A Universal Virtual Locomotion System: Supporting Generic Redirected Walking and Dynamic Passive Haptics within Legacy 3D Graphics Applications

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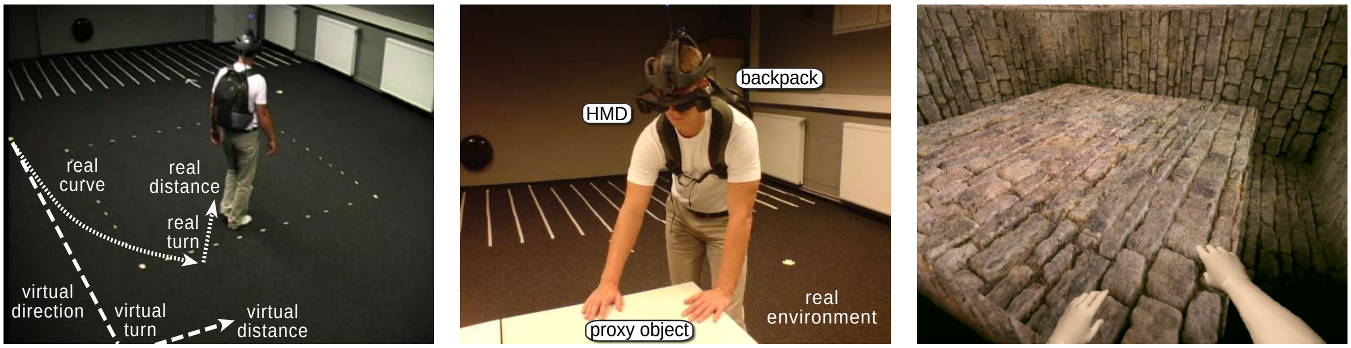

Figure 1: Virtual Locomotion Scenario: (left) a user walks through the real environment on a different path with a different length in comparison to the perceived path in the virtual world. (middle) the user touches a real proxy object which is considerably smaller than (right) the virtual object seen from the user's perspective.

Abstract

In this paper we introduce a virtual locomotion system that allows navigation within any large-scale virtual environment (VE) by *real walking*. In contrast to [5] we have developed *generic redirected walking* concepts by combining motion compression, i. e., scaling the real distance users walk, rotation gains, which make the real turns smaller or larger, and curvature gains, which bend the user's walking direction such that s/he walks on a curve (see Figure 1 (left)). Furthermore, we introduce the new concept of *dynamic passive haptics* which extends passive haptics [3, 4] in such a way that *any number* of virtual objects can be sensed by means of real *proxy objects* having similar haptic capabilities, i. e., size, shape and surface structure. We have evaluated these concepts and explain technical details regarding their integration into legacy 3D graphics applications.

Keywords: Virtual Realty, Virtual Locomotion Interface, Generic Redirected Walking, Dynamic Passive Feedback

1 Introduction

Walking is the most basic and intuitive way of moving within the real world. Keeping such an active and dynamic ability to navigate through large-scale virtual environments (VEs) is of great interest for many 3D applications demanding locomotion, such as urban planning, tourism, 3D entertainment etc. Although these domains are inherently three-dimensional, most of the applications do not support VR-based user interfaces, least of all *real walking* through the 3D scenes is possible. Therefore, virtual locomotion interfaces are needed that support walking over large distances in the virtual world, while physically remaining within a relatively small space [6]. Many hardware-based approaches have been presented to address this issue. 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.

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2 Universal Virtual Locomotion

Instead our virtual locomotion interface allows navigation within large-scale virtual environment (VE) by *real walking* by means of software-based approaches. Based on the results of a user study we have quantified to which degree users can unknowingly be redirected in order to guide them through an arbitrarily sized VE in which virtual paths differ from the paths tracked in the real world working space. In contrast to [5] we have developed *generic redirected walking* concepts by combining *motion compression*, which scales the real distance users walk, *rotation compression* and *gains*, which make the real turns smaller or larger, and *curvature gains*, which bend the user's walking direction such that s/he walks on a curve (see Figure 1 (left)). Furthermore, we introduce the new concept of *dynamic passive haptics* which extends passive haptics [3, 4] in such a way that *any number* of virtual objects can be sensed by means of real *proxy objects* having similar haptic capabilities, i. e., size, shape and surface structure. The mapping from virtual to real objects must not be one-to-one. Since the mapping can be changed dynamically during runtime, a small number of proxy objects suffices to represent a much larger number of virtual objects. For this purpose we have evaluated in how far the visual appearance of virtual objects may deviate from that of the real objects without the user noticing the difference. Dynamic passive haptics provide the

