A Constrained Path Redirection for Passive Haptics

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Abstract

Navigation with passive haptic feedback can enhance users' immersion in virtual environments. We propose a constrained path redirection method to provide users with corresponding haptic feedback at the right time and place. We have quantified the VR exploration practicality in a study and the results show advantages over steer-to-center method in terms of presence, and over Steinicke's method in terms of matching errors and presence.

Index Terms: Virtual reality—navigation—redirected walking—passive haptics;

1 Introduction

Redirected walking [3] is a feasible solution that relaxes the physical space constraints of natural walking by manipulating the user's position and view direction in the virtual environment. Passive haptics provides haptic feedback with passive objects at the right time. Kohli [2] combined passive haptics and redirected walking techniques by using multiple virtual pedestals in a virtual area but only one real pedestal in the tracking area. The method required that the pedestals in the virtual scene must be regularly arranged and that the users go to a set rotation point to apply the scene rotation. Steinicke [4] used circular arcs connected with line segments to redirect walking and added target prediction into the method. One limitation is using a static mapping between the virtual targets and their proxy props, which may increase rotations when redirecting the virtual path. Another limitation is using five strategies to redirect the virtual path, which may lead to large sudden changes in rotations, translations and matching errors.

In this paper, we proposed a constrained path redirection method to provide users with the corresponding haptic feedback at the right time in their navigation. The virtual target is estimated by analyzing the view direction, walking direction and distance from users. A dynamic real-virtual target mapping method is introduced to find the physical prop with the lowest matching cost for the virtual target. Then a Bezier curve-based path transformation method is proposed to update the rotation and translation gains, which define how tracked real-world motions are mapped to the virtual environment, in real-time. Finally, the virtual path is redirected with these gains. If there is no visible target candidate from the current viewpoint, a direction prediction method which provides a possible direction that the user may walk toward is provided to guide the path redirection. In Figure 1, image of (a) shows a user's view. He gets the haptic feedback from the props of the virtual target cat: a neck pillow in the real world (b). The images of (c) and (d) show the virtual and the real path the user is traveling in the virtual and real space.

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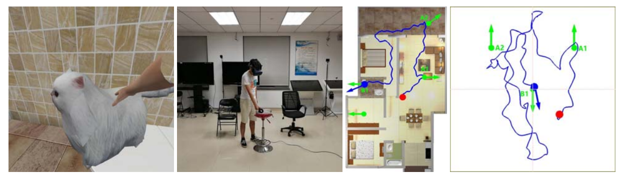

(a) (b) (c) (d)

Figure 1: A user gets passive haptic feedback of a cat and a chair in a virtual apartment scene (a) by touching a neck pillow with our constrained path redirection method in the real area that hosts the experiment (b). The virtual path and the corresponding real path are shown in (c) and (d).

2 Method

The constrained path redirection approach takes the virtual scene, the physical size of physical space, and the positions and the orientations of both virtual targets and the real props as inputs. The real target candidates corresponding to each virtual target need to be given. The method computes two 2D gains for each frame to redirect the path in navigation: rotation gain and translation gain.

The main steps of our method are as follows: 1) Virtual-real target mapping generation: We first find all visible virtual targets, and select one of them as the current virtual target. Then we find the real prop for the current virtual target. 2) Boundary and obstacles avoidance: If the user walks on the boundary of the physical area or around the obstacles in the real world (the real counterpart is not considered as an obstacle), the rotation gain is computed to avoid the boundaries and obstacles. Then go to step 4 directly. 3) Rotation and translation gain updating: The rotation gain and translation gain are computed based on the positions and the orientations of the current virtual target and its real prop. If there is no visible virtual target from the current viewpoint, the predicted direction is used to compute the gains. 4) Path re-direction: The user's movement path is redirected with the rotation and translation gains.

3 User Study

We conducted a user study to evaluate the effectiveness of our method. 48 participants were randomly assigned to four groups of twelve: CR_N, CR_P, S2C method, and FS method groups. Participants in CR_N/CR_P groups used our method without/with direction prediction function. Participants in the S2C group used the steer-to-center method [5]. No passive haptic feedback was provided. The Freeze-Turn resetting method [5] was used to help participants in the FS group to be inside of the boundary.

Task performance was measured with the following metrics: 1) error angle (EA) between the viewpoint's direction and the direction of the virtual target when the user arrived at the virtual target po-

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Table 1: Matching errors

Task	Group	$EA_{AVG}\pm$ $EA_{SD}(°)$	d	p	$ED_{AVG}\pm$ $ED_{SD}(m)$	d	p
TASK1	CR_N	45.9 ± 49.7	-	-	0.21 ± 0.18	-	-
	CR_P	41.8 ± 45.6	0.6	0.2187	0.18 ± 0.12	0.9	0.0906
	FS	72.2 ± 48.6			1.30 ± 0.94		
TASK2	CR_N	43.5 ± 29.3	-	-	0.05 ± 0.02	-	-
	CR_P	68.3 ± 46.1	0.4	0.4173	0.12 ± 0.09	**1.8**	**<0.0001**
	FS	90.7 ± 59.9			0.87 ± 0.60		

sition; 2) error distance (*ED*). The distance from the viewpoint to the position of the real prop when the user arrived at the virtual target position; 3) IGroup presence questionnaire (IPQ) and simulator sickness questionnaire (SSQ).

