Application of redirected walking in restricted space

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Abstract. Roaming large virtual environments by walking in a confined physical space is limited by the size of physical space. The technique of redirected walking enables to partially overcome this limitation. We present an extreme form of redirected walking where participants walk through an infinitely large virtual labyrinth consisting of T junctions at which they are free to turn either left or right. When turning at a junction, the system forces the participants to physically turn twice the angle perceived in VR, thus ensuring that they always walk back and forth on a straight line between two turning points and never leave a predefined walkable space. We evaluated the suitability of our technique with an experiment including 22 participants who were asked to walk through the labyrinth for 15 turns. For evaluation, the root mean square of the distance between the participants' position and the ideal line was computed and the score of the simulator sickness questionnaire (SSQ) was recorded. Furthermore, participants were asked how far they perceive the walked distance and the angle they turned in reality. Results of the present study show that our technique of hyper redirected walking yields a lower simulator sickness score than other VR locomotion techniques. We therefore consider our technique as suitable to overcome limitations in physical space when roaming large virtual spaces.

Keywords: virtual reality, redirected walking, simulator sickness

1. Introduction

User studies are performed in a variety of fields, for example when developing new products or work environments, and are a method for evaluating performance, acceptance, and aspects of health and well-being of humans interacting with a system. There has been a trend of performing these usability tests in virtual reality (VR). Among reasons for this trend are safety concerns when research questions require confronting users with potentially dangerous situations (Shibata & Fujihara 2002), time and cost-effectiveness in studies with a difficult and time-consuming setup (Mottura et al. 2003), or ethical questions when involving humans or animals (Balcombe 2004). VR technology further offers a controlled environment and replicable settings (Miller & Bugnariu 2016).

Recent developments in VR technology enables immersive setups where users can roam virtual spaces by physically walking in the real space. While this works well where enough physical space is available, it is challenging to roam a large virtual environment (VE) on limited space. Various techniques have been proposed, enabling users to roam a simulated virtual space that is larger than the available physical space.

Techniques include “resetting” users when they walk out of the walkable space (Williams et al. 2007), having users walk on an omnidirectional treadmills (Darken et al. 1997), and redirected walking (Razzaque et al. 2001). However, all these techniques suffer from limitations, which depend on the nature of the user study. For example, modifying a user’s virtual position or orientation without stimulating the proprioceptive and vestibular system, as it is done with the resetting method, disrupts spatial updating (Cherep et al. 2019) and therefore limits the user’s sense of orientation. Omnidirectional treadmills tend to be heavy, complex, expensive, and do not allow users to quickly accelerate or decelerate (Lee et al. 2016). Moreover, they often restrict the flexibility of the users by forcing them to wear a safety gear, which holds the upper body in a stable position. The technique of redirected walking relies on the user’s inability to notice small manipulations in the displayed world, which forces the users to reorient their heading. For example, Steinicke et al. (2010) discovered that users can be made to believe that they move along a straight line when in fact they walked along a circle. For this illusion not to be perceived by the user, a large physical space of at least 44 m × 44 m is still required, which exceeds the available space in most offices and laboratories. In smaller areas this technique generates a noticeable discrepancy between the sensory feedback of the visual system and the proprioceptive and vestibular system while walking on a long, straightforward virtual path.

Limiting the effect of the illusion in order to reduce the mentioned discrepancy would cause users to bump into the boundaries of the physical space. Current techniques to avoid bumping into the boundaries include a so called freeze turn, where users physically turn but the visual orientation does not change, or a 2:1 turn, where they physically perform a 180 degree turn while the visual representation shows a full 360 degree turn. Both methods result in the users gazing in the same direction in the virtual scene as they did when reaching the boundary of the physical space but after the freeze or 2:1 turn, their body is oriented away from the boundary. Williams et al. (2007) found that a freeze turn has a much stronger impact on the user’s orientation than the 2:1 turn.

In this paper, we focus on the method of redirected walking in strongly limited space. We investigate the feasibility and effects of a system where users can explore an infinitely large VR labyrinth in a limited physical space of 3 m × 1 m and without interrupting their walk through maneuvers such as teleportation, freeze turns, or 2:1 turns.

