Tracking Multiple Collocated HTC Vive Setups in a Common Coordinate System

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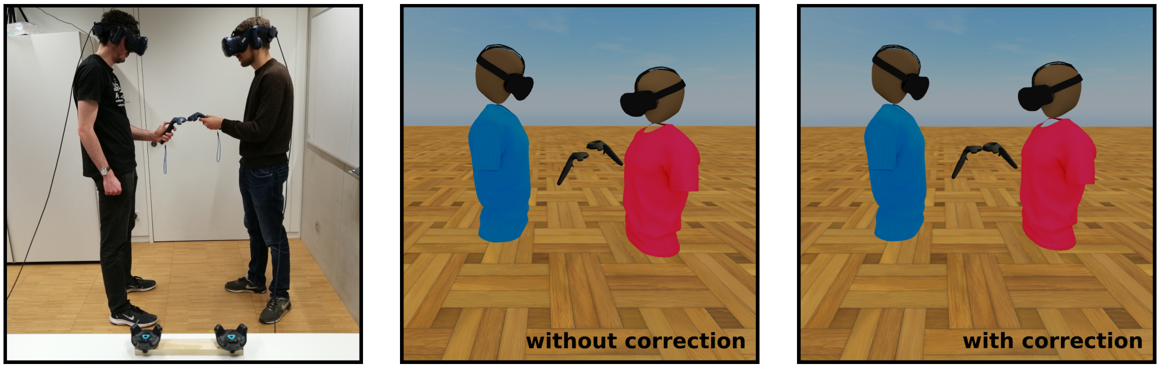

Figure 1: Two collocated users wearing *HTC Vive* displays interact with a shared collaborative virtual environment (left). Without additional mechanisms, both users are tracked and represented in slightly different coordinate systems (middle). We present a procedure for mapping the tracking data to a common coordinate system to allow for spatially consistent interactions (right).

Abstract

Multiple collocated *HTC Vive* setups sharing the same base stations and room calibration files still track their devices in different coordinate systems. We present a procedure for mapping the tracking data of multiple users to a common coordinate system and show that it enables spatially consistent interactions of collocated collaborators.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality
Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Collaborative interaction

1 Introduction

Virtual reality experiences require the accurate and precise tracking of all involved users and their input devices. A popular head-mounted display on the market is the *HTC Vive*, which uses inside-out tracking with external *Lighthouse* base stations to estimate the user's pose in the interaction space. Prior work has shown that the resulting tracking data is provided in an unstable coordinate system that changes every time that tracking is briefly lost [1]. In collocated setups, where more than one computer with a *HTC Vive* setup share the same base stations, each user is therefore tracked in different coordinate systems – even when the room calibration files are identical on each computer. This leads to spatially inconsistent visualizations of users and their controllers in collaborative virtual environments.

We propose a procedure for mapping the tracking data of multiple *HTC Vive* systems to a common coordinate system for spatially consistent interactions. Our approach requires one additional tracking target per user, which can be a controller or separate *Vive Tracker* target. We implemented our approach for a two-user scenario and were able to show considerably smaller differences between user offsets in the real and the virtual world.

Our work is motivated by the increasing popularity of social virtual reality systems using *HTC Vive* displays and controllers, in which the differing reference systems of collocated users are usually not taken into account (e.g. [3,4]). We underline that even small deviations in this regard can impair mutual awareness, the understanding of pointing gestures, and co-presence. As a result, we make the following contributions:

- a scalable procedure for mapping the tracking data of multiple collocated *HTC Vive* setups to a common coordinate system
- an initial evaluation of our procedure confirming considerably smaller deviations between user offsets in the real and virtual world for two collocated users

Our results encourage the integration of our procedure into social virtual reality systems for collocated users.

2 Correction Procedure for Tracking Data

Our proposed procedure maps the tracking data of each individual *HTC Vive* instance to the coordinate system of a designated reference instance. We achieve this by considering the data of an additional tracking target per user, which can be a controller or a separate *Vive Tracker* target. In an offline measurement process, we determine the ground-truth spatial relations between the target of the reference user and all other targets. During runtime, we can then repeatedly detect and correct undesired deviations from this ground truth. In the following, we will describe the two phases of our approach in more detail.

2.1 Offline Measurement of Targets

To measure the ground-truth spatial relations between the additional targets, all of these devices need to be paired with a single computer. By doing so, it can be ensured that all positions and orientations are measured in the same coordinate system. The relative difference matrix between the targets associated with the reference user r and another user i can be computed as follows:

$$\Delta_{ri} = T_r^{-1} \cdot T_i$$

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This expresses the position and orientation of user i's target (T_i) in the coordinate system specified by the reference user's target (T_r) and has to be computed for all non-reference users. Afterwards, all tracking targets involved in the correction process must be kept in the exact same relative spatial configuration. We suggest attaching them to a common object to ensure that they can only be translated and rotated together as a single entity.

