Unlimited Corridor:

Redirected Walking Techniques using Visuo Haptic Interaction

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Abstract

The main contribution is to realize an efficient redirected working (RDW) technique by utilizing haptic cues for strongly modifying our spatial perception. Some research has shown that users can be redirected on a circular arc with a radius of at least 22 m without being able to detect the inconsistency by showing a straight path in the virtual world. However, this is still too large to enable the presentation of a demonstration in a restricted space.
Although most of RDW techniques only used visual stimuli, we recognize space with multi-modalities. Therefore, we propose an RDW method using the visuo-haptic interaction, and develop the system, which displays a visual representation of a flat wall and users virtually walk straight along it, although, in reality, users walk along a convex surface wall with touching it. For the demonstration, we develop the algorithm, with which we can modify the amount of distortion dynamically to make a user walk straight infinity and turn a branch freely. With this system, multiple users can walk an endless corridor in a virtual environment at the same time.

Keywords: Redirection, Redirected walking, Haptic cues, Visuo-haptic interaction, Virtual reality

Concepts: **• Human-centered computing ~ Interaction paradigms;** Virtual Realty;

1 Introduction

"Unlimited Corridor" enables users to walk around virtual environments (VE) unlimitedly with touching walls although they are walking around circular walls within a limited space.
Many methods have been proposed and applied, to walk through a virtual environment (VE). One of them is tracking the user's position and reflecting it onto his/her virtual position in a VE. However, to replicate IVEs with such a system, we need an equally large physical space. The recent research proposed a redirected walking (RDW) method, which compresses a large VE into a physical room that could be significantly smaller while maintaining the sense of real walking [Razzaque, S et al., 2001]. RDW techniques use visual sensations to overwrite user's vestibular and proprioceptive sensations to manipulate user's spatial perceptions.

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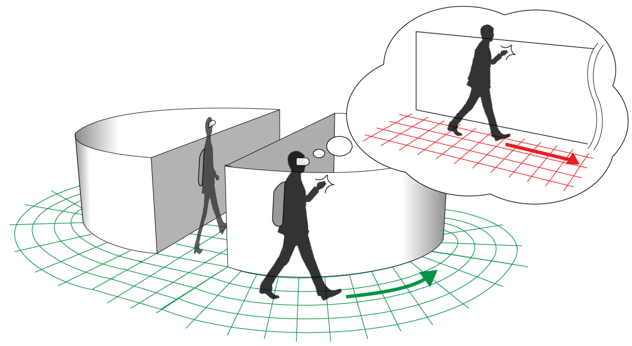

Figure 1: *Concept of "Unlimited Corridor"*.

Many research groups have studied RDW techniques in IVEs [Bowman, D. A. et al., 1997; Razzaque, S et al., 2001]. A well-known simple redirection approach is reorientation, which uses rotational manipulations to reset user's direction when they are close to walking out of the tracked space. The other approach is to apply redirection continuously while the users walk through the VE. In this approach, if the users want to walk straight in the VE, the camera in the VE acts as the users' eyes and rotates little by little, to redirect the users to walk along a circular path in reality. Both ways can reduce required actual space to display IVE. However, the former is possible to prevent the users from walking continuously because it requires users stop and turn on the spot. The latter has the limitation that a circular arc in the real world with a radius of at least 22m could turn into a straight path in the VE, for which the users cannot consciously detect manipulations [Steinicke, F. et al., 2010]. Therefore, with only the distortion of visual spaces, the RDW needs relatively large real space or has a risk of reducing the quality of experiences.
Although RDW techniques use the principal of visual dominance in spatial perception, some works try to modify the spatial perception using haptic stimuli. Steinicke et al. revealed that it is possible to explore arbitrary IVEs by real walking when consistent haptic feedback is provided [Steinicke, F. et al., 2008].
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 altering users' proprioceptive sensations corresponding to visual sensations by the combination of visual and haptic sensations. Some works tried to modify the perception of the curvature, angle, and size of an object by using distorted visual stimuli and the actual object as a haptic cue [Ban, Y. et al. 2012; Kohli, L. 2009]. These studies show the possibility that visuo-haptic interaction can modify users' spatial perception to enhance the effects of RDW techniques.
Therefore, to walk straight unlimitedly in a smaller actual space without using reorientation techniques, we focus on the effects of visuo-haptic interaction. We propose the method to improve the effect of manipulation in RDW by using haptic cues (Fig. 1), we call this system as visuo-haptic RDW. Besides, reducing inconsistencies between visual stimuli and haptic/proprioceptive stimuli could reduce sickness and uncomfortable feelings, and enhance the effectiveness of RDW techniques.

