

Virtual Prints: *Leaving trails in Virtual Environments*

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Abstract

In this paper the concept of Virtual Prints (ViPs) is introduced and alternative ways in which they can be used are suggested. The design and required functionality of a software mechanism for creating and interacting with ViPs in Virtual Environments are presented along with techniques and methods for overcoming related issues. Finally, the findings of an explorative study of the concept and pilot implementation are discussed.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interfaces] Interaction styles

1. Introduction

In the real world, every living organism constantly leaves everywhere tracks of its existence and its ‘interaction’ with the physical environment. Deer leave their paw marks in the soft forest soil, dolphins carve foam traces on the surface of the sea, flies leave annoying black spots on windows and young children imprint their fingerprints on the freshly painted house walls.

Since the early years of their presence on earth, humans observed this inherent property of the environment and learned to use it in various ways in order to make their life easier. For example, they learned to recognize the paw prints of animals to track down their prey or to avoid ferocious creatures, they used footprints to explore unknown territories or find his colleagues in search and rescue operations¹, they examined the fossils to study human history and evolution², and they revealed and analysed fingerprints to solve crimes³.

Virtual Environments (VEs) are three-dimensional, computer-simulated environments which are rendered in real-time according to the behaviour of the user⁴. In contrast to real environments, VEs do not allow their ‘inhabitants’ to leave any trace behind and usually suffer from an ‘extreme cleanness syndrome’. Walk into your house after leaving your children alone for the weekend and you can instantly realize that a wild party took place while you were away. Walk into a virtual chat room seconds after a meet-

ing of two hundred people has finished and it will be exactly as if no one has ever been there before.

This paper proposes the concept of Virtual Prints (ViPs) as the digital counterparts of real-life tracks that people leave behind, which can be manifested in three different types: (a) Virtual Footprints (ViFoPs); (b) Virtual Fingerprints (ViFiPs); and (c) Virtual Fossils (ViFossils). ViPs can aid navigation, provide useful feedback, work as a history mechanism, but also support *social navigation*⁵. The basic idea behind ViPs is that while a user is moving in a VE s/he is leaving behind his / her ViFoPs, while every time s/he is interacting with an object his / her ViFiPs are ‘imprinted’ on it. Both ViFoPs and ViFiPs can be time-sensitive, i.e., as (real or virtual) time goes by they can be gradually worn out. ViFossils are special marks that can be permanently left on the environment, or any object, upon user request and can be considered as a kind of ‘personal’ landmarks.

We argue that ViPs can have a variety of uses in a VE. For example, they can be used for navigation and wayfinding, tracking (or avoiding) other users or events, following predefined routes (e.g., in a training session), marking or identifying areas of interest, etc. Although in this paper we focus on using ViPs in a VE, they can also be used in Augmented Environments (AEs). For example, a person using an augmented reality system in a museum can follow ViPs that are related to a specific topic of interest, or those of a virtual guide.

2. Background and Related Work

One of the main goals of the work presented in this paper is to support navigation, orientation and wayfinding in VEs since these tasks (especially in large-scale VEs) can be very difficult, and may result in user disorientation and upsetting⁶. Previous related work mainly focuses on three complementary research directions:

2.1. Informing the design of Virtual Environments

This research direction is in principle concerned with the development of appropriate guidelines (mainly by exploiting existing environmental design principles) for the creation of well-structured spaces that inherently aid navigation and wayfinding. For example, Charitos⁷ presents a taxonomy of all possible objects a VE consists of (namely landmarks, signs, boundaries, and thresholds), as well as of the spatial elements these objects define (places, paths, intersections, and domains) and, based on architectural design and the way humans think about and remember space in the real world, suggests how these elements can be used to support wayfinding. Along the same line of work, Darken and Sibert⁸ have studied wayfinding strategies and behaviors in large VEs and suggest a set of environmental design principles that can also be applied in VEs. Also, Hunt and Waller⁹ examine the relation of orientation and wayfinding between physical and virtual worlds, and the way existing knowledge can be transferred from the first to the latter, while Vinson⁶ offers a set of design guidelines, which are based on navigation in real world, for the placement of landmarks in a VE in order to ease navigation. On the other hand, research findings presented by Satalich¹⁰ in her thesis, where she studies navigation and wayfinding in VR, argue that human behaviour in navigation and wayfinding in the real world is not identical to behaviours exhibited in VEs, and thus, it is likely that existing tools and principles may not be adequate or sufficient if directly transferred from the one domain to the other.

