Moving in a Box: Improving Spatial Orientation in Virtual Reality using Simulated Reference Frames

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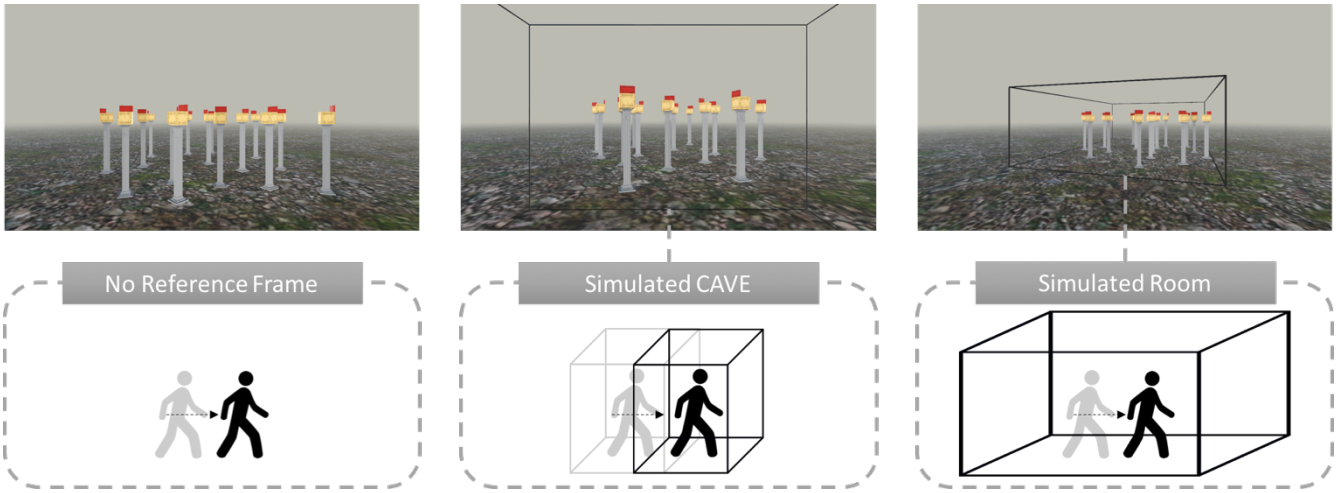

Figure 1. Three variations of reference frames. Left: No reference frame. Middle: Egocentric reference frame or Simulated CAVE. Right: Allocentric reference frame or Simulated Room

ABSTRACT

Despite recent advances in virtual reality, locomotion in a virtual environment is still restricted because of spatial disorientation. Previous research has shown the benefits of reference frames in maintaining spatial orientation. Here, we propose using a visually simulated reference frame in virtual reality to provide users with a better sense of direction in landmark-free virtual environments. Visually overlaid rectangular frames simulate different variations of frames of reference. We investigated how two different types of visually simulated reference frames might benefit in a navigational search task through a mixed-method study. Results showed that the presence of a reference frame significantly affects participants' performance in a navigational search task. Though the egocentric frame of reference (simulated CAVE) that translates with the observer did not significantly help, an allocentric frame of reference (a simulated stationary room) significantly improved user performance both in navigational search time and overall travel distance. Our study suggests that adding a variation of the reference frame to virtual reality applications might be a cost-effective solution to enable more effective locomotion in virtual reality.

Keywords: virtual reality, locomotion, spatial orientation, navigational search, reference frame

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction styles

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2017 IEEE Symposium on 3D User Interfaces (3DUI)
March 18-19, 2017, Los Angeles, CA, USA
978-1-5090-6716-9/17/$31.00 © 2017 IEEE

1 INTRODUCTION

Virtual Reality (VR) has become substantially more widespread and affordable in recent years. Recent advances have allowed more realistic representations of virtual worlds and more embodied interactions with such environments. Despite all the advancements, there remain a lot of challenges in the user experience of VR that cause inefficiency in self-navigation and self-localization in virtual worlds. Though VR could provide physically impossible locomotion such as teleporting or flying, spatial orientation in VR has not matched its famed advancements yet.

Previous research has shown that people take significantly longer time keeping track of where they are when traveling in HMD-based immersive virtual environments than they do in the real world [1]. Orientation is substantially dependent on a cognitive process called spatial updating. The inconsistency in spatial updating process is one of the factors that causes disorientation in VR [2]. Visual-vestibular conflicts and in particular latencies between physical movement and visual stimuli are examples of factors that can trigger motion sickness [3], [4].

To investigate how adding visual reference frames might affect spatial orientation and updating as well as the amount of motion sickness that participants might experience, we used a navigational search paradigm, which required frequent orientation and position changes and a high cognitive load.

