Straightening Walking Path Using Redirected Walking Technique

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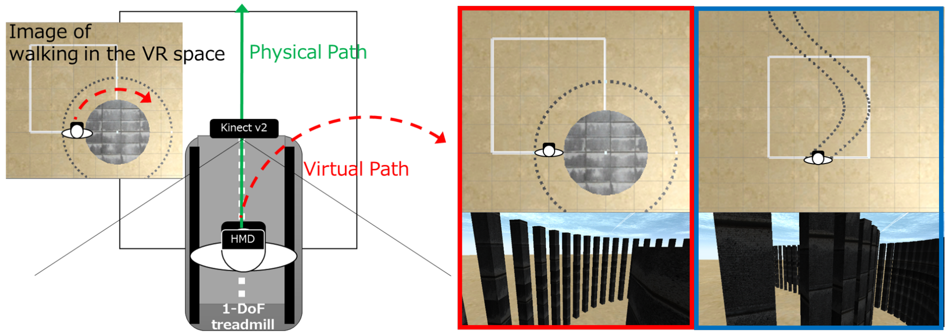

Figure 1 *Illustrates the (a) Approach, (b) Movement in the VR environment (Right: circle, Left: sinusoidal curve)*

Abstract

Virtually infinite space is a holy grail of immersive virtual environment (IVE), and numerous approaches have been proposed, yet there still is a hardware and spatial cost. We propose a novel low-cost locomotion interface that combines a 1-DoF treadmill and a head mounted display (HMD), in which displayed image is rotated to induce straightened trajectory for the treadmill, similar to the technique known as Redirected Walking. We conducted an experiment using the proposed method, and showed that by using PD control algorithm, the walking path became straightened.

Keywords: Redirected walking, locomotion interface, virtual environments

Concepts: • **Human-centered computing ~ Interaction paradigms;** *Mixed / augmented reality;*

1. Introduction

Numerous studies have been conducted on how to produce a more realistic walking movement method in a virtual reality (VR) environment. Typical solutions have used two-dimensional treadmills [Iwata1999] to let users walk around a wide VR space, but this requires high cost. The Redirected Walking technique [Razzaque2001] has also been used, and allow users the subjective experience of walking straight, whereas in reality their walking path is controlled by visual stimuli; however, this technique still requires a certain size of physical space.

The contribution of this paper is twofold. First, we propose a new locomotion interface that combines a relatively inexpensive 1-DoF treadmill and a head mounted display (HMD) (Figure 1(a)), and uses the Redirected Walking technique to make the walking path straight. We then evaluate this method by measuring walking trajectory in a simple setup without using the treadmill.

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2. Method

Our approach is to straighten the users' walking path by rotating the scene displayed on the HMD, just like in the Redirected Walking technique. Once the walking path is straightened, the relatively inexpensive 1-DoF treadmill can be used for infinite walking.

2.1 Algorithm

VR space is rotated using the following two algorithms.

$$\textbf{rotate} = K_p * d \tag{1}$$

$$\textbf{rotate} = K_p * d + K_d * V_x \tag{2}$$

Where the x-axis is in a direction orthogonal to the ideal straight walking path, rotate is the rotation angle of the image, d is the displacement along the x-axis, V_x is the velocity along the x-axis and K_p and K_d are the proportional and differential gains, respectively.

Equation (1) represents P control and equation (2) represents PD control. Furthermore, the IIR filter used in [Razzaque2001] was applied to smooth abrupt motion:

$$\textbf{rotate} \leftarrow (1 - s) \times \textbf{before\_rotate} + s \times \textbf{rotate} \tag{3}$$

Where "before_rotate" represents the rotation of the previous cycle. s was set to 0.8 in our experiments. The update cycle was set to 1/25 seconds.

3. Experiment 1: Induction of Straight Walking

In this experiment, we verified the straightening of the walking path sing the proposed method. We also examined optimal parameters for control, in terms of deflection from the center line, which determines the size of the treadmill.

3.1 Conditions

Participants wore the HMD and walked along the circular and sinusoidal curves that were created in the VR space (Figure 1(b)). The radius of the circle was 2m, and the wavelength and amplitude of the sinusoid were 8 m and 1.5 m, respectively. The positions of the participants' heads were tracked using a Kinect (Kinect ver2, Microsoft Corp, Redmond, USA). Based on the previous equations (1) or (2), the screen in the VR space was rotated. The control parameters K_p and K_d were also changed. The combinations of the parameters are shown in Table 1.

