Remapping a Third Arm in Virtual Reality

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Abstract

This paper presents development on a conceptual method to remap supernumerary limbs using Virtual Reality (VR) as a platform for experimentation. Our VR system allows users to control a third arm through their own limbs such as their head, arms, and feet with the ability to switch between them. To realize and experiment with our remapping method, we used the Oculus Rift in conjunction with OptiTrack to track users in a room-scaled virtual environment. We present some initial findings from a small pilot study and conclude with suggestions for future work.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Supernumerary Limbs; Third Arm

1 Introduction

In this paper, we present a method to remap human limbs to a virtual third arm in a Virtual Reality (VR) Environment. Our motivation for using VR was to experiment with our developed concept before potentially implementing our design with a physical robotic arm in the future. Use cases for requiring a third arm involve dual tasks where the user is required to perform two different tasks simultaneously. Previous work has shown that supernumerary limbs can assist in completing dual tasks quicker and more effectively [1, 4] and self-reported ownership of supernumerary limbs from users increases over the sessions that they use them [5]. We wish to determine if we can obtain positive results from self-reported ownership of the virtual third arm. Specifically, when the user is required to switch limbs in a fast search-based task. We conducted a small pilot study with five participants, and discuss their experience performing a search-based task using the system we developed. We conclude with our findings from the participants experience of using the virtual arm and our remapping method.

2 Background

Supernumerary limbs involves the concept of having additional limbs attached to your body that can be used to assist in simple and complex tasks [3]. Parietti and Asada explored the use of supernumerary robotic limbs on the back of a user that could support them acting as additional legs or arms for load lifting [4]. Saraiji et al. additionally experimented with supernumerary robotic limbs situated on a backpack that could be controlled with the user's feet [5]. They found that self-reported embodiment improved over the sessions that participants used the system, instigating that the robotic arm felt more like a limb from their own body. Abdi et al. investigated controlling a third hand in VR using their feet, finding that in a demanding task three hands performed better than two [1]. Sasaki et al. also investigated splitting tracked arms in VR to create supernumerary limbs for simple tasks [6].

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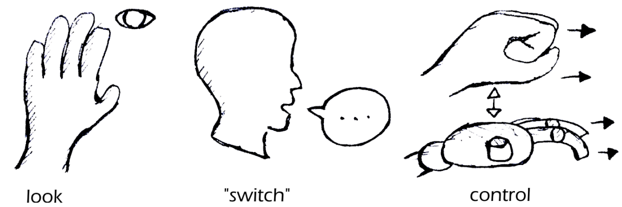

Figure 1: Process of remapping the third arm.

3 System Description

Using our system, users can remap a virtual third arm to their own head, arms, and feet. To remap the third arm to a limb, the process involves the user looking at a limb on their body, followed by saying "switch" which then remaps the third arm to the desired limb (see Figure 1). Following a successful switch, the user is given audio feedback through a simple beep sound. Additionally, a green sphere is placed at the limb the user is looking at to give them visual feedback of the limb they are about to select. If the user wants to control the third arm with their head, they simply have to look up above a pitch of 290°and then say "switch". Additionally, the third arm stretches upward when mapped to the head and downwards when mapped to the feet to motivate participants to switch in the pilot study to reach objects. The third arm was positioned inside the upper centre of the user's chest to avoid influencing their decision on remapping to a left or right limb.

3.1 Setup

Our experimental apparatus consists of an Oculus CV1 with tracking performed using 10 Optitrack Prime 13[1] cameras and 6 Optitrack Prime 17W[2] cameras with approximately $10.3m^2$ ($4.37m \times 2.37m$) of tracking space. We developed the study using the Unity games engine (version 2018.2.15). The participants head, hands, and feet were tracked with wearable rigidbody markers, with the rest of the skeleton being solved with inverse kinematics (IK) using the FinalIK Unity package[3]. The third arm skeleton was additionally solved using IK, which follows a target position dependent on the forward direction of the limb the user is using to control the arm. The bend goal for the third arm was positioned at the root of the chosen limb in an attempt to mimic the limb's joints. Voice was captured with a microphone embedded in the Oculus CV1, with the switch event being registered if the user spoke above a threshold of

[1]https://optitrack.com/products/prime-13/
[2]https://optitrack.com/products/prime-17w/
[3]http://www.root-motion.com/final-ik.html

0.0001. Microphone levels were obtained by finding the wave peak from the last 128 samples of audio recorded from the microphone at a sample rate of 44.1KHz.