2.2 Online Correction of Coordinate Systems

Before starting the collaborative application, the additional targets for each user need to be re-paired with their respective computers and *HTC Vive* systems. During runtime, our approach then compares the tracking data of the targets as measured by the different systems to the ground-truth data obtained before. In particular, a correction matrix C_i can be computed for each non-reference user i as follows:

$$C_i = T_r \cdot \Delta_{ri} \cdot T_i^{-1}$$

Here, T_i is the tracking matrix of user i's target measured by user i's system and T_r the tracking matrix of the reference target measured by the reference user's system. If both involved systems tracked T_i and T_r in the same coordinate system, C_i would be the identity matrix. Otherwise, C_i represents the correction matrix that needs to be applied to all tracking matrices M measured by user i's system (e.g. head-mounted display, controllers, etc.):

$$M_{corrected} = C_i \cdot M$$

Afterwards, all devices of user i will be represented in the same coordinate system as the reference user. Since the tracking coordinate systems of each *HTC Vive* system can change at any point during runtime [1], the correction matrices C_i need to be re-computed in every frame of the application.

3 Evaluation

We evaluated our correction procedure with two *HTC Vive* head-mounted displays and controllers in an interaction space with a size of 2.5m x 2.5m. Two ceiling-mounted base stations were placed on opposite corners as tracking references, and each user was assigned a *Vive Tracker (2018)* target for our correction procedure. Both targets were attached to a wooden plank to avoid accidental changes in their relative transformation (see Figure 1).

3.1 Experimental Procedure

We connected both head-mounted display systems to their respective computers. On one machine, we used the *Room Setup* tool of *SteamVR* to configure the boundaries of the interaction space and copied the resulting room calibration to the other computer. Afterwards, we paired both *Vive Trackers* with one machine and followed the procedure in Section 2.1 to measure the relative offset matrix between both targets. To investigate the stability of this step, we repeated the measurements for different positions and orientations of the wooden plank within the interaction space. Afterwards, we re-paired the *Vive Trackers* with their correct machines and started our collaborative VR application, which takes the tracking data of both *HTC Vive* systems and places corresponding user visualizations into a shared virtual environment. We placed one controller per system next to each other as shown in Figure 2 (top) and took a screenshot of the controller visualizations in the virtual environment. Next, we briefly covered the controller of the non-reference user with a piece of cloth to simulate a loss of tracking and uncovered it again before taking the next screenshot. This allowed us to study the differences in the obtained tracking data visually. We repeated this process 15 times with and 15 times without our correction computations activated.

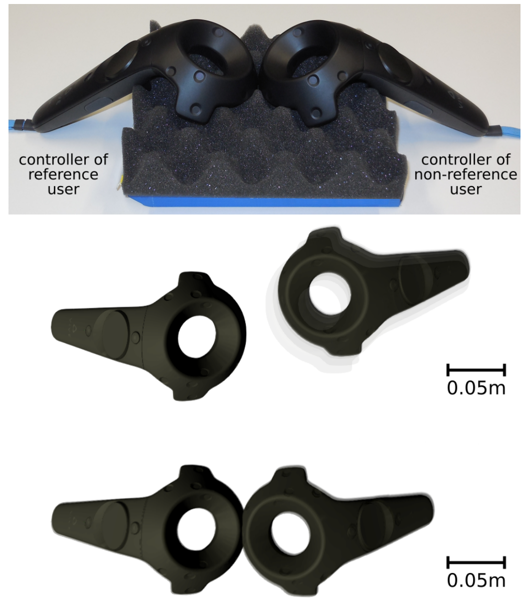

Figure 2: Hardware setup of our experiment (top) and overlaid top views of the 15 controller visualizations in the virtual environment without (middle) and with (bottom) our correction computations activated.

3.2 Results and Discussion

In the offline phase, our repeated measurements produced consistent offset matrices (rounded to 3 digits per entry) independent of the position and orientation of the wooden plank in the interaction space. Regarding the online phase, Figure 2 shows two overlaid top views of the 15 controller visualizations without (middle) and with (bottom) our correction computations activated. In the first case, the relative accuracy between both controllers is visibly low. Moreover, repeated measurements after tracking losses are unstable, which was also observed in related work [1]. Our correction procedure minimizes both of these problems and therefore fulfills our goal of improving spatial consistency of collocated interactions.

4 Conclusion and Future Work

We presented a procedure for mapping the tracking data of multiple *HTC Vive* setups to the coordinate system of a reference user and showed its improvements in spatial consistency for collocated interactions. Nevertheless, we would like to underline that the shared coordinate system is still subject to changes when tracking of the reference user is lost. As a result, future work will combine our correction procedure with established methods for aligning the reference coordinate system with the physical interaction space [2].

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