Walking Up Virtual Stairs based on Visuo-Haptic Interaction

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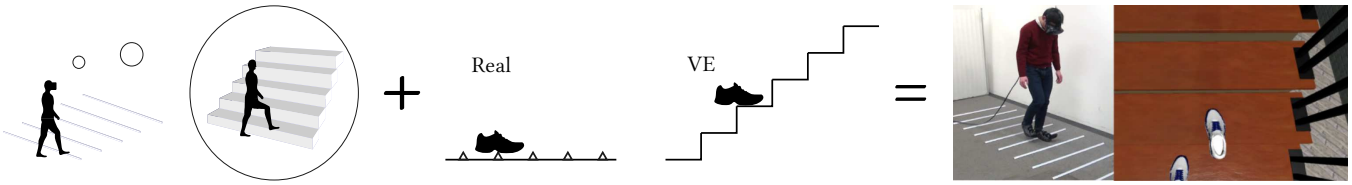

Figure 1: "Infinite Stairs," which evokes a realistic feeling of walking up/down virtual stairs in a virtual environment for users using the flat ground and tiny bumps based on visuo- haptic interaction.

CCS CONCEPTS

•Human-centered computing →Virtual reality;

KEYWORDS

Virtual stairs, foot-haptics, visuo-haptic interaction, virtual reality

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1 INTRODUCTION

In the field of virtual reality, a few methods exist that allow a user to walk up and down the stairs in a virtual environment (VE); however, most of them are based on a complicated device system that generates physical steps using actuators (e.g., [Iwata et al. 2005; Schmidt et al. 2015]). Because it is difficult for users wearing head mounted displays (HMDs) to keep track of the surrounding environment, walking on physical steps could prove to be very dangerous and lead to injuries. Further, these systems have disadvantages in that the user cannot walk naturally. Therefore, a simple and low-cost system that allows users to walk safely and freely in the vertical direction in a VE is highly desirable.

Meanwhile, the other studies attempted to modify users' spatial perception by using both visual and haptic stimuli to generate the effect of visuo-haptic interaction. Visuo-haptic interaction is a phenomenon that modifies users' proprioceptive perceptions according to visual stimuli when haptic and visual sensations are presented simultaneously. In particular, Ban et al. revealed that by presenting a small edge, it is possible to change the shape perception of an entire object that the user touches with their hand in the VE[Ban et al. 2012]. Furthermore, it is known that haptic information is very important for evoking the walking sensation in VEs. Matsumoto et al. showed that haptic signals strengthen the effect of redirected walking techniques[Matsumoto et al. 2016]. Redirected walking is a method for manipulating horizontal spatial perception by manipulating the visual information of a walking user.

Based on previous studies, we believe that we can change the shape perception of the ground surface into that of a stair by presenting haptic stimulus corresponding to the edge of the step on the soles of the user, thus creating visuo-haptic interaction. This would allow manipulating the user's spatial perception in the vertical direction strongly. In a previous study[Marchal et al. 2010], a method wherein the user experiences walking up and down stairs without performing physical steps was proposed; this method employed viewpoint manipulation to achieve this effect. By combining this type of viewpoint manipulation and visuo-haptic interaction, we believe that it is possible to evoke the strong sense of walking up and down stairs in users. Then, in this study, we propose a system that allows users to walk up and down stairs in a VE, even though the users walk on a flat ground in a real space (Fig.1). We hypothesize that our system strengthens the immersive and realistic feeling of ascent/descent and makes the user feel that he/she is walking up/down the virtual stairs. In addition, the proposed system enables us to present a sense of ascent/descent safely without presenting physical steps.

In this work, we present a novel technique to simulate the sensation of walking up the stairs in a VE based on visuo-haptic interaction. The haptic stimuli provided by a small bump under the feet of the users correspond to the edge of the stair in the VE, and the visual stimuli of the stairs and shoes, provided by the HMD, evoke visuo-haptic interaction for the user.

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To generate visuo-haptic interaction, small angle bars (height: 10 mm) are placed on the floor in the 4 m × 4 m tracking space. A user wears an HMD (HTC Vive) and shoes attached to the controllers. The HMD and controllers are motion-tracked. The HMD shows virtual stairs and sneakers corresponding to the position of user and their feet in the VE (Fig.1). To present a sense of walking up and down the stairs, the height of the virtual camera corresponding to the user's viewpoint and the sneakers are moved according to the position in the real space (Fig.1). The viewpoint is linearly raised according to the gradient of the stairs. When stepping on the stairs in the VE, the user steps on the small physical edge set at the position corresponding to the edge of the step. This haptic stimulus and the viewpoint manipulation introduced by the HMD generate visuo-haptic interaction, and this make the user feel the haptic sensation of the edge of the stairs. This shape perception strengthens the sense of ascent/descent on the virtual stairs for the user walking on the flat ground. Because physical steps are not used, there is no physical risk for the user.

It is possible to express multiple hierarchies by placing the small angle bars at the end of the tracking space. As the space is expanded in the vertical direction, it is possible to make complete use of the VE consisting of a 3D space. For example, our system can be applied for building simulations in architectural design.

2 USER STUDY

We conducted a simple user study to investigate the effect of our system. Twelve male candidates (mean age 21.9 years) from our institution participated in this user study. The participants wore an HMD and put on shoes with controllers. They climbed five steps in the VE. The VE was a simple one consisting of stairs and ground.

We presented 6 conditions (2 haptic conditions: with or without bumps on the floor in real world × 3 visual conditions: 75, 100, 125cm as the height of stairs in total). We compared the user's immersive feeling using SUS PQ[Slater et al. 1995] and the height felt by the user at the top of the virtual stairs between conditions.

The perceived height of the stairs in each visual condition was higher with bumps condition (57.7cm, 71,7cm, 87.5cm, respectively) than without bumps condition (53.5cm, 64.3cm, 83.6cm, respectively). There was a significant difference in the perceived height of the stairs between two haptic conditions (Fig.2). Moreover, the score of the immersive feeling is significantly higher with bumps condition than without bumps conditions (Fig.3). These results showed that the proposed method increased the immersive feeling and made the perception of movement in the vertical direction more realistic.

3 LIMITATION

Our system has several limitations. Since the user has to step on small bumps, the large steps of the tread face can not be reproduced. To accurately install bumps on the floor and manipulate the user's viewpoint, the dimensions of the 3d model of stairs must be known. Furthermore, there are individual differences in walking, our system may not be effective for a few users.

Although this time the user's viewpoint was raised linearly, it is necessary to verify appropriate viewpoint manipulation in the future. By manipulating the motion of the shoes in the VE, it may be possible to lead the user to step on small bumps.

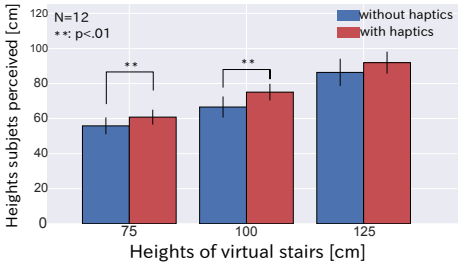

Figure 2: Heights subjects perceived (Mean±SE).

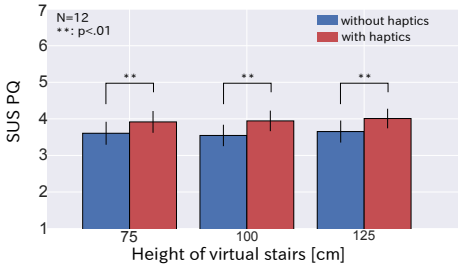

Figure 3: Immersive scores of SUS PQ (Mean±SE).

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