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A User Guidance Approach for Passive Haptic Environments

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Abstract

Traveling through virtual environments (VEs) by means of real walking is a challenging task since usually the size of the virtual world exceeds the size of the tracked interaction space. Redirected walking is one concept to solve this problem by guiding the user on a physical path which differs from the path the user visually perceives, for example, in head-mounted display (HMD) environments.The user can be redirected to certain locations in the physical space, in particular to real proxy objects which provide passive feedback. In such passive haptic environments, any number of virtual objects can be mapped to proxy objects having similar haptic properties, i. e., size, shape and texture. When the user is guided to corresponding proxy objects, s/he can sense virtual objects by touching their real world counterparts. Therefore it is vital to predict the user's movements in the virtual world in order to recognize the target location. Based on the prediction a transformed path can be determined in the physical space on which the user is guided to the desired proxy object. In this paper we present concepts how a user's path can be predicted reliably and how a corresponding path to a desired proxy object can be derived on which the user does not observe inconsistencies between vision and proprioception.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality I.3.6 [Computer Graphics]: Interaction techniques

1. Introduction

Walking is the most basic and intuitive way of moving within the real world. Keeping such an active ability to navigate through large-scale virtual environments (VEs) is of great interest for many 3D applications demanding locomotion. For this reason virtual locomotion interfaces are needed that support walking over large distances in the virtual world, while physically remaining within a relatively small space [IRA07]. Many hardware-based approaches have been presented to address this issue [IHT06, IYFN05]. Unfortunately, most of them are very costly, while providing only a single user a notion of walking, and thus they will probably not get beyond a prototype stage.

Redirected walking [Raz05] is a promising approach to the problem of limited tracking space and the challenge of providing users with the ability to explore the VE by unlimited walking. With redirected walking, the virtual world is imperceptibly rotated around the center of the user's head. Thus, when the user explores the potentially infinite VE and approaches a border area of the tracking space, s/he can unknowingly be redirected towards the center of the interaction space. Hence the VE that can be reached by walking can be increased significantly. The phenomenon that users do not recognize small differences between a path in the real world is based on principles from perceptive psychology: Perception research has identified essential differences between cognition as well as estimation of features in VR in contrast to their counterparts in the virtual world [WC71,IAR06,RW07]. It has been known for decades that visual perception usually dominates proprioceptive and vestibular senses [WC71]. Thus, if the visualization stimulates the user appropriately, it should be possible to guide her/him along a path in the real world which differs from the path the user perceives in the virtual world. For instance,

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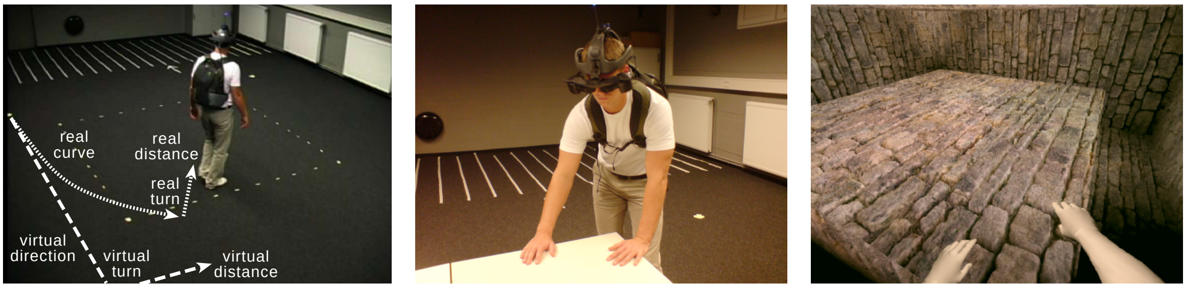


(a) (b) (c)

Figure 1: *Concept of generic redirected walking: (a) the user walks on a physical path which is different from the path the user perceives in the HMD environment. (b) a user touches a table serving as proxy object for (c) a stone block displayed in the virtual world.*

if the user wants to walk straight ahead for a long distance in the virtual world, small rotations of the camera *redirect* her/him to walk unconsciously in circles in the real world.

In our approach we have extended redirection concepts by combining translation gains, i. e., scaling the real distance a user walks, rotation gains, i. e., scaling the real turns, and curvature gains, i. e., bending the user's walking direction such that s/he walks on a curve [SBRH08] (see Figure 1). This generic redirected walking allows to guide a user to certain landmarks in the physical space, for instance to real *proxy objects*. Those proxy objects that are registered to virtual objects provide passive haptic feedback if the user touches them. Since in such passive haptic environments the mapping between virtual and proxy objects can be changed dynamically, a small number of proxy objects suffices to represent a much larger number of virtual objects. In order to guide a user to proxy objects it is essential to predict the users's movements in the VE such that potential target locations can be determined. Then the virtual path can be transformed to a different path in the physical space on which the user walks to the registered proxy object.

