Using Barriers in Immersive Virtual Environments

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Abstract

In many immersive virtual environment configurations, the user interacts with the virtual world while within a limited physical tracking range. While wearing a head mounted display, the real world is completely blocked out from the user's view, making it difficult for users to know where they are in relation to the tracking range. One problem with this is that users often find themselves outside tracking range, which leads to degraded performance due to tracking jitter and poor input registration. Also, some users are reluctant to walk around within tracking range, possibly because they are disoriented, in that they do not know where they are in relation to the physical room or lab. We present an investigation into the effect the presence of a physical barrier surrounding the tracking area has on user behavior and preference. Survey results collected after our experiment indicates that users prefer to have a visual barrier representing the tracking area to help guide them and that most users disliked having a physical barrier when the corresponding virtual barrier was absent.

1 Introduction

In many virtual environment configurations the user interacts with the virtual world within a limited physical tracking range, while the real world is blocked out from the user's view by the head mounted display (HMD). This makes it difficult for the user to know where they are in relation to the tracking range and forces the user to concentrate on where they are in the "real world". In experiments we have performed while evaluating interaction techniques we have observed that participants handle this in different ways and to varying degrees of success. Some participants clearly have a high degree of spatial ability; they are able to walk around comfortably within the tracking range without moving outside it. Other participants find it difficult to stay within range, and many of these participants have trouble determining the cause of the tracking "jitter" they experience and thus have trouble resolving the situation. Still another group of participants have another, more subtle problem. Some participants tend not to walk around when they are unsure as to where they are in the "real world". Their concerns range from being afraid they might walk into an object in the room to possibly damaging the equipment by stretching wires. In both cases, this ineffective use of the physical space in which they can walk negatively effects their performance, making it difficult to evaluate other properties of the environment which might be of interest.

A user walking beyond tracking range is a commonly recognized problem, and a simple solution is to erect a barrier around the tracking range to keep participants within range. A good example of the use of a barrier to limit the user's mobility can be found in (Zanbaka et al. 2004). Developers often do not consider representing the tracking area within the virtual environment however, and this may in fact cause more cognitive load on the user's part, since they must "feel" their way around the barrier.

In this paper, we examine whether or not users prefer or feel more comfortable using a physical and virtual barrier representing tracking area. We also examine how the presence of these barriers affects the user's mobility, in terms of area covered within the tracking range. While our results indicate that the barrier did not affect mobility, survey results do indicate that users preferred having a virtual barrier (with or without a physical one) over trials without a virtual barrier.

2 Related Work

There has been considerable research on navigation in virtual environments, particularly focused on enabling users to explore and traverse virtual worlds which are larger than their real-world surroundings (the laboratory), making physically walking inadequate. The more common techniques allow users to specify a direction to travel by pointing in the direction they wish to move. Bowman (Bowman, Koller & Hodges, 1997) provides a survey and taxonomy of these popular navigation techniques and discusses which techniques lend themselves well to specific interaction tasks. Researchers (Bowman et al. 1997), (Slater, Usoh, & Steed, 1995) have also identified the benefits of making navigation as natural as possible by allowing walking, due to its straightforwardness, simplicity, and because it helps preserve the user's sense of presence. Following this premise, Usoh (Usoh et al. 1999) has developed a technique which allows users to walk in place in order to cover large distances. All of this research primarily focuses on large scale (macro) navigation and way-finding, however in our research we are primarily concerned with "micro-navigation", where users are working on objects within or slightly outside arm's reach. In this situation, physically walking is usually the most practical and efficient method. We are unaware of any research that has investigated this; typically it is assumed that users will walk without hesitation in these situations while also making sure they do not leave tracking range. We have observed that this is often not the case when dealing with novice users.

