2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 978-1-6654-8402-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/VRW55335.2022.00266

Redirected Walking in 360° Video: Effect of Environment Size on Detection Thresholds for Translation and Rotation Gains

Yanxiang Zhang* Qingqin Liu† Yingna Wang‡

University of Science and Technology of China

ABSTRACT

Using real walking to control the playback of the 360° videos is a natural and immersive way to match visual and self-motion perception. Redirected walking can enable users to walk in limited physical tracking space but experience larger scenes. Environment size may affect user perception in 360° videos. We conducted a user study about the detection thresholds (DTs) for translation and rotation gains in 360° video-based virtual environments in three scenes with different widths. Results show that environment size of the scene increases the DTs for both lower and upper translation gains but doesn't affect the DTs for rotation gains.

Keywords: Virtual Reality, Redirected Walking, 360° Video, Locomotion, Virtual Travel.

Index Terms: [Systems, man, and cybernetics]: User interfaces—Human computer interaction—Immersive experience; [Electronic design automation and methodology]: Design methodology—Graphics—Virtual reality;

1 INTRODUCTION

Using natural walking in the physical tracking space and getting visually immersive in the head-mounted devices (HMD) can allow users to have a virtual travel that is full of presence in Virtual Environments (VEs) [1]. In the virtual tour of famous tourist sites of reality, creating an immersive VE is important. Compared to the computer-generated modeled environment, 360° video brings more realism. High-resolution 360° videos of scenic spots and tourist sites can easily capture the dynamic details of reality. The computer-generated VE takes lots of time to model, and the rendering is not as good as a captured 360° video.

When using real walking in virtual travel of tourist sites, an HMD user could literally walk through the physical tracking space and virtually explore the scenic spots. In principle, the user's movements would be detected by a tracking system and transferred to the VE to control 360° video's playbacks. Hence, the users obtain both visual and physical perception feedback that are consistent in their cognition. This system setting will make users think that they are visiting the attractions in presence. One problem is that, compared to the tracking space where users can walk, scenic spots are often larger in dozens of times. One promising solution is redirected walking (RDW) [2]. One goal of RDW technology is to explore large VEs using natural locomotion within a limited physical tracking space. Traditional RDW technology focuses on exploring detection thresholds (DTs) for translation, rotation, curvature and bending gains that make the user walk in the tracking space without noticing [3]. The DTs of RDW techniques mainly focus on the computer-generated VE, and the research about 360° video-based VE needs to be explored more. Zhang et al.[4] use the recorded 360° videos to test the DTs for translation and rotation gains in their telepresence system. Their results show that the lower and upper DTs are 0.942 and 1.097 for translation gains and 0.877 and 1.092 for rotation gains. But they didn't investigate the effect of environment size of the 360° video-based VE. Hodgson et al. [5] founded that the environment size in the computer-generated VE affects the DT on curvature walking, while the result from Nguyen et al. [6] contradicts the former. And the effect of environment size on DTs for translation and rotation gains in the 360° video-based VE has not been explored. The outdoor scenic spots are different from the indoor ones because the user perceives the size of the virtual space differently. In the scenic spots with different widths recorded by 360° cameras, the user will feel that the distance from the object is different. In this work, we investigated whether this may affect the user's DT on translation and rotation gains.

We designed the experiments using the two-alternative forced-choice (2AFC) [7] method to explore the DTs for translation and rotation gains in 360° video-based VEs in three scenes with different widths. Our work will help the research community to design and explore body-controlled locomotion in 360° video-based VE in the future.