In this paper we present an approach to predict a user's path in the VE reliably and to determine a corresponding physical path on which the user does not observe inconsistencies between vision and proprioceptive perception. The remainder of this paper is structured as follows. Section 2 outlines related work. In Section 3 we present how user targets can be predicted and how a continuous path to proxy objects is obtained. Section 4 concludes the paper.

2. Related Work

Currently the combination of locomotion and perception in virtual worlds is in the focus of many research groups [IAR06, RW07]. In this context we have introduced generic redirected walking, and we have provided guidelines derived from a user study [SBRH08]. The following guidelines allow sufficient redirection without the user perceiving redirected walking or scaling of the VE:

1. Rotations can be compressed up to 30%,
2. distances can be downscaled to 15% and upscaled to 45%†,
3. users can be redirected on a circle with a radius down to 3.5m, and

Indeed, perception is a subjective matter but with these guidelines only a reasonably small number of walks is perceived as manipulated.

Redirection approaches are also applied in robotics when controlling a remote robot by walking [GNRH05, Su07] or when supporting telepresence by navigating avatars through VEs. In [SH07] strategies are presented that show how virtual paths can be transformed to real paths that keep the user in the tracked interaction space. In particular, collisions with physical objects can be prevented. For this purpose a target object is predicted on the basis of the current walking direction only. With stochastic models priorities can be applied to each potential target. The length of the period during which it is predicted as target changes its priority [SH07]. However, using only the walking direction may predict wrong targets, for instance, if the user unintentionally walks around. Passive haptic feedback is not considered in these approaches.

3. User Guidance

In order to guide a user to a proxy object reliable prediction of the user's intention is crucial. Future movements can be predicted based on the user's current/past position and orientation. Obviously such a procedure allows to predict only short distances, whereas sudden changes of the travel cannot be incorporated. Long term prediction is possible if the

† The asymmetric assumption may result from the issue that users tend to underestimate distances in VE. Hence translational movements appear downscaled even if no gain is applied.

user's intention to head for a particular location in the VE can be recognized. This is only possible if further information about the potential goals of locomotion is available.

3.1. Environment Description

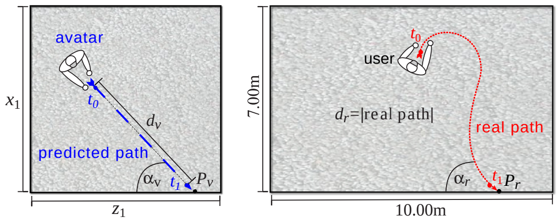
In order to support even long term prediction we represent the virtual and the physical world by means of an XML-based description in which *all* objects are discretized by a polyhedral representation, e.g., 3D bounding boxes. Furthermore, the orientation between virtual objects and their associated proxy objects is stored. The bounding boxes of a virtual object and a registered proxy object may vary. In our approach we ensure that the user approaches a proxy object from the correct direction regarding its bounding box. For a high fidelity passive feedback an additional registration process between virtual and proxy objects has to be taken into account. When proxy objects are tracked and they or virtual objects are moved, changes of their poses are updated in the XML-based description. Hence, also dynamic scenarios where the virtual but also the physical environment may change are considered in our approach.

3.2. Target Prediction

In order to redirect the user to a proxy object the virtual counterpart which the user approaches has to be predicted. We have developed a simple path prediction which considers the walking direction, but in contrast to [SH07] the viewing direction is also incorporated. While the current walking direction determines the predicted path the viewing direction is used for verification. When the projections of both vectors to the ground differ by more than 45°, no reliable prediction can be made, and the user is only redirected when a collision in the physical space may occur or when the user might leave the tracking area. In order to prevent collisions in the physical space only the walking direction has to be considered because due to the HMD the user does not see the physical space. When the angle between the projection of both vectors is sufficiently small ($< 45^\circ$), the walking direction defines the predicted path. Within the view frustum a line segment s_1 (given by the walk direction) is tested for intersections with virtual objects that are defined in the XML-based description (see Figure 2). This is achieved by a ray shooting similar to the approaches referenced in [Pel97]. Since the 3D bounding box geometries are stored in a quadtree-like data structure the intersection test can be performed in real-time. As illustrated in Figure 3 (a) if an intersection is detected, we store the target object, the intersection angle α_v, the distance to the intersection point d_v, and the relative position of the intersection point P_v on the surface of the bounding box.