A limitation of these approaches is that they require the modification of the virtual space's contents. This may not always be possible or desirable, as for example in the case of VEs that are based on real world environments, rendering these approaches inappropriate for a large number of widely used VE applications, such as simulations, engineering design and architectural walk-throughs.

2.2. Development of appropriate input techniques and devices for user movement in VEs

This research direction aims to provide easier and more intuitive navigation and wayfinding in VEs through the definition and development of appropriate hardware, as well as related input techniques and metaphors that allow the user to move more 'naturally' in a VE. For example, the Omni-Directional Treadmill Darken, Cockayne, and Carmein¹¹ and the Torus Treadmill¹² aim to offer novel hardware solutions for naturally walking or jogging in a VE. Peterson et al.¹³ propose a new input device in the

form of a body-controller interface called Virtual Motion Controller (VMC) and compare its performance in navigating a virtual world with a joystick. Templeman et al.¹⁴ present *Gaiter*, another input device and associated interaction metaphor that allows users to direct their movement through virtual environments by stepping in place. A different approach is followed by Razzaque et al.¹⁵ who try to solve the problem of locomotion in a VE through a new interaction technique named Redirected Walking that does not require any special hardware interface.

2.3. Development of VE navigation and wayfinding support tools

The third direction includes techniques and tools that are not integrated in the VE, but come in the form of virtual objects, that aid the user to identify his/her current (or target) location in a virtual world, and / or construct an overview or mental model of the overall VE. A variety of such tools have been developed including: position coordinate feedback¹⁶, 2D maps¹⁶, 3D maps (e.g., the Worlds in Miniature (WIM) metaphor¹⁷, metaphors for exploration and virtual cameral control¹⁸, dedicated windows offering alternative viewpoints (e.g., the Through-the-Lens techniques¹⁹), 3D thumbnails for providing memorable destinations to return later (i.e., Wordlets²⁰) and position coordinate feedback that mimics global positioning systems (GPS¹⁶).

3. ViPs vs. related work

The latter direction is the one more closely related to the work presented in this paper, and includes a few concepts that share some common attributes (but have significant differences) with ViPs. A relevant example is the concept of breadcrumbs¹⁶, which are markers in the form of simple unmarked cubes hovering just above the ground plane that can be dropped (manually or automatically) at the user's path as a means for marking trails or encoding locations but not offering any directional information. The notion of breadcrumbs is also referred to as trailblazing²¹ and Hansel & Gretel technique²². Edwards and Hand²¹ have also suggested that the trailblazing technique could be extended to support the notion of 'embodied bookmarks', allowing the user to record and return to specific previously marked positions.

More recently, Darken and Peterson²² revisited the notion of breadcrumbs by adding directional cues to them, admitting that "a better analogy is that of footprints since footprints are directional and breadcrumbs are not". They argue that the footprints technique can be useful for exhaustive searches since it allows users to know if they have already been in some place before. Furthermore, Darken and Peterson²² report two related problems, namely that: (a) as navigation proceeds, the environment becomes cluttered with footprints; and (b) when the user crosses paths it becomes difficult to disambiguate which footprints belong to a given trail. A suggested solution for the first problem is to

make trails disappear over time, which however creates a new problem, since a user can no longer tell if a place has been visited before. Finally, a concept that shares some common attributes with ViFossils is that of environmental landmarks that can be explicitly placed by the user²².

The only issues explored by related work are marking trails and creating landmarks in single-user VEs. This paper builds upon, and extends this work by introducing new concepts, such as the notion of Virtual Fingerprints (leaving tracks of the user's interaction with, as opposed to mere movement in, the environment), the notion of ViPs in multi-user environments, as well as appropriate mechanisms for their control, customisation, and utilization in an effective and efficient way.