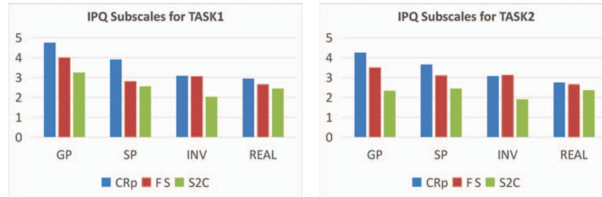
We set up two tasks: in TASK 1, participants were asked to sit on chairs, sofa, and pat a cat in a virtual apartment (size 16m × 8m); in TASK 2, participants were asked to find the items on the shopping list in a virtual supermarket (20m × 20m) and put the real items into the shopping bag. For both tasks, participants can touch or sit on the real props with the order they prefer to. The tracked physical space was 4m × 4m. For TASK1, two chairs and a neck pillow on a bar stool are placed in the space. For TASK2, three chairs with a bunch of bananas, a bottle of water or a box on them are placed in the space. The participant used a handle to start and end the experiments. When the distances from the participant to the virtual target and the distances from the participant to the real prop were both less than 0.3m, we highlighted the scene. During the highlight phase, the participant can disable the redirection function by long-pressing the trigger of the handle, and get the passive haptic feedback. We recorded the error angle and the error distance when the participant had gotten the haptic feedback of the target by releasing the trigger. We asked participants to fill out SSQ before the experiments. After the experiment, participants were required to fill out the IPQ and the post SSQ.

4 Results and Discussion

The matching errors are shown in Table 1. The average error angle of CR_N and CR_P groups with our method is 43.9 degrees for TASK 1 and 55.9 degrees for TASK 2, the average error of distance is 19.5cm for TASK 1 and 8.5 cm for TASK 2. The only exception error is the matching angle error of CR_P group for TASK 2, which is 68.3 degrees. The reason for this is that we didn't consider the direction of the virtual target when we generate the shortest path to the invisible target. In the supermarket scene, all items the participant are required to find are placed on the shelves.The shortest path generated is parallel to the shelves, but the path guiding the participant is vertical to the direction of the virtual target. Thus for the supermarket case, the participant doesn't have enough time and space to adjust his direction when he approaches the item.

Compared with the FS method, our method reduces the matching angle errors slightly, which is due to the smoothness of our path. The Bezier curve based redirected path generated with our method is smoother than the circular arc and line segment based path of the FS method. Our method reduces 71% of the distance error for TASK 1, p=0.09 and the effect size is "Large". Our method performs better in TASK 2, and reduces 86% of the distance error, the difference is significant ($p<0.001$) and the effect size is "Very Large". The reason for the higher distance error of the FS method is because it switches five redirection strategies with high frequency, which introduces a higher cumulative distance error.

Figure 2 shows the IPQ scores of three methods. The S2C method doesn't match the virtual targets to the real objects, and the participants can not get the haptic feedback when they approach the virtual targets. Thus, the IPQ scores of S2C are significantly lower than our method. All subscales of our method are significantly lower than subscales of S2C (i.e., $p<0.05$). Our method provides a significant



(a) (b)

Figure 2: IPQ subscales for TASK1 and TASK2

higher general presence, spatial presence and experienced realism than the FS method for both TASK 1 and TASK 2 (i.e., $p<0.05$). The involvement scores of our method is similar to those of the FS method (p=0.91 in TASK1, p=0.88 in TASK2), which is because that the size of virtual scenes is much larger than the size of the physical area, especially for the supermarket scene, 20m × 20m vs 4m × 4m, and the participants of both groups can realize the existence of the real environment when they are redirected in the virtual scenes.

We use the Total Severity score (TS) to quantify the SSQ results.The TS scores increase from pre-exposure to post-exposure for all groups are below 70, which indicates that simulator sickness is not a factor for either group of participants [1].

5 Conclusion

We have presented a constrained path redirection method with passive haptic feedback in a VR HMD exploration of virtual environments. The main idea is to dynamically match the virtual targets and the real objects and to use the positions of the virtual-real target pair as constrains to redirect the path. The path redirection can be guided with the predicted direction even if no virtual target is visible. Compared to the conventional S2C path redirection method, the passive haptic feedback of our method increases the presence in VR environment exploration. Compared to the FS method, our method takes advantage of dynamic matching, Bezier curved path redirection and the virtual target prediction, which reduces task completion time, produces more accurate matching and better Presence.

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