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Effects of Physical Prop Shape on Virtual Stairs Travel Techniques

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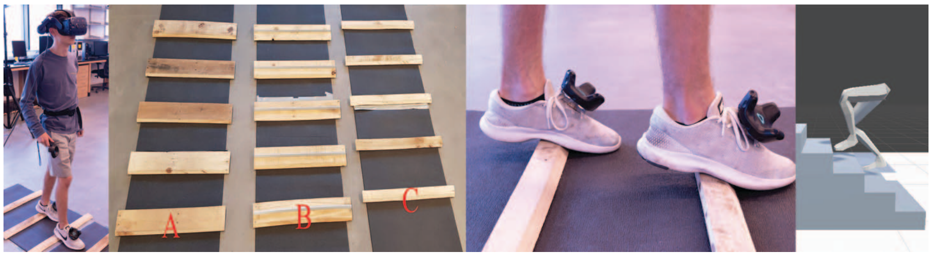

Figure 1: (Left)A user ascending virtual stairs on prototype. (Middle Left)Physical prototype. A-Elongated ramp. B-Elongated ramp with a bump. C-Normal ramp. (Middle Right)A user's feet on ramps, descending virtual stairs. (Right)Virtual stairs and legs in a VE.

Abstract

Experiences of Virtual Reality training and architectural virtual environments benefit when provided a higher sensation of stair climbing. Passive haptic props can add that sensation. These methods present a safe approach by placing short ramps on the floor rather than a physical staircase. To improve a user's level of immersion, we conducted an experiment to explore the shape of physical props to change the way users were aligned and moved while traveling up or down a virtual set of stairs. We investigated three methods for physical props while ascending and descending virtual stairs. Results suggest that elongated props provide a better experience and are more preferred.

1 Introduction and Related Work

Due to the range of current VR tracking stations, the volume of the physical space can be limited. A chosen travel technique, such as teleportation or joystick, that will enable exploration of a virtual environment larger than the physical tracked space may disorient a user [1] or reduce sense of presence [2] respectively. Redirected walking is an approach to this problem, imposing small manipulations to the VE in order to enlarge the VE, but at the same time, ensuring these changes are not noticeable to the user. This technique involves exaggeration of the user's rotations or linear movement [6]. However, redirection has largely been explored for horizontal navigation but less so for vertical navigation. Vertical redirection comes with the challenge of translating a user's motion on flat ground into motion that mimics the climbing of a hill or a staircase. Without a physical step to push off of or descend onto, the change in weight that occurs during stair climbing is removed, thus taking away a level of immersion from the user. Previous studies have explored the use of short ramps in place of a real-life staircase to simulate the edge of a step safely and in a cost effective manner [4]. Although effective at returning visuo-haptic feedback, this solution runs into issues when the user attempts to descend the staircase. For both walking on level ground and up stairs, the foot must be raised off either the floor or the previous step, respectively. Except in the descending case, there comes the challenge that the foot must be placed below the previous step. Since the user cannot place their foot below the physical ground in the tracking space, simulating the sensation of descending stairs becomes difficult. A previous study implemented an array of small rails to simulate the feeling of touching the edge of stair steps [4]. This approach is more cost effective than alternate systems that require machinery to achieve the same effect. These designs also turned out to be safer than the utilization of a normal staircase. Another study compared a variety of small ramp shapes and found that a slanted triangle was the optimal shape for ascending a staircase [5], yet descending remains less optimal. However, our research focuses on both physical and virtual approaches.

We present research that investigates a novel implementation of both physical props and algorithms derived from real-world body movement to displace the user vertically during stair climbing. Additionally, our research explores manipulation of the user's view, virtual 3D legs and surrounding virtual environment. The addition of an even smaller ramp placed atop a set of one of the ramp designs was the physical approach. This change allows the user's foot to sense the edge of the step while also being able to sense the drop from one step to the next. The addition of algorithms that alter the user's view, as well as the angle of the stairs and room, is the virtual approach. In our experiments, we will evaluate how these changes effect the feeling of traveling up and down stairs.

2 User Study: Determining the Best Haptic Prop

2.1 Experimental Design

Researchers found that using passive haptic feedback while descending the stairs in the VE is not as effective compared to ascending of the stairs [5]. To investigate this problem, we conducted a within-subjects experimental user study where we designed a ramp from the previous study [5] (normal ramp) and also added two more new designs of the ramp for it, an elongated ramp with a bump and an elongated ramp without a bump. The first ramp design was based on the best shape of a previous study (see figure 1 middle-left, C), having a peak height of 2 cm and a hypotenuse of 6 cm [4]. The second design takes the hypotenuse of the first design and extends it to 12 cm long while keeping the height at 2 cm (see figure 1 middle-left, A). The third design is a modification of the second design (see figure 1 middle-left, B). It has the same width, hypotenuse, and height, but it also adds a set of 3D printed bumps glued widthwise along the middle of each step. The 3D printed bumps were shaped like an isosceles triangle and had a height of 1 cm and a base length of 2 cm. All of the ramps were 70 cm in width. When connecting

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the ramps to the mat, their peaks remained at a constant 30 cm away from each other. To prevent any tripping hazards, the edge of every ramp was cut off at a 45-degree angle to ensure safety among all participants. The peak of these props play a role in visuo-haptic feedback, simulating the edge of a stair step (Figure 1 middle-left). In previous studies [5], props were found as a cheaper and safer solution over heavy machinery and real staircases.