2. Methods

2.1 Participants

Via mailing lists addressing bachelor's and master's students at our university, we recruited a total of 22 participants (10 females) with an average age of 27.6 [SD = 4.7] years.

2.2 Instrumentation

For our experiment, we created a dynamically generated virtual labyrinth consisting of 90 degree T junctions. The length of the corridor between two junctions of the virtual labyrinth is 5 m long.

The labyrinth is presented in a HTC Vive Pro head-mounted display (HMD). The position of the HMD is tracked within a walkable area of 3 m x 1 m (Figure 1). Position and orientation of the HMD was recorded every 100 ms. At the end of each turn, the direction (left or right) and the rotation error (difference between actual orientation and ideal orientation towards the other turning point) was also recorded.

The system doubles the perceived walking speed so that walking along a corridor or 5 m length can be simulated on a physical space of less than 3 m. When users turn at the end of each corridor, the labyrinth turns with half the rotation speed of the user, therefore forcing the users to perform a 180 degree rotation in real space for a 90 degree turn in VR. We call this a 1:2 turn. If users deviate from the ideal path (the straight line between point A and point B in shown in Figure 1), a slight rotation of the labyrinth forces them back onto the ideal line so that they walk straight towards the next turning point and don't drift out of the walkable area.

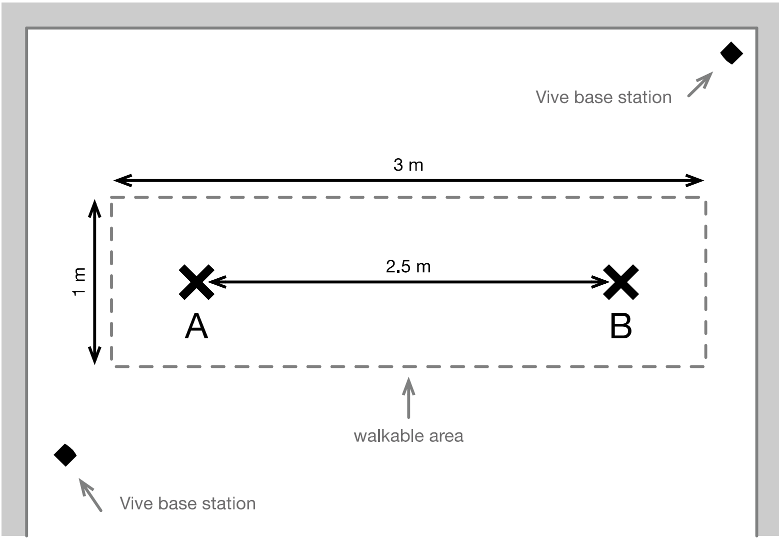

Figure 1. *Physical layout of the area in which the users could walk. They started on point A and moved along a straight line towards point B, where they performed a 180 degrees turn and walked back towards point A to turn again. The entire process was repeated until 15 turns had been performed.*

2.3 Procedure

Before the experiment, all participants were given a short introduction and had to fill in a motion sickness susceptibility questionnaire (MSSQ-Short; Golding 2006). Two of the participants showed an MSSQ score of more than one standard deviation above the mean in Golding's reference norms and were therefore exclude from the study. The remaining participants filled in the simulator sickness questionnaire (SSQ; Kennedy et al. 1993) a first time before being equipped with the HMD where they saw themselves placed inside the labyrinth. They were then instructed to follow the walk through the labyrinth and turn left or right at each intersection. The participants were stopped after 15 turns and asked to take off the HMD. In order to assess the effect of the illusion, the participants filled in the SSQ a second time and were asked the following questions:

- "Was there anything that felt strange or awkward when walking or turning? If so, please describe it in a few words."
- "How far (in meters) would you estimate you walked (in reality) between each turn?"
- "How much (in degrees) would you estimate you turned (in reality) at each turn?"

The experimenter closely followed the participants during the entire experiment so that they could be stopped in case they were to collide with an obstacle. The participants were also instructed to immediately stop the experiment in case they experienced discomfort of any kind. They were free to quit the experiment at any time, without providing a reason, and without any personal drawbacks.