A number of studies have shown that virtual environments can illicit physiological and psychological responses from users. Studies (Meehan, Insko, Whitton & Brooks, 2002), (Slater et al. 1995) have demonstrated that users are very hesitant to physically walk over or near virtual cliffs, occasionally refusing to do so entirely. Hodges (Hodges et al. 1995), (Hodges, Rothbaum, Watson, Kessler & Opdyke, 1996) has effectively used virtual environments to help users with fears of heights and flying through exposure therapy; showing that virtual environments can elicit similar anxiety responses in users as real world situations. Our use of a virtual barrier to indicate the "safe" walking area draws on the same principles, however instead of eliciting anxiety responses from users we are attempting to provide the necessary feedback to a reluctant user in order to make them feel confident walking around the environment.

3 Experiment

In order to address the problem of users walking outside of tracking range we felt that the best solution might be to construct a physical barrier around the tracking area in order to keep the users in. We felt this barrier would also be a good object to replicate inside the virtual environment in order to give users (reluctant to walk) a point of reference. Thus we chose to erect a barrier (Figure 1) surrounding the valid tracking range1[1] and to put a virtual barrier which directly corresponds to the physical one inside the environment so users would always know where they were in relation to it. This virtual representation can be seen in Figure 2. Note that the virtual and physical barriers are aligned as precisely as possible, markers were placed on the lab floor to indicate where the barrier should be and the virtual barrier was of the same dimensions. This alignment meant that when users reached out to touch the barrier their virtual hand intersected the virtual barrier just as they came into contact with the physical one.

[1] The valid tracker range was determined by measuring the error between physical and virtual positions over a large area around the receiver. Positions within a 1 meter radius of the receiver were found to be reliable. In order to allow users to reach over the barrier and still be within range, the barrier's radius was 0.8 meters.

Figure 1: Image of the physical barrier used. Dimensions match the calculated tracker range.

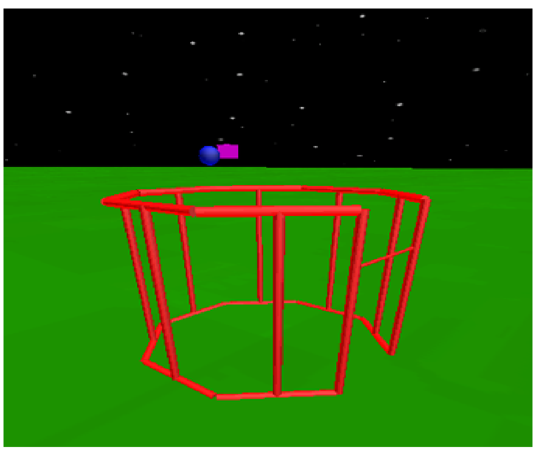

Figure 2: Screenshot of Virtual Barrier, which corresponds to physical barrier in Figure 1.

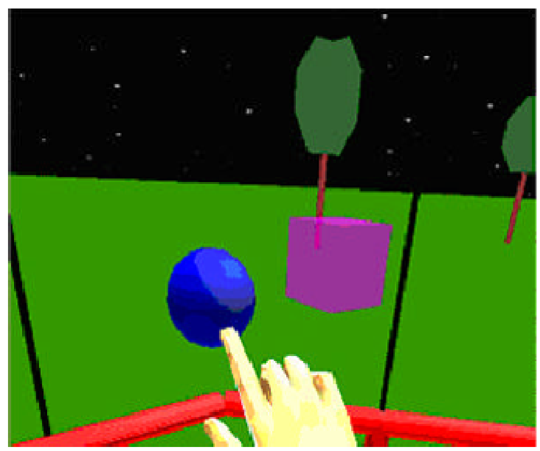

Figure 3: User placing a sphere inside the target. The top of the virtual barrier is visible at the bottom

We designed an experiment in which subjects placed virtual marbles inside three arbitrarily placed boxes as quickly as possible. Once the marbles were centered fairly accurately within the box, the box changed color, and a "success" was recorded. When the participant had successfully centered each marble, the trial was complete. Each box was within arms reach of the participant and each participant performed four trials in which completion time was tracked. The order of the following trials was randomized, as to minimize learning effects.

- No Barrier
- Virtual Barrier Only
- Virtual and Physical Barrier
- Physical Barrier Only

Sixteen participants performed the experiment. Participants were given an extensive training period in which they performed a similar task using each of the four configurations (no barrier, virtual barrier, physical barrier, both barriers). We recorded the body positions (arm, head, and waist) in order to determine the participant's mobility (cm2). A summary of our results is shown in Table 1.