It is also argued that ViPs can also be used for other purposes beyond the exploration of unfamiliar virtual territories, such as:

- Location of other participants (e.g., friends, enemies, people we wish to meet or avoid) in multi-user environments (e.g., MUDs, chat worlds).
- Ability to easily (re)visit places where the user (or somebody else) has been before (i.e., a kind of a history or bookmark mechanism).
- Support for *social navigation*. Social navigation is a concept based on the fact that when people are looking for information (e.g., directions, recommendations) they will turn to other people rather than use formalized information artifacts. For example, participants of a multi-user VE can easily identify popular places or options through the number of ViFiPs or ViFoPs in them, follow routes, etc.
- Creation of tutorial sessions. A tutor can leave behind a number of ViPs that the 'students' may follow, for example, to learn a specific procedure in a "step by step" fashion.
- Development of virtual tours. By following the ViPs of virtual guides, the users can tour virtual museums, exhibitions, stores, etc.
- Visualization and tracking of the path of moving objects. For example, they can be used for observing (and even predicting) the paths of friendly and enemy units in military Command & Control Center applications or, for visualizing the orbit of planets and other celestial objects in virtual planetariums.

A considerable advantage of ViPs is that they can be used in any VE and in combination with any of the aforementioned navigation and wayfinding support approaches, since they do not require any alterations of the virtual space and they are not attached to a specific input interface metaphor / device. Furthermore, the fact that ViPs have real-life counterparts with which humans are very familiar renders them an intuitive and potentially easy to use metaphor.

4. ViPs Distinctive Properties and Characteristics

Just like in the real world, ViPs can be personalized (see Figure 1), thus helping the participants of a multi-user VE to find out who has been where and what each user has been doing. Furthermore, ViPs can be time-sensitive (for example they can get worn out or become transparent as time goes by, see Figure 2) in order to help the users distinguish the older from new(er) ones.



Figure 1: Personalized ViFoPs and ViFiPs belonging to different users.

ViPs can also provide a full record about their creator and the time of their creation (see Figure 3), and support a useful set of actions, such as finding the next / previous ViP, following them, tracking their owner, etc. (see Figure 4).

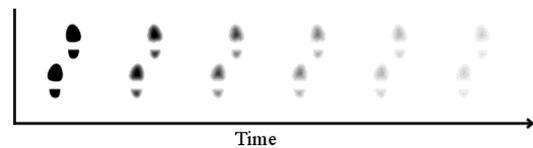


Figure 2: Example of a time-sensitive ViP.

4.1. Interacting with ViPs

Each ViP is associated to an information sheet that includes information about the ViP's type, owner, creation time and date (see Figure 3) that can be viewed by using a 'pointing device' (e.g., the mouse cursor in a 2D environment, or the 3D pointer or virtual hand in an immersive environment).

If the ViP does not belong to the current VE user, then when selecting it (e.g., clicking the right mouse button, or pressing the data glove's button) a menu appears (see Figure 4) that offers the following options:

- automatically follow* the ViPs (of the same type, e.g., ViFoPs) forward / backward;
- leap to the next / previous ViP;
- track the ViP's owner;
- turn on / off a line connecting consecutive ViPs;
- find the closest ViP of one of the other two remaining types that belongs to the same owner (e.g., if a ViFoP is selected, find the closest ViFiP or ViFossil);

* The user can stop following the ViFoPs at any time.

- f) hide all the ViPs (of the selected or all types) belonging to the specific owner;
- g) change ViP viewing options.

In case the ViP belongs to the user, then by selecting it, in addition to the aforementioned options, the user can delete it and change ViP creation options, while there is no option to track the ViP's owner.

4.2. Creating and viewing ViPs

ViPs creation and viewing can be customized according to several parameters.