* petrel@ustc.edu.cn
† neoluxqq@mail.ustc.edu.cn
‡ wynnewang@mail.ustc.edu.cn

2 EXPERIMENT

We conducted two experiments to investigate the DTs for translation gains and rotation gains in three different environment sizes of 360° video scenes separately. The experiment of translation gains (E_T) recruited 20 participants (9 females, age 19-25, M=22.3), and the experiment of rotation gains (E_R) recruited 20 participants (10 females, age 20-27, M=23.6). All participants are right-handed, with normal or corrected-to-normal vision. Each participant in E_T and E_R was tested under 15 different gains in the range of {0.6, 2.0} in steps of 0.1 and repeated each gain six times. Participants in E_T and E_R would experience three scenes with different widths in randomized order. The number of the gain in each scene appeared in randomized order too. E_T and E_R have the same hardware setup and similar experiment procedures. In E_T and E_R, participants took a 5min rest without HMD between each scene, and we asked whether they were affected by dizziness or other sicknesses. No participant in E_T reported sickness, but two participants in E_R reported dizziness. So, we analyzed 20 participants' data in E_T and 18 participants' data in E_R.

2.1 Hardware Setup and Materials

The experiment was conducted in an indoor space with a 6m x 3m (height: 3.1m) physical tracking area. The HMD used in this work is Oculus Quest. The VE is developed in Unity3D. We captured three 360° videos of (a) a 3m wide hallway, (b) a 20m wide square, (c) a 100m wide outdoor playground with a normal forward walking in the middle of the scenes with speed of 1.0m/s. Fig 1 shows the screenshots of three scenes. The recorded 360° video resolution is 7680*3840@30fps 8bit. The height of the 360° camera is 1.65 m, which is similar to walking people's eye height.

978-1-6654-8402-2/22/$31.00 ©2022 IEEE
DOI 10.1109/VRW55335.2022.00266

Figure 1: Three scenes used in the experiment. From left to right: scene(a): 3m wide; scene(b): 20m wide; scene(c): 100m wide

2.2 Procedure

To implement RDW in 360° video-based VE, we developed a system to control the playback of 360° videos by the user's walking in physical space. So, the route user takes in the physical tracking space can coincide with the route of the 360 cameras in the shooting. The alignment of vision and body perception can make users feel as if they are visiting the scenic spots in reality.

In E_T, participants traveled 5m in the tracking area. We used different translation gains to control the playback speed of the 360° videos. For example, when walking with the translation gain (g_T), the 360° video would be played in the speed of $g_T \cdot v_r$, while v_r is the participant's real-time speed along the fore-aft direction in the tracking area. Once they crossed the end line, the scene in the HMD would automatically pause. The participants would have to estimate whether the virtually displayed motion was faster or slower than the physical translation in the real tracking space.

In E_R, participants stood in the tracking area and watched the 360° screenshots of the recorded video. They would see a turning arrow and turn their head from right to left to follow the arrow until the arrow became red. The virtual rotation shown on the HMD of different scenes was always 90°, and the participants would have to rotate their heads for $90°/g_R$, where g_R is the rotation gain. The participants would have to estimate whether the virtually displayed rotation was faster or slower than the physical rotation in the real tracking space.

3 Results

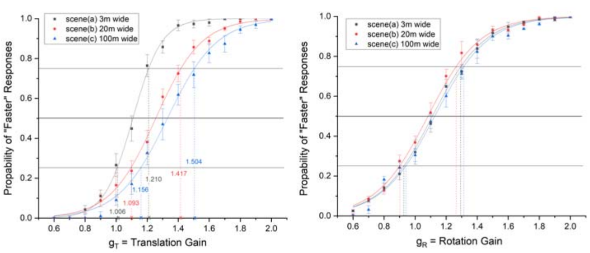

Figure 2: Detection thresholds on g_T and g_R in scene(a), (b), (c)

We used one-way ANOVA method to analyze the effect of environment size. Our results indicated that the environment size of 360° video scene would affect the translation DTs ($p < 0.05$), and the LSD results showed that as the width of the scene increases, the users have higher DTs. But our results show that the effect of environment size on the rotation DTs in 360° video-based VE is not significant ($p > 0.05$).

