Towards Imperceptible Redirected Walking:
Integrating a Distractor into the Immersive Experience

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Abstract

Physically walking in a virtual world has been repeatedly demonstrated to be superior to navigation with game controllers and the like. The problem is that virtual worlds are often much larger than the available physical space. Redirected walking, a technique in which the users orientation in the physical space is constantly and imperceptibly changed from their orientation in the virtual world, has been shown to be an effective technique for walking in a limited physical space [Razzaque et al. 2001], but it needs frequent and rapid head rotation to keep the reorientation changes imperceptible. A rapidly moving object in the environment, a distractor, has been shown to be effective at inspiring the users to rapidly rotate their head, but such a distractor can be distracting to the user's main activity in the virtual world. We introduce the notion of the distractor being integrated into the user's main activity in the virtual world - in our example, a fire-breathing dragon into an immersive adventure game. With such an integrated character, the users do not need any special instructions about redirected walking; they are simply performing their intended activities. We report the results of a small (N=24) user study which indicates that for the majority of subjects (17 of 24) the illusion is maintained of unconstrained walking in a very large area (a full-sized basketball court, 45 x 90 feet) even while they were limited to a small, 16 x 16 feet region. We speculate that this technique may extend to many other applications in which the distractor can be integrated into the major immersive activity and thus enable the illusion of natural, unconstrained walking in large virtual worlds even when only a small physical space is available.

Keywords: redirected walking, virtual environment, distractor

Concepts: •**Computing methodologies** → **Virtual reality;** *Perception;*

1 Introduction and Related Work

A challenge for redirected walking is that users will frequently attempt to walk across the boundaries of the tracked area that is limited in size and the prevention of it faces difficulty in maintaining the sense of presence. Effective redirection requires sufficient head rotation from the users, but large degrees of head rotation may not be guaranteed in free exploration of VE. In an attempt to instruct the users to rotate head without breaking the sense of presence, Peck [Peck et al. 2010] designed Improved Redirection with Distractors (IRD) to guide the users to stop and turn their head back and forth to watch a virtual target when they approach the edge of the tracked space. The experiment indicates that IRD may have less impact on the sense of presence compared to physical intervention, if users are distracted by cues that are adequately immersive themselves. However, the usefulness of IRD is weakened by the needs for training the user to visually follow the humming bird whenever it appears. In an attempt to address the previously mentioned challenge, we propose that a redirected walking interface is capable of delivering an improved immersive experience if distraction is appropriately integrated with the immersive activity of the VR experience. An immersive VR experience requires the application of redirection to be imperceptible: to navigate a large VE in a small physical space, a user does not need to be aware of redirection and should not be interrupted by instructions that break the sense of presence. To test this theory, we designed an algorithm based on IRD and implemented it through interactive mechanism of a VR game. We evaluate the effectiveness of our algorithm through a user study of the developed VR game.

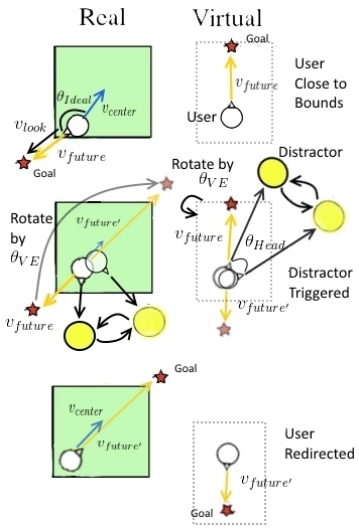

Figure 1: *When the user is near the tracking bounradies, distractor is triggered to turn the user around, until the future walk direction of the user is steered towards the tracking center. The example scenario shown in the figure redirects the user for approximately 180°.*

2 Redirection with Integrated Distraction

Our redirected walking system is composed of a redirection algorithm and a distractor algorithm. The two algorithmic components operate independently of each other. The redirection algorithm merely tries to redirect the user so they don't travel out of the physical tracked space. Because the users may not turn their head fast enough or frequently enough to achieve adequate redirection, the distractor is triggered whenever the user approaches the edge of the physical tracked area until sufficient redirection is accomplished (see figure 1).

The redirection algorithm is a modified version of the steer-to-

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center IRD algorithm proposed by [Peck et al. 2010]. We redirect the user's walking path by continuously and imperceptibly rotating the VE around the user. The rotation amount of the VE at every frame is computed by

$$\theta_{VE} = min(\theta_{Head} * c * d, \theta_{ideal}) \quad (1)$$

where θ_{ideal} is the angle between v_{future} and v_{center}, d is the distance to the center of the tracked area, and c is the rotation coefficient. To determine c, We adopt the finding of [Steinicke et al. 2008] that the rotation of VE is imperceptible and effective when it is 30 percent more or less than head rotation.

