Walking Uphill and Downhill: Redirected Walking in the Vertical Direction

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Figure 1: The left is the appearance of our system, the center is the first person view, and the right is the image diagram.

ABSTRACT

This paper proposes a novel redirected walking technique that creates the feeling of walking uphill and downhill in the virtual environment while actually walking on a flat floor in the real world. We focus on the amount of energy consumed while walking uphill and downhill. Previous studies show that walking uphill takes three times as much energy as walking on a flat ground while walking downhill takes only half as much energy. We believe that the walking feeling in the virtual environment could be improved by changing the walking distance according to the gradient and bringing it closer to the energy consumption at the actual ascending and descending walk. We conducted a preliminary experiment to confirm that the proposed method is effective and the experimental results imply that our method is efficient for walking uphill.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**;

KEYWORDS

Virtual Reality, Redirection

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1 INTRODUCTION

Thanks to the emergence of redirected walking [Razzaque et al. 2001], it has been possible to explore vast virtual environments (VEs) in a smaller tracking space without complicated equipment. Although much research has been done on redirection on the plane [Razzaque et al. 2001], [Steinicke et al. 2010], little research on vertical redirection has been done [Marchal et al. 2010]. The way to walk uphill or downhill, which is the fundamental movement, has not been reported yet.

There are many differences between walking on flat ground and on sloped ground but one of them is the amount of energy consumed. It is known (see for instance, [Minetti et al. 2002]) that walking uphill on a slope with 0.1 gradient requires nearly three times as much energy as walking on a flat ground while walking downhill on a slope with 0.1 gradient requires nearly half the

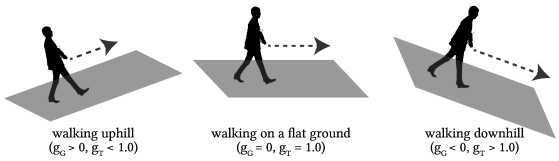

Figure 2: Our proposed method: The arrows indicate the translation distance.

amount of energy. In this paper, we focus on energy consumption. To improve the feeling of walking uphill or downhill, we try to increase or decrease the energy consumption by using translation gains, which is one of the fundamental methods of redirect walking.

2 VERTICAL REDIRECTED WALKING

We propose gradient gains $g_G \in R$. The gradient gains are similar to translation gains, but are applied to vertical directions instead of progressing directions. [Steinicke et al. 2010] defined the translation gain as follows:

$$g_T := \frac{T_{virutal}}{T_{real}} \tag{1}$$

where $T_{virtual}$ is the mapped virtual world translation—i.e., the amount of movement of the virtual camera in VEs—and T_{real} is the tracked real world translation—i.e., the amount of the user's head movement in the real world. On the other hand, the gradient gain is defined as

$$g_G := \frac{T_{height}}{T_{real}} \tag{2}$$

where T_{height} denotes the height of a virtual slope and T_{real} is the tracked real world translation. When a gradient gain g_G is applied, the virtual camera is moved by $g_T \cdot T_{real}$ in the horizontal direction and by $g_G \cdot T_{real}$ in the vertical direction.

We thought that by increasing or decreasing the translation gains according to the gradient gains, the energy consumption can be brought closer to the scenario of walking uphill and downhill in the real world and the feeling of walking uphill and downhill can be improved. Specifically, when users are walking up the slope, the system increases the amount of energy consumption by setting the translation gain less than one and when users are walking down the slope, the system reduces the energy consumption by setting the translation gains more than one (see Fig. 2).

3 PRELIMINARY STUDY

We conducted a preliminary user study to investigate the effect of our proposed method. Three male candidates (mean age 23.3 years) from our institution participated in this user study. We used a 4×2 full-factorial within-subjects experimental design. We tested 4 different gradient gains for the virtual slopes: $g_G \in \{-0.2, -0.1, 0.1, 0.2\}$ and with/without translation gains. We set $g_T = 1 - g_G$.

After wearing a head-mounted display, a participant was instructed to walk along the virtual sidewalk, which had a total distance of 4 m (fig. 1 center). While participants were walking along the virtual sidewalk, we applied gradient and translation gains. We presented two conditions of the presence or absence of a translation gain in succession at the same gradient slope. After the two trials, we asked the participants, which they felt was the steeper slope. The participant had the two answer options "before" and "after".

Table 1 shows the percentage of participants who felt a steeper gradient. The gains $g_G > 0$, that is when they were walking up the virtual slopes, participants felt that with translation gains conditions is steeper than without translation gains conditions. On the other hand, the gains $g_G < 0$, that is when they are walking down the virtual slopes, participants felt that with translation gains conditions are less steep than without translation gains conditions.

Since the difference in energy consumption between walking downhill and walking on the flat ground is smaller than the difference between walking uphill and walking on the flat ground, it is considered that the effect of the amount gained in the translational movement was not obtained on the descending slope.

Table 1: The percentage that the subjects answered that it was the steeper slope.

Grades: gG	With translation gains	Without translation gains
-0.2	33%	67%
-0.1	33%	67%
0.1	100%	0%
0.2	100%	0%

4 CONCLUSION AND FUTURE WORKS

We proposed a novel redirected walking technique that creates the feeling of walking uphill and downhill in the virtual environment by changing the walking distance according to the gradient while walking on the flat floor of the real world. The user study implied that our method is efficient for walking uphill. However, it is necessary to analyze the users' ability to recognize vertical redirected walking manipulations.

Our method could be applied in various virtual reality applications such as architecture, training, and entertainment by providing the sensation of walking on inclined grounds.

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