Regarding the creation of ViPs, the user can select (for each different type of ViPs) their appearance and the information they will reveal about him / her, who will have the right to see them, whether they should be created upon user demand or automatically (not applicable to ViFossils), and if so when they should be created (e.g., at specific time / space intervals). Additionally, the user can select if ViPs will be time-sensitive (not applicable to ViFossils), meaning that they will disintegrate as time goes by, and if so, what will happen when a ViP will be totally worn out (e.g., whether it 'disappears' but the information about it is stored and can be accessed or it can be completely destroyed).

In order to minimize the effect of ViP pollution (see section 5.1) a filtering mechanism is supported that allows the user to view or hide specific (sets of) ViPs according to their creators (e.g., user's own ViPs, all ViPs, ViPs belonging to specific users or user groups), their creation time (e.g., last X minutes, from time A to time B), proximity (e.g., the Y closest ones) and their number (e.g., only the Z most recent ones). Through this filtering mechanism the user has also the option to view ViPs that exist in the VE, but are no longer visible (because they have 'disappeared' – see previous paragraph).



Figure 3: Example of a ViP's information sheet (see also Figure 3c at the colour section).



Figure 4: Example of interacting with a ViP (see also Figure 4c at the colour section).

Furthermore, two more options are offered; one for using a line to connect ViPs that belong to the same path to reinforce visual continuity of paths (see section 5.2), and one for viewing all ViPs by using a specific predefined image. This last option is quite useful for places that are overcrowded with ViPs (especially if these have different colours, shapes and sizes), since they can be all represented, for example, as small semitransparent dots or arrows, offering to the user a clearer view of the environment in combination with useful ViPs related information (e.g., amount of ViPs present, areas of interest, paths).

5. ViPs-related issues and challenges

Preliminary investigation into the deployment of ViPs has revealed several issues that need to be addressed.

5.1. ViPs "pollution"

According to Darken and Peterson²², as navigation proceeds the environment can become cluttered with footprints. This, of course, becomes far worse in a multi-user environment. In the implemented system, two different functions are supported to overcome this problem. The first one is to use the ViPs filtering mechanism (see previous section) that allows the users to select which ViPs they will be able to see, according to several alternative parameters.

Another way to fight ViPs pollution is to use time-sensitive ViPs. However, a user can no longer tell if a place has been visited after the ViPs disappear. This new problem can be dealt with through the option offered by the filtering mechanism that allows viewing ViPs that were 'disappeared' (but were not destroyed). Another solution is the use of ViFossils for marking places, since they are not time-sensitive.

5.2. ViPs continuity

This problem, also reported by Darken and Peterson²², arises when the user crosses paths while leaving footprints, since it might become difficult to disambiguate which footprints belong to the same trail. In the proposed approach this problem can be solved by selecting to view a connecting line between all ViFoPs belonging to the same path.

5.3. Overlapping ViPs

When two or more ViPs overlap, apart from the aforementioned problem of continuity, visual and interaction ambiguity problems may also occur. Visual clarity may be lost when, for example, two or more ViPs of similar colour overlap, while interaction ambiguity occurs when the pointing “device” is concurrently intersecting more than one ViPs and it is not apparent which one the user wishes to interact with.

One approach to overcome this shortcoming is to always consider only the topmost ViP. Visual clarity is provided through the representation of the ViP in the information sheet (see Figure 3). Another approach is to present a list containing information about all of the overlapping ViPs. From this list the user can select the ViPs to interact with. If the number of overlapping ViPs is very large then the list is separated in pages and a “next page” and a “previous page” buttons are added.

Each approach has advantages and disadvantages. The first approach is more straightforward and effective to use, but prevents the user from accessing information that exists in the environment. The second one is more flexible and provides all the available information, but at the cost of adding another step to the interaction process, potentially reducing its usability and effectiveness.

5.4. Privacy and protection of personal data

Since ViPs can be considered as a mechanism that collects, and thus can also potentially expose, personal information, adequate policies should be adopted to protect the privacy of the participants of a VE, in accordance to established relevant guidelines and principles, such as those included in the European Community Directive on Data Protection* and the Privacy Guidelines by the Electronic Privacy Information Center†.