The distractor algorithm is devised in an immersive way to prevent the user from crossing the edges of tracked area. The choice of "distractor", virtual objects or characters that are part of the experience, must consider its capability of attracting attention. The advantage of choosing a dragon in an interactive game representation in our user study is that the users are implicitly compelled to look at it. To minimize its interference with navigation, the distractor is only active when redirection is most needed. The action of distracting is therefore determined by a "trigger on" condition and a "trigger off" condition. First, a safe circle, whose radius was heuristically determined to be 3 feet for a balance between effectivness and frequency of distraction, is placed at the center of the tracked area. The distractor is triggered on if 1) the user is outside the circle and 2) v_{future} from the user's position does not intersect the safe circle. It is triggered off if the above condition is false.

3 Experiment Design

We investigate with an experiment the effect of our redirected walking technique on its ability to maintain immersion when the subject navigates in a large virtual environment. The experiment is described as a VR game experience, in which the subjects physically walk to reach a destination, while they experience continuous redirection from the start of experiment. The subjects are asked to answer a series of questions after the experience while they are still in the virtual environment wearing the headset. To provide a locomotion experience that is indistinguishable from walking in a physical environment as large as the virtual environment, the subjects are not revealed prior to the study that their walking path would be redirected. To ensure that the subjects were unaware of redirection, we chose to conduct the study on a full-sized basketball court with 55 feet by 100 feet open space. Lighthouse trackers were placed around the basketball court to create an illusion that the entire area was tracked, while only two of them were turned on.

We modelled the interior of a virtual medieval style house with a floor size of 105 feet x 184 feet. The house has two 6-foot wide pits at each side to implicitly warn the subjects against walking out of the house. The subjects were told to play a VR game using the HTC Vive headset, in which they tried to reach a pile of gold at the other end of the house while defending themselves against a fire-breathing dragon with a water pistol. There was no training prior to the study and the subjects were not instructed to turn their heads to the dragon. However, the screen would gradually turn red if the subjects were exposed to the dragon's fire. The subjects were also free to choose their navigation route to the pile of gold.

4 Results

Figure 2 shows a plot of the reported distances by the subjects. The subjects could walk at most 22-25 feet from the starting position. 87.5 percent of them, who did not notice that they were redirected, significantly overestimated their walked distances, and they were

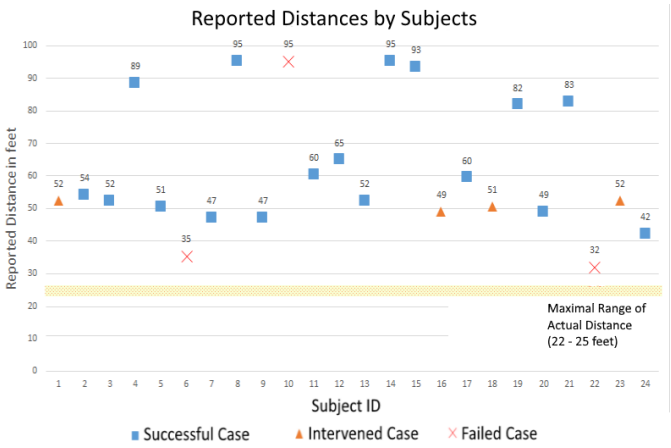

Figure 2: *The reported distances from the 24 subjects. The maximal actual distance in the 16 feet by 16 feet tracked square from the starting corner is the diagonal, which is approximately 22 feet. As we observed that the subjects were tracked when they were 2 to 3 feet away from the boundaries, we extend the maximal range of actual distances to 25 feet.*

genuinely surprised after taking off the headset and finding that they were very close to where they started. However, redirection failed to remain imperceptible for 3 cases. On average, the distractor was active in 48 percent of the time the subjects spent in the VE. During distraction, the subject's head orientations were distorted 29.8 percent on average, while the average was 21 percent otherwise. Our designed distractor (the dragon) successfully prevented 17 out of the 24 subjects from leaving the physical tracked space without requiring intervention from the researchers.

5 Conclusion

We have introduced a redirected walking interface that incorporates distraction as an integrative part of the immersive VR experience, such that the users can be steered away from the tracking boundaries without being aware of redirection and without a break of presence. We evaluated our technique with a user study by recording the subjects' perceived walked distance and whether the subjects were intervened by research administrators. Our results shows that at a 71 percent success rate, the implemented program redirected subjects imperceptibly and maintained immersion without intervention. We believe that this is an important step towards making redirected walking a more effective immersive experience.

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