Application of Redirected Walking in Room-Scale VR

Eike Langbehn*
Human-Computer Interaction
University of Hamburg

Paul Lubos†
Human-Computer Interaction
University of Hamburg

Gerd Bruder‡
Institute for Simulation and Training
University of Central Florida

Frank Steinicke§
Human-Computer Interaction
University of Hamburg

ABSTRACT

Redirected walking (RDW) promises to allow near-natural walking in an infinitely large virtual environment (VE) by subtle manipulations of the virtual camera. Previous experiments showed that a physical radius of at least 22 meters is required for undetectable RDW. However, we found that it is possible to decrease this radius and to apply RDW to room-scale VR, i. e., up to approximately 5m × 5m. This is done by using curved paths in the VE instead of straight paths, and by coupling them together in a way that enables continuous walking. Furthermore, the corresponding paths in the real world are laid out in a way that fits perfectly into room-scale VR. In this research demo, users can experience RDW in a room-scale head-mounted display VR setup and explore a VE of approximately 25m × 25m.

Keywords: Virtual Reality, Redirected Walking, Room-scale

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1 INTRODUCTION

Walking is usually considered the most natural form of self-motion and one of the most basic kinds of interaction in a virtual environment (VE). Perception and cognition research has shown benefits of traveling through an immersive virtual environment (IVE) by a natural, multi-modal method like walking compared to other locomotion techniques [4], e. g., flying by hand-controller, and walking-in-place. Multi-sensory cues like vestibular, proprioceptive, as well as visual information enable a higher sense of presence and a better navigational performance, for instance. Hence, real walking is becoming increasingly important to improve virtual reality (VR) setups, e. g. in fields like tourism, architecture, or video games. But real walking in IVEs is restricted to the size of the physical workspace. The confined physical workspace of typical VR setups is nowadays often denoted as *room-scale VR*, i. e., up to approximately 5m × 5m.

Redirected walking (RDW) [2] provides the user with near-natural sensory feedback and enables users to explore a VE that is considerably larger than the tracked workspace by guiding them on paths in the real world which differ from the paths perceived in the virtual world. One of the most interesting characteristics of redirected walking is that if the visual-proprioceptive conflicts are small enough, humans will not even be able to notice that they are manipulated. Results of psychophysical experiments analyzing human sensitivity to walking a curved path in the real world when walking a straight path in the VE have revealed that the physical workspace in VR setups needs to cover at least 45m × 45m for unnoticeable real walking [3]. Unfortunately, this space requirement exceeds the space which is available in most existing VR laboratories nowadays, and furthermore, is incompatible with the above mentioned room-scale VR setups.

*e-mail: eike.langbehn@uni-hamburg.de
†e-mail:paul.lubos@uni-hamburg.de
‡e-mail:gerd.bruder@ucf.edu
§e-mail:frank.steinicke@uni-hamburg.de

2017 IEEE Virtual Reality (VR)
March 18-22, 2017, Los Angeles, CA, USA
978-1-5090-6647-6/17/$31.00

Figure 1: An architectural visualization that can be explored by using the virtual path layout of the footprints on the floor.

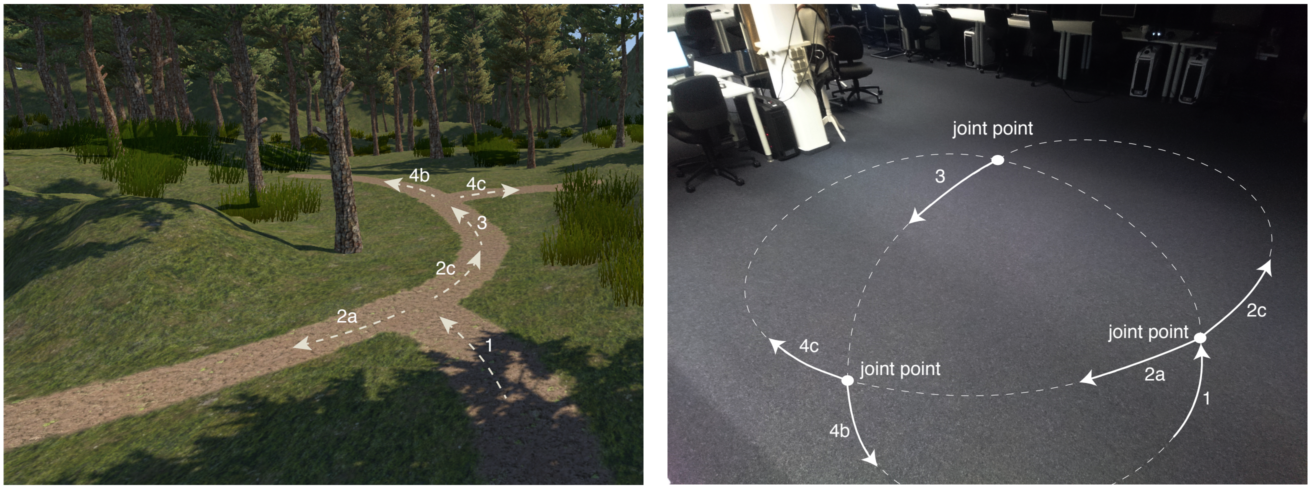
However, when walking through VEs, users do not always follow an exactly straight path but tend to walk on curved paths more often. Such curved walking paths can be often observed, for example, when users walk on virtual trails, through bent corridors, or when circling around obstacles. In a research paper for this year's IEEE VR, we have investigated how much the bending of a physical path can vary from the bending of a virtual path in situations in which users already walk on such a curved virtual path [1]. We showed that users will be much less aware of the redirection in such situations and we introduced *bending gains* that define discrepancies between physical and virtual paths in situations where both are bent. Furthermore, we proposed a novel method for generalized RDW that exploits this fact and makes it possible to leverage undetectable RDW even in room-scale VR setups.