Table 1: Experimental Results

ANOVA Table for Barrier's Effect on Mobility					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	110702	3	36900.5	0.33	0.8049
Within Groups	6.74E-06	60	112415		
ANOVA Table for Barrier's Effect on Completion Time					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	3561.28	3	1187.09	0.07	0.9752
Within Groups	1.00E-06	60	16687.2		
Pearson Product Moment Correlation (Mobility and Completion Time)					
Correlation Coefficient:	0.6762				
P-Value:	0.00001				

Overall our results pertaining to completion time did not show that the presence of a virtual or physical barrier effected performance or mobility in a statistically significant manner (P-Value < 0.98). Similarly, the presence of a barrier did not have a statistically significant effect on mobility either (P-Value < 0.81). Mobility did indicate performance, in that participants who completed the task quickly tended to move less (P-Value < 0.01). It is unclear to us that a high mobility leads to decreased performance however; a more likely explanation is that the task didn't require them to move much, people with a higher skill level (steady hands?) were simply able to do it without moving. People who had trouble needed to revert to walking around the target to view it from all sides.

Mobility plots were created to give a visual indication of the participant's movements during the course of the experiment. The octagon represents the barrier and tracking range. The larger squares (red) at the top, left, and right sides of the barrier represent the target cubes in the experiment. The smaller square data points (blue) concentrated in the middle of the figures are the waist positions of the participants, while the points near the targets are the hand positions (purple) while the participant was manipulating the sphere.

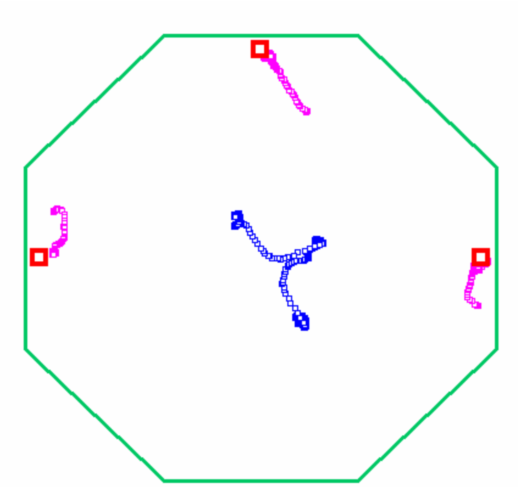

Figure 4: Example of a user who did not move around much

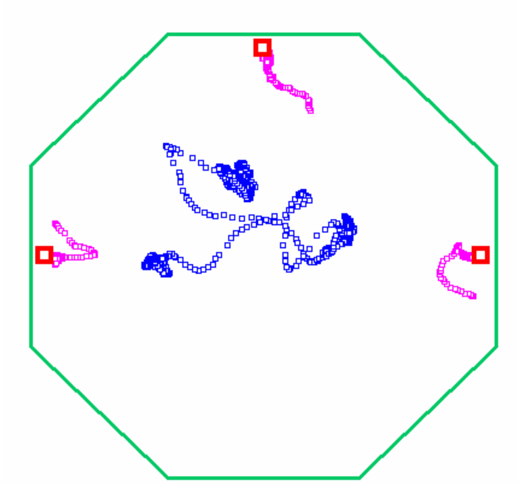

Figure 5: Example of the typical user's mobility.

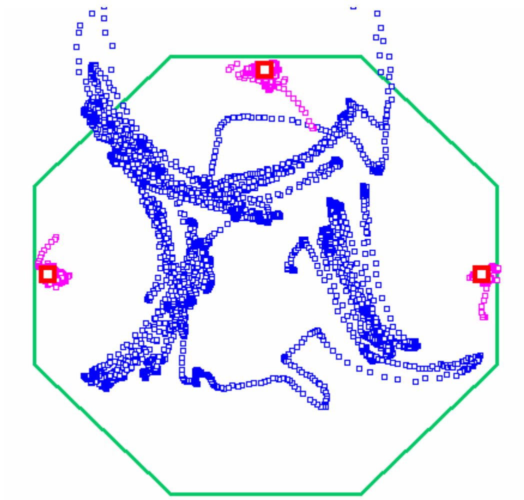

Figure 6: Example of a user who moved around quite a bit (taken from a *No Barrier* trial).