3.3. Path Transformation

Since the XML-based description contains the initial orientation between virtual and proxy objects, it is possible to

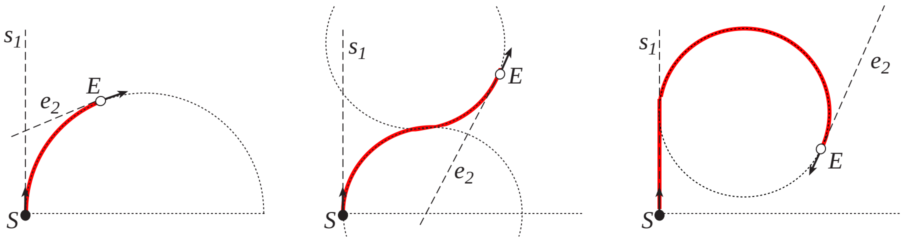


(a) Virtual environment (b) Real environment

Figure 3: *Redirection technique: (a) a user in the virtual world approaches a virtual wall such that (b) s/he is guided to the corresponding proxy object, i. e., a real wall in the physical space.*

redirect a user to the desired proxy object from the corresponding direction in order to enable a consistent passive feedback. As mentioned above, we predict the intersection angle α_v, the distance to the intersection point d_v, and the relative position of the intersection point P_v on the surface of the bounding box of the virtual object. With respect to the associated proxy object, these values define the target position and orientation E (with line segments extending the orientation of E, i. e., forward e_1 and backward e_2) in the physical world. The main goal of redirected walking is to guide the user along a real world path (from the start position S to E) which varies as little as possible from the visually perceived path. We constrain the path such that a continuous transition between the path and the start position/orientation S as well as the end position/orientation E is ensured. Thus, no breaks or jumps are allowed and smooth paths are guaranteed. A composition of continuous line and curve segments is determined resulting in corresponding parameters in the real world, i. e. α_r, d_r and P_r (see Figure 3 (b)). The trajectories can be computed as illustrated in Figure 2, considering the start position/orientation S and the end position/orientation E with ray s_1 starting from S and ray e_2 ending in E. Different situations for the orientation between S and E may occur. As illustrated in Figure 2 (a) if s_1 intersects e_2 the path on which we guide the user from S to E is a segment of a circle having its center on the line orthogonally to s_1. If s_1 does not intersect e_2 two different cases are considered, i.e., the angle between s_1 and e_2 is less or equal, or greater than 180° (see Figure 2 (b) and (c)). All other cases can be derived by symmetrical arrangements or by compositions of the described cases. The resulting paths can be further smoothed by using for example, B-splines.

Figure 3 shows how a path is transformed as described above in order to guide the user to the predicted target location associated with a proxy object. Figure 3 (a) shows an illustration of the VE. Assuming that the angle between the projections of viewing direction and walking direction is sufficiently small, the desired target location in the VE is determined as described in Section 3.2, i.e., point P_v at the



(a) s_1 intersects e_2 (b) s_1 does not intersect e_2 and $\alpha(s_1,e_2) \leq \pi/2$ (c) s_1 does not intersect e_2 and $\alpha(s_1,e_2) > \pi/2$

Figure 2: *Corresponding paths for different positions/orientations of start point S and end point E.*

bottom wall. The resulting path illustrated in Figure 3 is a composition of the paths shown in Figure 2.

In order to prevent collisions with physical objects which do not serve as proxy objects redirection is applied by means of bypasses around the obstacles. Each path is segmented into two paths where an intermediate point serves as end-point for the first path and start point for the residual path. Indeed, unpredicted changes of the user's motion may result in strongly curved paths, and the user will recognize this. Moreover, significant inconsistencies between vision and proprioception may cause cyber sickness. However, none of the participants have mentioned any inconvenience caused by transformed paths during the test phase.

4. Conclusions

In this paper we have presented concepts how a user's target location can be predicted reliably, and how a corresponding path to a registered proxy object can be derived. Most of the time the user does not observe inconsistencies between visual and proprioceptive cues. With increasing number of virtual and proxy objects respectively more rigorous redirection concepts have to be applied, and users tend to recognize the inconsistencies more often. However, first experiments show that it becomes possible to explore arbitrary VEs by real walking.

One drawback of our approach is that the registration process between proxy objects and their virtual counterparts has to be done manually. Computer vision techniques may be applied in order to extract information about the VE and the real world automatically.

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