In this research demonstration, we want to present this method and enable users to experience RDW in a room-scale VR setup (cf. Figure 1). Therefore, we offer a 5m × 5m large head-mounted display setup that can be used to explore a VE of approximately 25m × 25m by using the method explained in Section 2.

2 APPLICATION

In contrast to previous work on RDW, the main idea of our approach is to provide users with virtual curved paths on which they can walk. Our approach is based on the idea to use several curved paths with intersections between them. At each intersection, the user may continue her walk either on the curve or change the direction by walking on a different curve. Figure 2(a) shows such a situation in the VE with several curves and intersections between them.

Figure 2(b) shows how a real-world walking configuration with several curved paths is constructed in such a way that users can walk on them while remaining within a room-scale VR setup. This configuration fulfills the following constraints:



(a)

(b)

Figure 2: Illustration of our approach in a VR-based outdoor application: (a) a virtual pathway in the VE constructed of several curves and intersections with (b) the corresponding real-world walking configuration consisting of several curve segments in the laboratory. The presented application requires approximately a tracked real-word space of about 4m $\times$ 4m, whereas the VE presents approximately a 25m $\times$ 25m large model. The virtual pathways have been generated according to the detection thresholds identified in our research paper [1].

- *Constraint 1*: At each joint point the user can continue walking in the same curvature direction, i. e., either to the left or to the right. Hence, it is possible to walk infinitely in the same direction; indeed, the amount of curvature slightly change at joint points or might lead to a circle.
- *Constraint 2*: There are three joint points. At each of these joint points, the user can continue walking along four possible directions.
- *Constraint 3*: At each joint point, there are two curves that share a common tangent direction, e. g., curve 3 and curve 4b.
- *Constraint 4*: The curves of the Reuleaux triangle feature a large radius, but the curves of the three overlapping circles have only a smaller one due to the other constraints, i. e., providing intersections at joint points.

A room-scale VR setup of 4m $\times$ 4m results in curves of $r_1 \approx 2.5$ and $r_2 \approx 1.25$. Then, bending gains can be applied to the real-world curves with these radii.

According to the detection thresholds identified in our experiment [1], the virtual curves can provide much larger radii without users being able to identify the discrepancy. Figure 2 shows an example of some virtual paths with a corresponding real-world walking configuration. The layout of the virtual path as illustrated in Figure 2(a) was constructed by using detection thresholds $2 \leq g_B \leq 4.35$. The arrows and numbers at each path show how virtual and real curves are connected. Starting with path number 1, the user can decide if she wants to go left (2a) or right (2c) at the first joint point. The real-world walking configuration (Figure 2(b)) also offers the possibility to continue straight ahead. However, there is no corresponding virtual path (2b) in the VE since the designer of the VE has not implemented this path. Hence, users should not walk in this direction (cf. Figure 2(a)). In a similar way, when the user walks along path number 2c there is only one directional option at the next joint point as she has to follow path number 3. According to *constraint 3*, the paths 2c and 3 are directly connected and no turning is required at the joint point. Although, paths 2c and 3 have different radii in the real-world configuration, the virtual paths can be adjusted by different bending gains to seamlessly fit together. Hence, we have to apply a different gain at each joint point depending on the direction the user chose. This is done by tracking the user's position in the real world and triggering the specific action in the virtual world when the user leaves a joint point to a certain path.

Although we used a visual appearance of the virtual paths, which is similar to those used in the experiments, the visual representation of the curves in the VE is not limited to trail-like paths. The described concept can be applied to curved corridors, hallways, streets, or footprints on the floor (see Figure 1).

3 Conclusion

In this research demo, we show a new RDW concept, which is based on guiding users to walk on curved paths. For this purpose, we use bending gains and the detection thresholds for the human sensitivity to discrepancies between the bending of curved paths in the real world and a curved path in the virtual environment, that were presented in our research paper [1]. Furthermore, we construct a walking configuration in a reasonably small tracking space in such a way that users are able to walk infinitely on a curved path with the same curvature direction or change their direction at defined intersections. This enables RDW in room-scale VR without using interruptions or overt reorientation phases.

References

[1] E. Langbehn, P. Lubos, G. Bruder, and F. Steinicke. Bending the curve: Sensitivity to bending of curved paths and application in room-scale vr. In *Proceedings of IEEE Virtual Reality (VR)*, 2017.

[2] S. Razzaque, Z. Kohn, and M. Whitton. Redirected Walking. In *Proceedings of Eurographics*, pages 289–294. ACM, 2001.

[3] F. Steinicke, G. Bruder, J. Jerald, H. Fenz, and M. Lappe. Estimation of Detection Thresholds for Redirected Walking Techniques. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 16(1):17–27, 2010.

[4] M. Usoh, K. Arthur, M. Whitton, R. Bastos, A. Steed, M. Slater, and F. Brooks, Jr. Walking > Walking-in-Place > Flying, in Virtual Environments. In *Proceedings of ACM SIGGRAPH*, pages 359–364, 1999.