4 User Surveys

A post-experimental survey was conducted to determine the most and least preferred types of barrier, and the most and least comfortable barriers. The survey results indicated that users felt their best performance and highest comfort level was obtained when using some sort of visual barrier. The actual performance results confirm the users' perceptions. Participants seemed to dislike the configuration in which the physical barrier was present without a visual counterpart, perhaps because they could not see the barrier. Survey results from an experiment run in 2003 were similar in that participants tended to prefer having a visible barrier (Frees & Kessler, 2004).

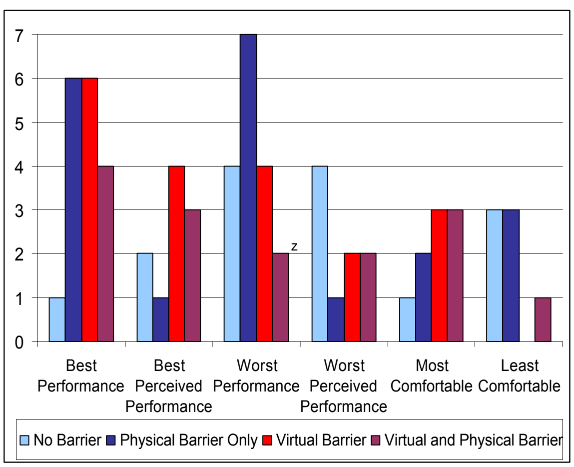

Figure 7: Survey Results for all 4 trials (participants who answered "none of the above" are omitted). Best and Worst Performance is based on completion time from experiment

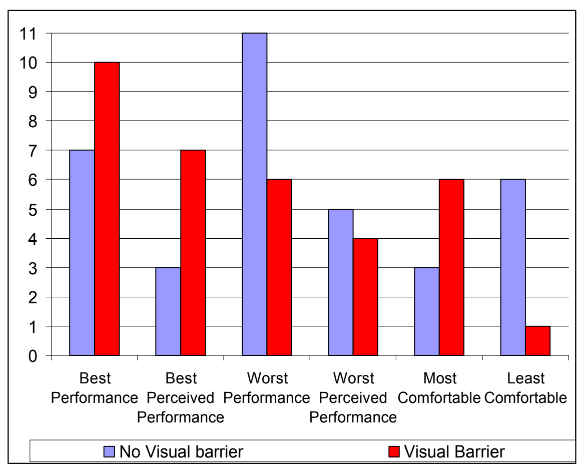

Figure 8: Survey results grouped as according to the presence of a virtual (visual) barrier.

5 Conclusions

Our study results indicate that using a barrier or delimiter around the permissible walking area is desirable. Users seem to prefer barriers; however a physical barrier without a corresponding visual representation was undesirable and at times decreased performance. One possible reason for users being uncomfortable with physical barriers without visual representation is that it was intimidating. By bringing a part of the real word into the virtual world, the user has a better frame of reference when the virtual barrier is present. The visual barrier also seems to help those who walk outside of tracking range understand why tracking is becoming error-prone.

6 Future Work

Despite our results, which do not indicate a relationship between comfort level and mobility, we do believe that a user's ability to judge their location in the "real" world has an effect on their use of the physical space in which they can walk around. One important property of most virtual environments is that the user normally navigates a larger space in the virtual world than available in the real world. This necessitates the use of an alternate navigation technique such as gaze directed flight. Once the user employs such a navigation technique, the relationship between their position in the lab and their position in the virtual world changes and the user must concentrate more on staying within tracking range. In the experiment described above, there was no use of alternate navigation; everything in the world was within a few steps of the user. We believe that this reduced the likelihood of the user becoming disoriented as to where they were in the terms of the tracking area. As a future study, we would like to examine this intuition further by designing an experiment which requires the user to navigate around a larger world while completing the interaction tasks.

7 References

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