The entire experiment lasted approximately 20 minutes with a mean duration of the walking task of 256.28 [SD = 66.38] seconds. The study protocol was approved by the ethics committee of the local university (Ethics Approval Number: EK 2019-N-140).

3. Results

From the recorded data, we calculated the following characteristics for each user:

1. The root mean square (RMS) of the deviation from the ideal path in meters.
2. The RMS of the rotation error in degrees.
3. The RMS of the walking speed in meters / second.
4. The RMS of the rotation speed in degrees / second.

RMS data were plotted as a function of the simulator sickness score. A visual inspection of the plots showed no correlation between any of RMS and the simulator sickness score and neither for the total SSQ score or any of the SSQ subscales.

Evaluation of the answers to the user questions revealed that 11 participants (55%) perceived the physical rotation to be less than 180 degrees. 6 participants (30%) believed that they were walking further than the 2.5 m they moved in reality. The distribution of perceived physical rotation and perceived walking distance is shown in Figure 2.

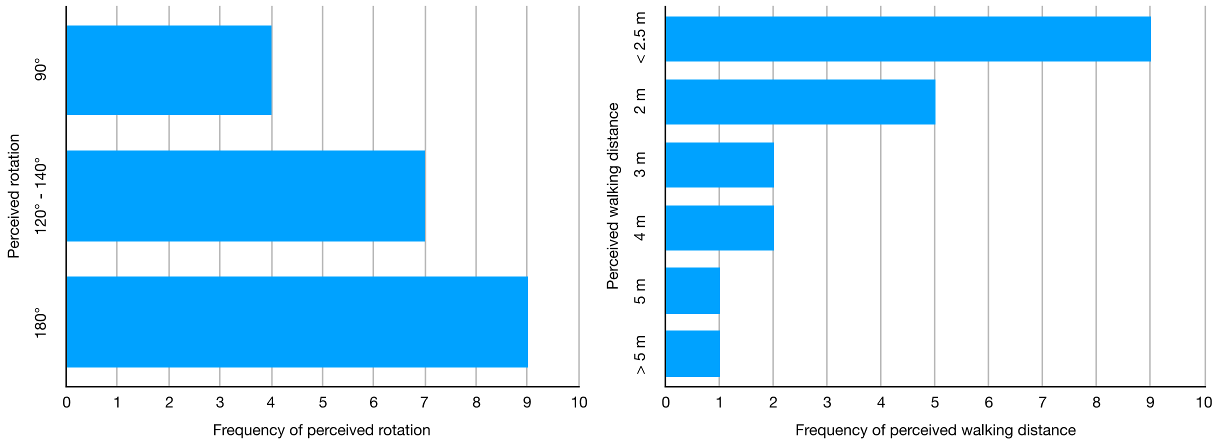

Figure 2. *Left: Distribution of perceived physical rotation at the turning points. Right: Distribution of the perceived distance, physically walked.*

The total SSQ score (taken after the VR experience) was calculated and compared to SSQ assessed in three studies about VR locomotion techniques reported in recent publications: 1. Moving with a gamepad, 2. March-in-place using gyro sensors (Lee et al. 2017), and 3. teleporting (Líndal et al. 2018). In the mentioned publications, the average duration of the VR exposure was similar to the duration in our experiment (in 1. and 2.: 300 seconds, in 3.: 335 seconds). The results are shown in Table 1.

Table 1. *Comparison of our SSQ score to the SSQ score of other locomotion techniques: 1. Moving with a gamepad, 2. March-in-place, and 3. Teleporting.*

	1. Gamepad	2. March-in-place	3. Teleporting	Ours
Mean	31.98	28.8	93.7	18.28
SD	28.67	22.03	12.75	13.48

During the experiment, some participants described experiencing the turns as “tough,” “unstable,” or “wobbly”. Walking on a straight line generally caused no problem. The first steps after the turn, when the walls of the labyrinth forces users back onto the ideal line, were sometimes perceived slightly more difficult but all participants got used to it and felt comfortable walking after a few turns. After the experiment, one participant reported to have felt claustrophobic due to the narrow corridors in the simulation.