In this context, the system collects only data that are relevant and legitimate for the purposes of the pilot imple-

mentation, which are internally stored and do not become widely available or communicated through a network. Furthermore, the system allows each user to:

- a) View at any time the data that have been (and are) recorded about him / her and destroy any or all them.
- b) Define what information ViPs will provide to other users.
- c) Turn the recording mechanism on or off at any time, as well as select to manually place ViPs in the VE.
- d) Use the system anonymously.

Another feature under implementation offers a user the possibility of (dis)allowing access to his/her ViPs and related information.

6. Pilot Implementation and Study

In order to study the concept of ViPs, as well as their envisaged functionality and properties, a prototype VE equipped with a simplified ViPs mechanism incorporating part of the functionality has been implemented‡ and tested. The pilot experiments presented in this section were performed using a non-immersive version of the system that was projected on a 17” monitor. The interaction devices used were a standard keyboard’s arrow buttons and a mouse for user movement (the users could select their preferred device), while the mouse was also used for interacting with the virtual objects and the ViPs. Users were able to move forward, backward and turn left and right, but not up and down (i.e., fly above the virtual ‘floor’).

The virtual environment used for the study was a maze that included several corridors and rooms, populated with simple objects with which the user could interact (such as a door that opens when selected, a 3-item menu, a ball). Although the test environment was a single-user system, in order to simulate and demonstrate the use of ViPs in multi-user environments a number of ViPs of imaginary ‘other’ users were placed in it. In addition to this environment, a simple room (the “warming up room”) with a few objects was also constructed for user familiarization before the actual test with the system and its interaction facilities.

Two separate studies of explorative nature were conducted. The aim of these studies was to collect qualitative data, such as comments, ideas and opinions about the overall concept of ViPs and their potential usefulness and shortcomings, as well as about the adopted design and implementation approach of the ViPs mechanism. These data are very helpful not only towards validation of the usefulness of the concept, but also towards fixing problems and

* *European Community Directive on Data Protection (95/46/EC)*, 1995. On-line available: <http://www.acs.ohio-state.edu/units/law/swire1/psecind.htm>

† *Privacy Guidelines for the National Information Infrastructure. A review of Proposed Principles of the Privacy Working Group (EPIC, 1994)*. On-line available: http://www.epic.org/privacy/internet/EPIC_NII_privacy.txt

‡ *Maverik for Linux*, was used a publicly available Virtual Reality system developed by the University of Manchester (<http://aig.cs.man.ac.uk/maverik/>). The prototype was installed on a dual Pentium III 1GHz PC with 768 MB of memory and a GeForce II Pro graphics card with 32MB RAM.

improving the overall usability of both design and implementation before proceeding to further formal user testing.

The first study was performed with two expert interaction designers with the aim to present the concept and the design of ViPs and get comments about their value and usability, but also useful ideas for improving the design and identify potential usability problems.

The second study included six subjects, potential end-users of the system (4 males and 2 females), all of them experienced computer users, but with different level of expertise in the use of VEs. Two of the users had experience in using immersive VEs, such as a CAVE or HMD-based system. Two users were familiar with VRML-based worlds, 3D games and 3D chat applications. Finally, the remaining two users had no previous experience in using a VE.

The procedure followed for each different user group consisted of the subsequent steps:

1. Before the test, an introduction to the ViPs concept and the related functionality was presented, followed by a short demo of the test system and of the supported functionality.
2. After the introduction, each subject was able to use the "warming up room" to get familiar with navigating and interacting in the virtual space, identify a preferred navigation device by trying the alternative ones and experiment with leaving ViPs in it. The warming up time ranged from 5 to 15 minutes, depending on their previous experience with VEs.
3. A list of simple tasks to perform was given to the subjects, such as moving through the maze trying to locate a specific room and then returning to their initial position, exploring the whole maze and identifying the most popular place, interacting with specific objects, locating another user, etc. The users had the possibility to perform the tasks by enabling or disabling the ViPs mechanism and to experiment with the different options provided (e.g., automatic or user-driven creation of ViPs, time-sensitiveness of ViPs, etc.).

