Investigation of Visual Self-Representation for a Walking-in-Place Navigation System in Virtual Reality

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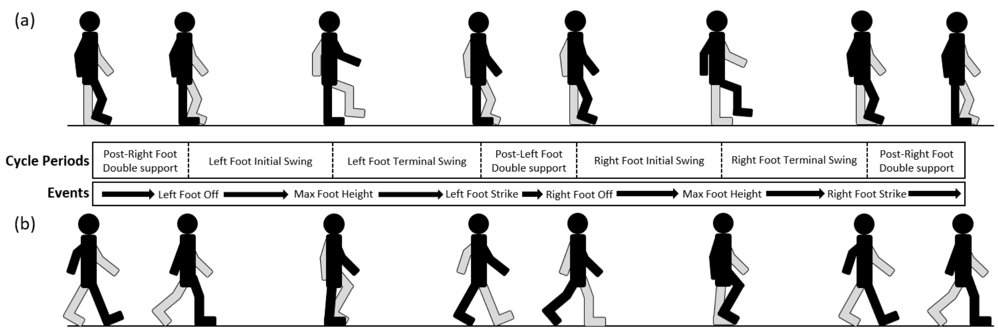

Figure 1: (a) WIP-based gait cycle [10], (b) Real walking-based gait cycle corresponding to the WIP's period timings.

Abstract

Walking-in-place (WIP) is one of the techniques for navigation in virtual reality (VR), and it can be configured in a limited space with a simple algorithm. Although WIP systems provide a sense of movement, it is important to deliver immersive VR experiences by providing information as similar as possible to walking in the real world. There have been many studies on the WIP technology, but it has rarely been done on visual self-representation of WIP in the virtual environment (VE). In this paper, we describe our investigation of virtual self-representation for application to a WIP navigation system using a HMD and full body motion capture system. Our system is designed to move in the pelvis direction by calculating the inertial sensor data, and a virtual body that is linked to the user's movement is seen from the first-person perspective (1PP) in two ways: (i) full body, and (ii) full body with natural walking. In (ii), when a step is detected, the motion of the lower part of the avatar is manipulated as if the user is performing real walking. We discuss the possibility of visual self-representation for the WIP system.

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

1 Introduction

For navigating a virtual world, it is important to provide a navigation performance similar to that in the real world. Natural walking is the most natural and efficient way to understand virtual environments (VEs), but this approach is only available when the tracking system is as large as the size of the virtual world [8]. On the other hand, a walking-in-place (WIP) interface performs virtual movement with step-like motions in a limited tracking space [7], stimulating proprioception as in natural walking.

WIP technology is controlled by the user's leg motion [6], but there is no actual translation to the user. That is, the user only moves in VEs using the movement of the feet or knees. Therefore, WIP technology does not provide the same vestibular cues as natural walking. In an immersive VE, there is a contradiction between sensory data and proprioception because the user's body is not visible. Having a virtual self-representation in a VE can reduce this contradiction and increases the degree of immersion and presence [1, 5]. In addition, spatial orientation relies on visual and body information for navigating in the VEs [9]. Visual self-representation with a WIP system has rarely been studied, but this will become important issue when full body tracking is available.

In this study, we investigated visual self-representation methods for WIP technology. Our WIP system provides virtual locomotion by step detection based on IMU sensors [10], and adds a virtual body from the first-person perspective (1PP) using a full body motion capture system with two methods: (i) full body, and (ii) full body with natural walking.

2 Method of Visual Self-Representation for WIP

It is important to provide visual self-representation with the WIP system to experience the sense of body ownership. Maselli et al. [4] found that a 1PP over a virtual body is an essential condition for experiencing the illusion of body ownership. In the 1PP, the avatar's motion needs to be similar to the user's actual motion. When the virtual body is similar to the real one, having an avatar increases the sense of presence [1]. We propose a 1PP visual self-representation in two ways as follows:

- Method 1: This method displays the user's full body avatar in the VE. When the user performs WIP, the avatar translates the motion in the VE, but the lower part of the avatar does not move like in natural walking (Fig. 1(a)).
- Method 2: This method is a complement to Method 1. If a step is detected, the lower part of the avatar is manipulated to move like real walking (Fig. 1(b)).

3 Implementation

Our system used a HMD (Oculus Rift DK2; 100° FOV diagonally) and full body motion capture system (Perception Neuron) for implementing WIP technology and a virtual avatar (see Fig. 2(a)). Graphics were rendered using the Unity 3D engine.