4. Discussion

We were surprised that the illusion of rotation worked so well that more than half of the participants thought that they turned less than 180 degrees. Only two participants (10%) believed that they walked a distance of five meters (as simulated), which can probably be explained by the fact that the participants were familiar with the size of the lab in which the experiment was conducted. It would be interesting to run the same experiment in a larger room (e.g. a gym hall) where the physical space is far larger than the simulated one. This could reveal how much of the effect is caused by knowledge about the real physical environment.

The relatively low simulator sickness score shows that our technique is a valid alternative to existing locomotion techniques in VR. However, one limitation that has to be noted is that this technique only works in a scenario where participants walk through a labyrinth-like environment where a left or right turn is required after each corridor segment (i.e. no four-way intersections).

5. Conclusion

From what we found in this experiment, we conclude that our modified version of redirected walking can be applied to simulations where users navigate a virtual environment on foot. Overall, users managed to quickly adapted to this locomotion technique and did not require any further information how to roam the virtual labyrinth. We haven’t observed negative effects such as disrupting spatial updating, restricting a user’s flexibility, or inducing strong simulator sickness.

6. References

Balcombe J (2004) Medical Training Using Simulation: Toward Fewer Animals and Safer Patients. Alternatives to laboratory animals 32 Suppl 1B:553-560

Cherep LA, Lim A, Kelly JW, Ostrander A, Gilbert SB (2019) Spatial Cognitive Implications of Teleporting Through Virtual Environments. doi:10.31234/osf.io/cx9vt

Darken R, Cockayne W, Carmein D (1997) The Omni-Directional Treadmill: A Locomotion Device for Virtual. Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology, UIST 1997. Banff, Alberta, Canada

Golding F (2006) Predicting individual differences in Motion Sickness Susceptibility by Questionnaire. Personality and Individual Differences 41(2):237-248

Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG (1993) Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. The International Journal of Aviation Psychology 3(3):203-220

Lee H, Pyo S, Park S, Yoon J (2016) Design of the Omni Directional Treadmill Based on an Omni-Pulley Mechanism. Proceedings of the 13th International Conference on Ubiquitous Robots and Ambient Intelligence, URAI 2016. Xi'an, China

Lee J, Kim M, Jinmo K (2017) A Study on Immersion and VR Sickness in Walking Interaction for Immersive Virtual Reality Applications. Symmetry 9(5):78

Líndal PJ, Jóhannsdóttir KR, Kristjánsson U, Lensing N, Stühmeier A, Wohlan A, Vilhjálmsson HH (2018) Comparison of Teleportation and Fixed Track Driving in VR. Proceedings of the 10th International Conference on Virtual Worlds and Games for Serious Applications, VS-Games 2018. Würzburg, Germany

Miller HL, Bugnariu NL (2016) Level of Immersion in Virtual Environments Impacts the Ability to Assess and Teach Social Skills in Autism Spectrum Disorder. Cyberpsychology, Behavior, and Social Networking 19(4):246-256

Mottura S, Viganò GP, Sacco M (2003) Virtual Reality for Product Layout Configuration. Proceedings of the 1st International Conference on Research in Virtual and Rapid Prototyping, VRAP 2003. Leiria, Portugal

Razzaque S, Kohn Z, Whitton MC (2001) Redirected Walking. Proceedings of Eurographics 2001. Manchester, UK, 2001

Shibata T, Fujihara H (2002) Development of Railway VR Safety Simulation System. Quarterly Report of RTRI 43:87-89

Steinicke F, Bruder G, Jerald J, Frenz H, Lappe M (2010) Estimation of Detection Thresholds for Redirected Walking Techniques. : IEEE Transactions on Visualization and Computer Graphics 16(1):17-27

Williams B, Narasimham G, Rump B, McNamara TP, Carr TH, Rieser JJ, Bodenheimer B (2007) Exploring Large Virtual Environments with an HMD when Physical Space is Limited. Proceedings of the 4th Symposium on Applied Perception in Graphics and Visualization, APGV 2007. Tübingen, Germany

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