2.2 Procedure and Apparatus

Participants wore a HTC Vive Pro Head-Mounted Display (HMD) with a resolution 2160 by 2160 pixels to view the VE generated from Unity3D game development platform (version 2019.1.7) with C#. In the real world, small wooden ramps provided visuo-haptic feedback for virtual stairs. The ramps had a height of 2 cm and a width of 70 cm. The small bumps were attached to the top of the ramps for 1 of the 3 sets, had a height of 1 cm and a base of 2 cm (see figure 1). Each physical ramp peak was aligned to correspond to each edge of a virtual step. A virtual 3D model of low-poly legs was developed and displayed to the user to increase immersion. VIVE trackers were placed on the top of each user's feet and the back of their hips. The virtual legs mimicked the user's legs using Inverse Kinematics (IK) from the Unity Assest Store [3]. IK is used to calculate how a limb moves, where the input is the desired position in 3D space to place the end effector, representing the foot and the output is the angle for each joint. We calculate the height of the user's view, H_p, in addition to the IK. H_p is calculated with H_{hmd}, the current height of the HMD in the real world, and X, the horizontal distance travelled over the invisible ramp in the VE. R_{rise} and R_{run} are the rise and run, respectively, of the slope of the invisible ramp in the VE:

$$H_p = H_{hmd} + (R_{rise}/R_{run})X \tag{1}$$

We collected data using pre- and post-questionnaires, stereopsis test, realism questionnaire, and SUS presence questionnaire [7]. Each participant was asked to sign a consent form, then complete a pre-questionnaire, the Butterfly sterescopic test, and training in the VE. Next, participants completed three blocks of trials (x5 trials) for the experimental user study, one block for each of the three different physical prototype. For each physical prototype condition, per trial, a participant was asked to go up the set of stairs to look at a picture on the wall and come back down. The SUS post questionnaire, our own post-questionniare, and an open-ended interview were administered to each participant to provide more information each experience.

3 Results

We collected data from 14 participants for this experimental study (18 to 54 years old). As shown in Figure 2, we found participants were more comfortable walking on the virtual stairs using elongated ramp without a bump (M= 5.36, S.D.=1.39) compared to the elongated ramp with the bump (M = 5.07, S.D. = .977) and normal ramp (M = 5.21, S.D.=1.251). We conducted a repeated measures ANOVA, with a Greenhouse-Geisser correction, which showed there was no significant difference among the physical ramp conditions, F¡1. Furthermore, we collected qualitative data from the participants to understand their experience while ascending and descending the virtual stairs. Slightly higher preference scores were reported for both elongated ramps (with and without a bump) over the normal ramp, however there were no significant differences among the three. Participants' comments about the elongated ramp without the bump are: "Faster over steps cause more comfortable", "easier going down", "felt like real stairs", "more comfortable", and "best one". Participants' comments about the elongated ramp with bump are: "going up good but down was flat", "even though saw stairs, while looking down felt like falling", "going down not right", and "going upward is easier but not downward". With supporting evidence from the qualitative and quantitative data from the experimental study, participants preferred elongated ramp without the

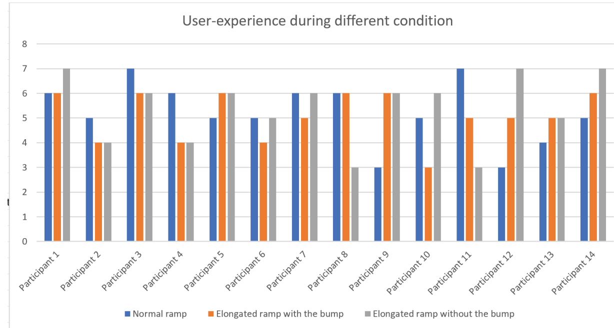

Figure 2: Participants' experience of using each physical prop type.

bump while ascending and descending the virtual stairs. Results from the SUS presence questionnaire provide evidence of increased sense of presence for elongated props. Comments include: "The room felt immersive and going up and down the stairs was convincing visually". Another participant responded "I shuffle so going down the stairs was weird at first. Once I articulated my steps they felt more real". A participant also commented "elongated ramp without a bump felt the best overall".

4 Conclusion and Future Work

Our results found that an elongated haptic prop is more preferred and provides a higher sense of presence than the shorter prop evaluated in previous experiments [4, 5]. We evaluated whether an added triangular bump on top of the flat prop would improve a participant's experience. There were no significant differences found with or without the bump, yet including more participants may change this. This research will initiate discussions about vertical travel and may help design VEs with virtual stairs. We will conduct a more extensive study on physical props and visual displacement algorithms.

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References

[1] D. A. Bowman, D. Koller, and L. F. Hodges. Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality*, pp. 45–52. IEEE, 1997.

[2] W. Chen, A. Plancoulaine, N. Férey, D. Touraine, J. Nelson, and P. Bourdot. 6dof navigation in virtual worlds: Comparison of joystick-based and head-controlled paradigms. In *ACM VRST 2013*, p. 111–114, 2013.

[3] J. Díaz. Inverse kinematics script, https://assetstore.unity.com/packages/tools/animation/inverse-kinematics-1829, 2017.

[4] R. Nagao, K. Matsumoto, T. Narumi, T. Tanikawa, and M. Hirose. Infinite stairs: simulating stairs in virtual reality based on visuo-haptic interaction. In *ACM SIGGRAPH 2017*, p. 14, 2017.

[5] R. Nagao, K. Matsumoto, T. Narumi, T. Tanikawa, and M. Hirose. Ascending and descending in virtual reality: Simple and safe system using passive haptics. *IEEE transactions on visualization and computer graphics*, 24(4):1584–1593, 2018.

[6] S. Razzaque, Z. Kohn, and M. Whitton. *Redirected walking*. Citeseer, 2005.

[7] M. Usoh, E. Catena, S. Arman, and M. Slater. Using presence questionnaires in reality. *Presence: Teleoperators & Virtual Environments*, 9(5):497–503, 2000.