Figure 2: Example images illustrating the integration of the concepts into exemplary applications.

user with the illusion of interacting with a desired virtual object by redirecting him/her to the corresponding proxy object (see Figure 1 (middle) and (right)). In this paper we show how far visual perception dominates proprioceptive and vestibular cues similar to [1], but we are focussed on walking through VEs.

3 Pilot Study and Guidelines

We have performed a pilot study in which we have evaluated how much paths and objects in both worlds can differ in order to determine limits and thresholds for redirecting users and for employing proxy objects without letting users notice the difference between both worlds. A total of 8 (7 male and 1 female) subjects participated in the study. In our experiments movements of the users are restricted to a $10 \times 7 \times 2.5$m tracking range. In the center of a 6×6m area we placed a square table of size $1.5 \times 1.5 \times 1$m. The user's path always leads him/her clockwise or counterclockwise around the table which is represented as virtual block in the VE (see Figure 1 (right)).

In order to support generic redirected walking concepts as well as dynamic passive haptic strategies, we have modulated the real and the virtual environment by means of the applying motion, curvature and rotational gains as well compression respectively. For the results of a user study we derive some guidelines in order to allow sufficient redirection such that the user neither perceives the redirected walking nor the dynamic scaling of objects:

1. Rotations can be compressed or gained up to 30%,
2. distances can be downscaled to 15% and upscaled to 45%,
3. users can be redirected such that they unknowingly walk on a circle with a radius up to 3.3m,
4. objects and the VE can be downscaled to 38% and upscaled to 45%.

As evaluated in a test of significance when these requirements are fulfilled less than 15% of all walks are perceived as manipulated (p-value < 0.05).

4 Integration into 3D Legacy Application

In order to integrate these concepts into 3D legacy application, for example from the geospatial visualization domain, we have developed a 3D interceptor library. This library allows us to trace and modify 3D content from any graphics application based on OpenGL or DirectX. Our library is similar to the procedure of Chromium [2], but in contrast it allows to modify the camera without typical problems caused by such approaches. For instance, when prepending additional transformations in captured 3D graphics function calls directly the entire application logic is not aware that the camera position has changed. Thus, culling cannot be performed correctly.

Widely used geographic visualization application such as Google Earth or Microsoft's Virtual Earth combine search engines with satellite imagery, maps, terrain and 3D city models in order to collect geographic information. By now some city models include 3D buildings modeled up to a LoD 4, which corresponds to textured models of interiors. The user is able to virtually navigate world-wide and to explore specific features and landmarks within urban environments.

We have integrated our approaches in such geographic visualization applications which enables users to explore a virtual model in a natural way. In Figure 2 the user travels through a virtual environment by means of real walking combined with both-handed navigation metaphors. When using our generic redirection concepts the user is able to walk through 3D city models without any restrictions in the physical space. In the future we will apply dynamic passive haptics in Google Earth, which means to provide proxy objects and to generate a corresponding XML-based description that we extract from the Google KML file format. Hence the user will be able to sense virtual walls displayed in Google Earth by means of proxy objects.

5 Discussion

The application of the concepts presented in this paper raises further interesting questions, in particular, multi-user scenarios in which several users interact simultaneously may show great potential. In these cases even virtual avatars of certain users might be associated to other users; this procedure would be similar to the approach of dynamic proxy objects.

In summary, the introduced virtual locomotion interface seems to be a promising approach to increase the user's presence in virtual worlds. Many existing applications from different domains could potentially benefit from the possibility to naturally explore virtual environments in an immersive way.

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