Table 1 *Parameter combination table*

	no control	P control			PD control								
Kp (degree/m)	0	1	2	3	1	1	1	2	2	2	3	3	3
Kd (degree*s/m)	0	0	0	0	2	4	6	2	4	6	2	4	6

There were 26 trials (two pathways ×13 conditions for control), all in random order. After each trial, participants were asked to answer two questions: (1) Whether they felt visual discomfort (e.g., the scene moved the screen in an unexpected direction), and (2) whether they felt discomfort when walking (e.g., walking was unstable). We recruited six participants, four male and two female, aged 20－24.

3.2 Results

Figure 2 shows the trajectory of one participant, for sinusoidal (left) and circular (right) paths. The figure legend shows (K_p, K_d) for each condition. The yellow solid lines shown the path in VR space, the black dotted lines show the control-free conditions, the dotted lines are the P controlled cases, and the solid lines are the PD controlled cases.

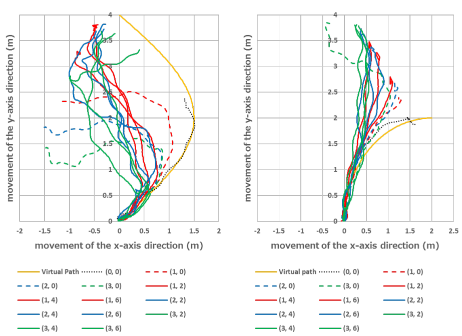

Figure 2 *Walking trajectory (Left: sinusoidal curve, Right: circle)*

Figure 4 shows the maximum deflection from the center line in the sinusoidal curve condition.

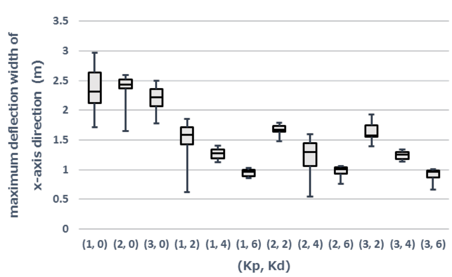

Figure 3 *Maximum deflection width of the x-axis (Sinusoidal curve)*

Comparing the control parameters in Figure 2, PD control gave smaller deflection. While the path became more stable as the K_p value increased, we found that subjective discomfort for both of the questions also increased. Based on these observation, we determined the optimum values of the control parameters to be (K_p, K_d) = (2 deg/m, 6 deg s/m).

4. Experiment 2: Verification of Magnitude of Inducible Curvature Radius

We can assume that the system works better when the virtual path is close to straight, and it cannot induce straight walking when the curvature radius is small. This experiment explores the range of curvature radius that can be straightened with reasonable deflection.

4.1 Conditions

The experiment was conducted in the same environment as in Experiment 1 with the obtained optimum control parameters (K_p, K_d) = (2, 6). Curvature radius was set to 1m, 1.5 m, 2 m, and 2.5 m. Each condition was conducted twice, resulting in a total of 8 trials in random order. After each trial, participants were asked to answer three questions on a seven-point Likert scale: (1) whether they felt as if they had walked on the visually displayed path; (2) whether there was any visual discomfort; and (3) whether there was any discomfort in walking. We recruited six participants, five male and one female, aged 20－24.

4.2 Results

Figure 4 shows that the maximum deflections for each curvature radius were all within 1 m. Available treadmills typically have at most a 0.6 m wide walking belt, so the ideal deflection is less than half of that value. However, from Figure 4, if the radius of curvature is 2 m or more, the walking path can be controlled within a 1 m width, so we will need to improve this in future work. Our questionnaire result also indicated that for a 2 m and 2.5m curvature radius circle, almost no discomfort was reported.

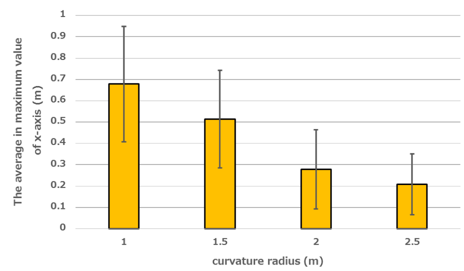

Figure 4 *Maximum deflection width of the x-axis*

5. Conclusion and Future Work

The purpose of this research was to create a low-cost walking interface that required only a small space. We proposed a method of combining a relatively inexpensive linear exercise treadmill and visual walking induction. As a preliminary study, we verified the method of guiding the movement of the participant in the VR environment into a straight line with visual rotation. The results indicated that is possible to induce straight line walking using PD control, and if the curvature radius of virtual space is more than 2m, the real walking path can be confined to a straight line on a general 0.6 m wide treadmill.

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