Our fitting results of lower and upper translation gains are showed in Fig 2. The point of subjective equality (PSE) is defined as the gain for which the participants answer "Faster" in 50% of the trials. Translation PSEs of scene(a), (b), (c) are 1.108, 1.255 and 1.330. Also, lower and upper DTs for translation gains of scene(a), (b), (c) are (1.006, 1.210), (1.093, 1.417) and (1.156, 1.504). Rotation PSEs of scene(a), (b), (c) are 1.112, 1.082 and 1.127. Lower and upper DTs for rotation gains of scene(a), (b), (c) are (0.928, 1.297), (0.899, 1.266) and (0.9391, 1.315). The results indicate that as the width of the scene increases, the users have higher DTs for both lower and upper translation gains.

4 Discussion and Conclusion

There are a few possible explanations to our finding. Compared with the computer-generated VE, the high-resolution 360° based VE has a more realistic feeling, and better reflects the parallax scrolling of near and far objects when the user takes the virtual walk with the HMD. The user will form the perception of motion through the movement of objects in scenes. Compared with the 3m wide scene(a), when moving in the 100m wide open scene(c), the user feels that the objects are far away, and the movement of the objects is relatively small, thus increases the DTs for translation gains. Therefore, as the width increases, the user has higher DTs. While we use static panorama images to test the rotation DTs in the experiment, different widths of the scenes do not bring about dynamic position changes of near and far objects. In addition, the difference between our experimental results and Zhang et al. [4] may be due to the differences of the HMD, walking speed and the resolution of 360° videos. Our results show that the scene affects DTs for translation gains, but the precise numerical relationship needs to be explored in future work.

In this work, we conducted a user study to investigate the DTs for translation and rotation gains under different environment sizes of 360° video-based VEs. Our result shows that the width of the scene would affect the DTs for translation gains, and the users have higher DTs for both lower and upper translation gains in the wider scene. But the result doesn't show a significant effect of the width of the scene on rotation thresholds in 360° video-based VEs. Using the real walking in physical tracking space to control the playback of the 360° videos, which will generally match the visual and self-motion perception of users, is a technique to prevent cybersickness and enhance presence. The DTs in 360° video-based VEs need to be explored in future research. These findings can provide implications for the design of virtual locomotion and travel using RDW in 360° video-based VEs.

Acknowledgements

This paper is supported by National Social Science Foundation of China, under grand number: 21VSZ124

References

[1] N. C. Nilsson, S. Serafin, F. Steinicke, and R. Nordahl, "Natural Walking in Virtual Reality: A Review," *Comput. Entertain.,* vol. 16, no. 2, p. Article 8, 2018, doi: 10.1145/3180658.

[2] S. Razzaque, *Redirected walking*. The University of North Carolina at Chapel Hill, 2005.

[3] N. C. Nilsson *et al*., "15 years of research on redirected walking in immersive virtual environments," *IEEE computer graphics and applications,* vol. 38, no. 2, pp. 44-56, 2018.

[4] J. Zhang, E. Langbehn, D. Krupke, N. Katzakis, and F. Steinicke, "Detection thresholds for rotation and translation gains in 360 video-based telepresence systems," *IEEE transactions on visualization and computer graphics,* vol. 24, no. 4, pp. 1671-1680, 2018.

[5] E. Hodgson, E. Bachmann, and D. Waller, "Redirected walking to explore virtual environments: Assessing the potential for spatial interference," *ACM Transactions on Applied Perception (TAP),* vol. 8, no. 4, pp. 1-22, 2008.

[6] A. Nguyen, Y. Rothacher, A. Kunz, P. Brugger, and B. Lenggenhager, "Effect of environment size on curvature redirected walking thresholds," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2018: IEEE, pp. 645-646.

[7] F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe, "Estimation of detection thresholds for redirected walking techniques," *IEEE transactions on visualization and computer graphics,* vol. 16, no. 1, pp. 17-27, 2009.