The thinking aloud method²³ was adopted, where subjects were allowed to express their thoughts, comments and feelings at any time during the test and also interact with the two observers that were present. The role of the observers was to prompt the users for comments but also for alternative ways of performing the tasks. Due to the qualitative nature of the study, user-observer interaction was highly encouraged, since user performance was not traced or evaluated. The conversations were recorded using a digital audio recorder.

4. After using the system, a small debriefing session was held, where the overall impression of the user's interaction with the system was requested, as well as sugges-

tions for improvement, modifications and personal preferences.

6.1. Study findings

The overall impression of the subjects with respect to the concept of ViPs and the pilot implementation was positive. All of them agreed that ViPs can be really useful in several cases and that the overall metaphor that ViPs introduce in the context of moving and using a VE is very easy to grasp and utilise. Indisputably, the favourite part of the particular system was the option for personalized ViPs. All users spent considerable time browsing the relevant list of images to pick one, and most of them changed it quite a few times while using the system, trying to find the one that they preferred or that they considered best-suited to their personal 'image'. Furthermore, all subjects contributed with a number of ideas and suggestions about the instantiation of alternative images. This fact comes as no surprise, since the image of a user's ViPs is actually his / her representation in the virtual world and is often implicitly associated with traits of their character and personality.

The two interaction designers were mostly concerned with potential usability problems of the system. They contributed their views with respect to the problem of overlapping ViPs presented in Section 5.3, and commented on potential interaction patterns, organization of the presented menus, and alternative parameters that could be employed for creating and viewing ViPs.

All subjects that had previous experience with (any type of) VEs did not face any particular problems in using the system. Users of multi-user VEs expressed their concerns about privacy issues and the way they could be handled. Novice users mainly had difficulties in navigating and using effectively the input devices. Half of the users commented that the suggested ViPs viewing and creation parameters were too many, and that they would not be able to use them effectively without previous training.

An unexpected result of the tests was that one of the subjects used ViPs in an artistic and playful way that was not foreseen when the system was designed, to draw patterns on the ground the way people make sketches in the sand.

7. Conclusions & Future Work

This paper has introduced the concept of Virtual Prints (ViPs) and suggested alternative ways in which they can be used. Furthermore, the design and required functionality of a software mechanism for creating and interacting with ViPs in Virtual Environments was presented along with techniques and methods for overcoming some potential related problems.

The findings of a preliminary study confirmed the initial hypothesis that ViPs can work as a handy tool, as a useful navigation aid, but also as a feedback and history mechanism. In addition, the support that ViPs can provide

for collaborative environments and social navigation was considered as significant and innovative. This study also allowed to identify potential usability problems of the initial design and missing functionality, to collect user preferences that will help in refining and improving the concept and the resulting system, as well as identify areas where further experimentation and testing is needed.

Currently, the full ViPs functionality is under implementation in both an immersive (utilizing a head-mounted display and a dataglove) and a non-immersive VE. In this context, a number of user tests (with both the immersive and non-immersive version of ViPs) to formally assess the usability (effectiveness, efficiency and user satisfaction) of ViPs are planned. Furthermore, it is planned to experiment with alternative ViPs viewing and creation parameters, to study the tradeoffs between different approaches to solving ViPs-related problems (especially overlapping and pollution) and to evaluate their effectiveness.

In conclusion, it is argued that ViPs constitute a very powerful and practical concept that should be further explored and tested. In principle, they have the potential to offer substantial support in the way people move and interact with VEs, and can contribute towards more intuitive and usable human-VE interaction. Towards this end, our goal is to create a re-usable ViPs mechanism able to be used as a plug-in to VEs, so that ViPs can be easily adopted and exploited by the broader VE development community, thus making ViPs a basic component of future VEs.

