves in a virtual mirror or interacting with virtual objects. Every participant will test each system in a randomized order. Questionnaires for the subjective measurements, e.g., presence and body ownership, will be given to the participants at the beginning, after each system, and at the end of the user study. The participants are encouraged to think aloud during the study. Afterwards they are asked about system preferences.

Connecting the objective and subjective findings we hope to better understand the effects of different tracking technologies.

4 DISCUSSION

In this work we presented a methodology for a comparison of three different tracking systems. We want to gain insights on the differences between tracking technologies and their influence on user embodiment and experience. A comparison of different tracking approaches is challenging and hardly provides clarity about which characteristic has which effect. However, this study is intended to look at an overall effect between different systems and it can be a first starting point to analyze the parameters. We are aware that this comparison has limits when it comes to the interpretability of the results. In a second step, specific parameters like temporal and spatial resolution or invasiveness can be taken for further studies within one of these systems. Investigations of these influences shall provide useful information to improve VR experiences.

We expect that the Optitrack will offer a high overall reconstruction accuracy of the body and will also offer a relatively low latency [12]. However, the high preparation time and the invasiveness of the system may change the user experience causing a Cyborg's Dilemma [2]. The Vive system would have the advantage of a high precision at the end-effectors and low latency. According to Caserman et al. [5], an end-to-end latency below 20 ms could be possible. However, it can impair the sense of body ownership through incorrect estimations of elbow and knee positions. But due to a less invasive setup this system could result in a better user experience. Based on results from Waltemate et al. [12] we assume that the system with the Azure Kinect will have an end-to-end latency around 100 ms. This could lead to a visual discrepancy of the movements. For an immersive VE an optimal range for latency would be between 40-70 ms [12]. While this could limit the sense of agency and ownership, the short preparation time and markerless usage could have a positive effect on the user experience. As a higher latency can break the sense of presence [4], we assume that the comparably high latency of the kinect will also affect the embodiment.

We suppose that different tasks in an embodied VE have different priorities in terms of accuracy and user experience. The correct position of the end-effectors might be more important for interaction tasks, like grabbing or touching virtual objects. Correct joint angles and natural movements could be more important for full body tasks, e.g., observing yourself in a virtual mirror. Therefore, future works should test different tracking systems for specific use cases to classify the quality aspects.

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