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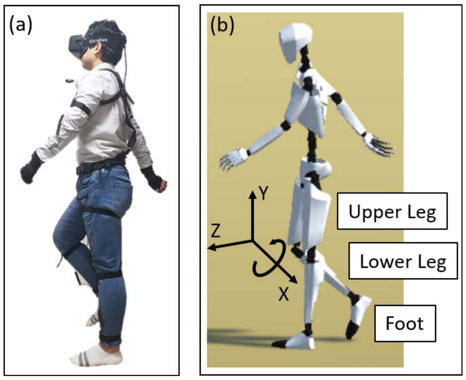

Figure 2: (a) System configuration: HMD and IMU based motion capture system (b) Demonstration example of the avatar in Method 2

3.1 Step Detection and Locomotion

Wendt et al. [10] proposed a gait-based state model for a WIP system. This state machine is classified into four states (no gait, single foot initial swing, single foot terminal swing, and post-single foot double support) and each state is changed by four gait events (foot-off, max foot height, foot-strike, gait stop) as shown in Fig. 1(a) (no gait is a state when the user keeps both feet on the ground). We determined the gait event condition by referring to [10] as follows: **Foot Off** occurs when a single foot leaves the ground and the ankle's vertical velocity is more than a threshold (V_{thr1}). **Max Foot Height** is identified if the moving ankle's vertical velocity decreases below a threshold (V_{thr2}). **Foot Strike** occurs when the moving foot contacts the ground. **Gait Stop** is identified if each state lasts too long ($0.4s$). It also occurs when the moving single foot touches the ground in the foot initial swing state. If gait stop is detected, our system returns to no gait state.

The contact state of two feet and the ankle's vertical velocity are obtained from the Perception Neuron SDK at a 120Hz frame rate. If a step is detected (all states except no gait state), the user moves to V_0 $(= 2m/s)$ in the VE. Locomotion direction is determined by the orientation of the pelvis.

3.2 Visual Self-Representation with a WIP system

The method of visual self-representation is presented in Section 2. In Method 1, the motion of the avatar corresponds to the data by the motion capture system. Method 2 represents the same visual stimuli as Method 1 in the no gait state. However, in the gait state, the avatar should be moved as in real walking, so our system controls the avatar with the following process by referring to the real walking-based gait cycle [2] (see Fig. 1(b)):

- We calculated the step period (T_{step}) from the past three states (within the three gait states, $T_{step} = 700ms$). Then, we determined the cycle period rate as the Initial Swing (45%), Terminal Swing (45%), and Foot Double Support (10%) through preliminary experiments.
- Each lower limb joint angle rotates linearly in proportion to T_{step} around the x axis (Fig. 2(b)) as shown in Table 1.

3.3 Discussion

In the preliminary study, five participants experienced three minutes each of the WIP system with the two visual representation methods (set $V_{thr1} = 0.4m/s, V_{thr2} = -0.1m/s$). Participants were asked to observe their avatars as they moved forward in the VE. After each trial, they commented on the movement of the avatar. In both methods, all participants felt that they were located in VE when they saw the avatar and the motion of the virtual legs were their motion. Most participants said that Method 2 had more natural walking than Method 1. However, in Method 2, some participants reported unintended leg movements; we think that was because we did not limit the step frequency range.

Table 1: Avatar joint angle rotation of Method 2 in the gait state

	Left Foot Initial Swing	Left Foot Terminal Swing	Post-Left Foot Double Support	Right Foot Initial Swing	Right Foot Terminal Swing	Post-Right Foot Double Support
Left Upper Leg	-20°	-25°	-25°	0°	25°	25°
Left Lower Leg	50°	0°	15°	0°	0°	15°
Left Foot	0°	0°	10°	0°	0°	10°
Right Upper Leg	0°	25°	25°	-20°	-25°	-25°
Right Lower Leg	0°	0°	15°	50°	0°	15°
Right Foot	0°	0°	10°	0°	0°	10°

4 Conclusion and Future Work

We investigated visual self-representation for a WIP system using a full body motion capture system. We confirmed the possibility of providing a better walking feeling by manipulating the lower part motion of the avatar. In the next step, we will further investigate how to determine the avatar joint rotation angle and gait cycle period for each user's natural walking. And we will apply various visual stimuli that have not yet been studied (e.g., only feet [3]).

Acknowledgments

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