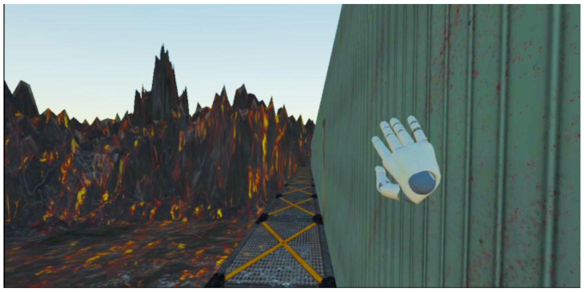

Figure 2: *Unlimited straight corridor in the VE.*

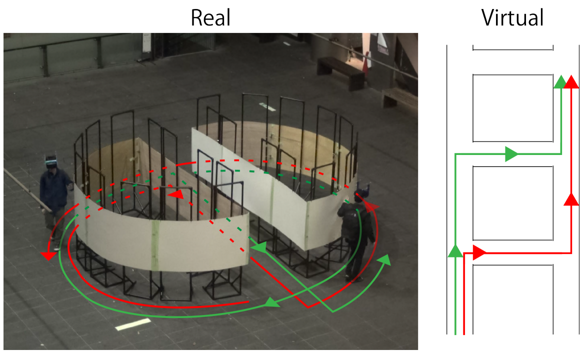

Figure 3: *Multi users can experience this system at the same time.*

2 Visuo-Haptic RDW feedback

To evoke the effect of visuo-haptic interaction, we set a curved wall in a tracking space. A user wears an HMD (Oculus Rift DK2) with infrared markers to track the position of a user's head. We track the position of these markers within the room using a motion-capture system, which consists of twelve Flex 13 cameras of Optitrack. For 3-degrees of freedom orientation tracking, we use the Oculus Rift DK2 sensors.
Through the HMD, a user watches the VE with a straight wall, and s/he walks along with this wall while touching it, although actually, s/he walks along with a curved wall. To create such visual feedback, the system detects the difference between real and virtual wall's shape. Using this difference, the system distorts the VE to arrange the relative position of a user and a wall like Figure 1. Also, the system displays a virtual hand and synchronizes the times at which the real/virtual hand touches a wall physically and virtually (Fig. 2). The hand position is detected by IR cameras (Leap Motion), which is attached on the HMD.
With this feedback, the visuo-haptic interaction occurs, and a user feels as if s/he touches a straight wall and walks along with it, although s/he walks in a curved line in actual. Synchronization between distorted visual space and haptic space can enhance the effect of RDW and help to reduce an actual space to enable a user to walk around in IVEs. Through experiments, we have already revealed that visuo-haptic RDW enhances the effect of curvature manipulation techniques and immersion for the VE and reduce uncomfortable feeling than conventional redirection techniques [Matsumoto et al., 2016].
To realize a branched corridor, we also propose modifying the amount of spatial distortion dynamically due to the actual position of a user. The system performs a curvature manipulation when a user is in the outer peripheries and does not perform any manipulation in the straight central passage.
When a user is in an outer periphery (upright of Fig. 4), O^v is moved by θL and a virtual semicircle is rotated by $-\theta$. On the other hand, when in the straight central passage (downright of Fig. 4), the system doesn't perform manipulations. This algorithm can keep relative position between a user and a touching wall.

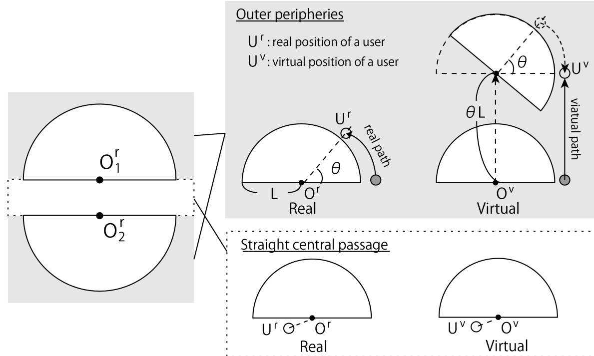

Figure 4: *Algorithm of redirection methods.*

3 Demonstration at SIGGRAPH 2016

Using findings from the experiments, we constructed the system, in which a user can walk straight in the VE unlimitedly using a round wall in actual. The diameter of this wall is 5m because participants feel walking straight with this curvature gain in the user study. Besides, by setting a passage at a center of this round wall, the user can turn at a branch in the VE, and the system can create branches and passages unlimitedly like Figure 3.
Also, to make multiple people experience this system at the same time, the system controls the route of a corridor to prevent a collision of users. The system judges the possibility of the collision of users from users' positions and directions, and decides the route by opening and closing virtual automatic doors.
Using visuo-haptic RDW methods, we'll enable people to walk around a variety of VR experiences in limited physical space.

Acknowledgements

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