Navigational Search Task: To compare the user performance between different environments or interfaces, previous work has used a navigational search task in which participants were in an environment consisting of 16 boxes. In this task, participants were asked to find eight target objects hidden in these 16 boxes [5], [6].

Previous results have shown that participants perform the task much more efficiently in physical walking condition than they do in vision-only condition. However, there are still situations in which visual cues alone can enable effective execution of

locomotion and spatial orientation in VR. For example, naturalistic, landmark-rich environment and room geometry provide strong supports for continuous spatial updating [7]–[9]. These findings motivated us to investigate if adding reference frame as a visual cue in HMD-based VR might enable more effective spatial orientation and enhance user performance in VR.

Reference Frames: When people navigate in an environment, a representation of their physical location and orientation is formed and continuously updated. The egocentric frame is centered on the navigator, whereas the allocentric or environment-centered frame is centered on an external point in the environment [10].

To enable more effective locomotion in VR, we proposed using an overlaid wireframe of a rectangular box as a frame of reference for participants in VR locomotion, as illustrated in Figure 1. The goal of this project was to investigate if simply adding a visual representation of a fictitious rectangular box to virtual scenes would be sufficient to improve users' spatial orientation while not increasing cognitive load noticeably. If successful, this could provide a cost-effective method to help improve users' spatial orientation and performance in VR applications involving large amount of rotation and translation.

2 Methods

To investigate the effectiveness of adding reference frames to the virtual world, we compare user performance and usability ratings between three variations of reference frames as illustrated in Figure 1. 27 volunteers (16 female, 11 male), aged 18-41 years old (M = 21.79, SD = 4.39), participated in the experiment. The experiment used a within-subjects design where every participant took part in all three conditions in counter-balanced order.

No reference frame: Participants did the task without any additional visual cues. This baseline condition enables comparisons with other ones that overlaid a visual reference frame.

Egocentric reference frame or **Simulated CAVE**: We added a rectangular box of 3×4×2m to help participants recognize their direction after rotations. In this condition, the frame moved with participants such that they were always positioned at the center of the frame. This frame made participants feel like they were using a CAVE, which is a classic projection-based virtual reality setup.

Allocentric reference frame or **Simulated Room**: It was a 3D rectangular box of 5×6.6×2m, which enclosed covered the area of target objects. The most important difference with Simulated CAVE is that it is stationary: the frame's position did not change with participants' movement, as if displaying the room corners.

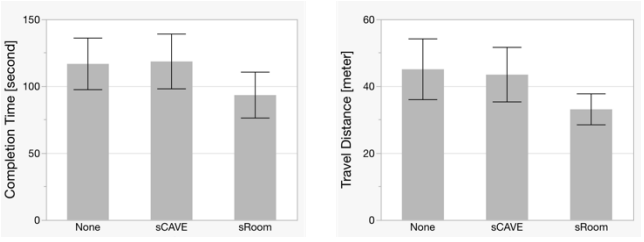

Figure 2. Mean data of completion time (left) and travel distance (right). Error bars indicate confidence intervals (CI = .95)

3 Results

Task completion time: A repeated-measures ANOVA revealed a significant effect of reference frame on completion time, $F(2, 34) = 3.87$, $p = .03$, $\eta_p^2 = .19$. Tukey's post-hoc tests showed that simulated room helped participants finish the task faster, compared to simulated CAVE ($p = .04$) and the condition of no reference frame ($p = .06$), as illustrated in Figure 2 (left).

Travel distance: Analysis also revealed a significant effect of reference frame on travel distance, $F(1.36, 23.23) = 3.89$, $p = .04$, $\eta_p^2 = .19$. Figure 2 (right) showed that participants significantly traveled a longer path in the condition of no reference frame compared to the condition of simulated room ($p = .03$).

4 Discussion and Conclusion

Though previous work has shown that egocentric reference frame can dominate spatial updating processes [11], our simulated CAVE, which also provides an egocentric frame of reference, has not shown a significant benefit over the baseline condition. However, an allocentric frame of reference consisting of a wireframe simulating the room corners seems to be helpful in this navigational search task. Post-experimental debriefing also showed that participants preferred the simulated room over the simulated CAVE or having no added reference frames. However, the presence of a simulated reference frame did not reduce user's motion sickness in the current study.

Whereas previous studies showed a clear benefit of reference frame in spatial updating tasks [10]–[12], the current study provides first evidence that simply adding visually simulated reference frame consisting only of a wireframe rectangular box can also provide significant benefits. In future studies, we can apply these reference frames on other locomotion modes to investigate the interaction between locomotion mode and the visual cues.

Acknowledgements

Thanks to Duc-Minh Pham for help with software implementation.

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