4 Pilot Study

We conducted a pilot study with five participants to obtain preliminary feedback for the system. Participants are initially trained how to switch limbs and are freely allowed to experiment using different limbs to control the third arm. In training, the participant is allowed to push and interact with floating boxes for 5 minutes in a play area (see Figure 2). Following training, participants are required to reach and collect as many moving pink boxes as possible in a time limit of 10 minutes, which they can only collect using their third arm. The pink boxes are in fixed locations and become active one by one as the participant collects the boxes (see Figure 2). The pink boxes appear above, below, and in reaching distance to motivate participants to switch limbs to reach different boxes. A box disappears if the participant does not collect it within 15 seconds which results in other box appearing. The boxes additionally rotate around a pivot in order to make them harder to collect.

After the pilot study, participants were required to take a handedness and footedness questionnaire to determine if they were right or left dominant for their hands and feet. Following this, participants were required to fill a body ownership questionnaire to investigate ownership of the third arm. The body ownership questionnaire consisted of the following questions adapted from Gonzalez-Franco and Peck's [2] avatar embodiment work, with subjective experience ranging from (strongly disagree) to (strongly agree) on a seven point likert scale:

Q1. I felt as if the virtual third arm was my own arm.
Q2. It felt as if the virtual third arm was synchronized with my physical arm motion.
Q3. It felt like I could control the virtual third arm as if it was my own arm.
Q4. The movements of the virtual third arm were caused by my movement.
Q5. I felt as if the movements of the virtual third arm were influencing my own movement.
Q6. I felt as if the virtual third arm was moving by itself.

Participants were then asked if they could imagine using the third arm in their own day to day life, and whether they had any final thoughts about the pilot study.

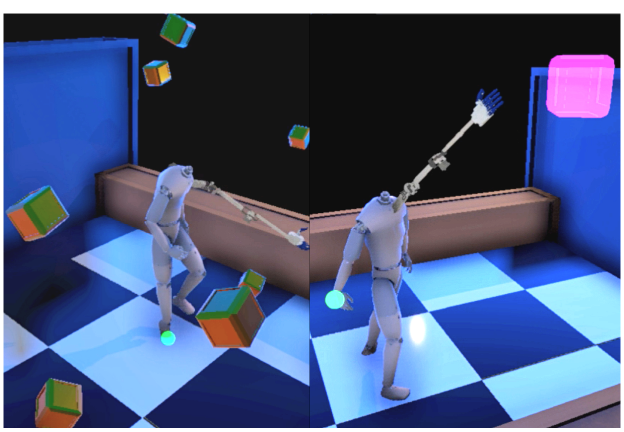

Figure 2: (Left) Initial training where participants are freely allowed to switch limbs to control the third arm to play with floating boxes. (Right) Participant in the main experiment reaching out and collecting boxes.

5 Results

We found from our body ownership results that 4 out of 5 participants agreed on Q1 to feeling as if the virtual third arm was their own arm. Responses for Q2 varied suggesting improvements are needed regarding synchronous movement of the arm. Most participants disagreed on Q3, likely due to how different it feels in contrast to using their own limbs. Participants however agreed on Q4 and Q5, suggesting positive results for synchronous movement. Participants disagreed on Q6, additionally indicating positive results for body ownership. All participants were right-handed, most participants were right-footed with one participant in the middle decile.

We observed that participants did not mind using their non-dominant arm to control the third arm. Furthermore, participants occasionally used their non-dominant leg to control the third arm, but less frequently than with their non-dominant arm. The main criticisms in feedback were directed at controlling the third arm with feet. One participant commented "When I retracted my leg the arm was extending and when I was extending my leg the arm retracted". This is likely to be a result of the bend goal's position for the feet, and could be fixed with some tweaking. Additionally, another participant commented "it was hard to stay on one foot" when controlling the third arm with their leg. Overall, participants commented that they could imagine using the third arm for "holding a door", "manual work", "soldering" and "reaching high objects".

6 Conclusion

We obtained positive results for body ownership for the third arm in regards to remapping. Additionally, participants appeared to not mind using their non-dominant limbs to control the third arm. We plan to run a full study to validate our findings as significant in the future. Additionally, we plan to put our remapping system through more rigorous tasks and test it with physical robotic limbs.

We also plan to measure and validate usability of the system itself, as well as third arm control with the head, arm, and feet. Furthermore, we wish to determine how to embed grasping with the variety of limbs that the third arm can be remapped to. We are also interested in whether remapping can have an affect in perceived body ownership in contrast to not remapping.

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