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References

1. J. Kearney. *Tracking: A Blueprint for Learning How*. Pathways Press, 1999.
2. I. Tattersall. *The Fossil Trail : How We Know What We Think We Know About Human Evolution*. Oxford University Press, 1995.
3. C. Beavan. *Finger prints: The Origins of Crime Detection and The Murder Case That Launched Forensic Science*. Hyperion, 2001.
4. C.E. Loeffler and T. Anderson (Eds.). *The Virtual Reality Casebook*. Van Nostrand Reinhold, 1994.
5. A.J. Munro, K. Höök, D.R. Benyon. Footprints in the Snow. In A.J. Munro, K. Höök, D.R. Benyon (Eds.), *Social Navigation of Information Space*, 1999. London: Springer. On-line available: <http://www.sics.se/~kia/papers/IntroFINALform.pdf>
6. N.G. Vinson. Design Guidelines for Landmarks to Support Navigation in Virtual Environments. *CHI '99 Proc.*, 278-285, 1999.
7. D. Charitos. Designing Space in Virtual Environments for Aiding Wayfinding Behaviour, *Electronic Proc. of the fourth UK VR-SIG Conference*, 1997. On-line available: <http://www.brunel.ac.uk/faculty/tech/systems/groups/vvr/vrsig97/proc.htm>
8. R.P. Darken and J.L. Sibert. Navigating in Large Virtual Worlds. *The International Journal of Human-Computer Interaction*, 8(1):49-72, 1996.
9. E. Hunt and D. Waller. *Orientation and Wayfinding: A Review*. (ONR technical report N00014-96-0380). Arlington, VA: Office of Naval Research, 1999.
10. G.A. Satalich. *Navigation and Wayfinding in Virtual Reality: Finding the Proper Tools and Cues to Enhance Navigational Awareness*. MS thesis, University of Washington, 1995.
11. R.P. Darken, W.R. Cockayne and D. Carmein. The Omni-Directional Treadmill: A locomotion device for virtual worlds. *Proc. of UIST '97*, 213-221, 1997.
12. H. Iwata and Y. Yoshida. Path reproduction tests using a Torus Treadmill. *Presence*, 8:587-597, 1999.
13. B. Peterson, M. Wells, T.A. Furness III, and E. Hunt. *The Effects of the Interface on Navigation in Virtual Environments*. In Human Factors and Ergonomics Society 1998 Annual Meeting, 1998.
14. J.N. Templeman, P.S. Denbrook, and L.E. Sibert. Virtual Locomotion: Walking in Place through Virtual Environments. *Presence: Teleoperators and Virtual Environments*, 8(6): 598-617, 1999.
15. S. Razzaque, Z. Kohn, and M. Whitton. Redirected Walking. *Eurographics 2001 Proc.*, 2001 (to appear). On-line available: <http://www.cs.unc.edu/~eve/pubs.html>
16. R.P. Darken, and J.L. Sibert. A Toolset for Navigation in Virtual Environments. *Proc. of ACM User Interface Software & Technology*, 157-165, 1993.
17. R. Stoakley, M.J. Conway, and R. Pausch. Virtual reality on a WIM: Interactive worlds in miniature. *Proc. of ACM CHI '95 Conference on Human Factors in Computing Systems*, 265-272, 1995.
18. C. Ware, and S. Osborne. Exploration and virtual camera control in virtual three dimensional environments. *Proc. of the 1990 Symposium on Interactive 3D Graphics, Special Issue of Computer Graphics*, 24:175-183, 1990.
19. S. Stoev, D. Schmalstieg, and W. Straßer. Through-The-Lens Techniques for Remote Object Manipulation, Motion, and Navigation in Virtual Environments. *Proceedings of the Joint Immersive Projecti-*

- on Technology / EUROGRAPHICS Workshop on Virtual Environments (IPT/EGVE 2001), 51-60, 2001. Wien-New York: Springer.
20. T.T. Elvins, D.R. Nadeau, and D. Kirsh. Worldlets - 3D thumbnails for wayfinding in virtual environments. *Proc. of the 10th annual ACM symposium on User interface software and technology*, 21 – 30, 1997.
 21. J. Edwards, and C. Hand. MaPS: Movement and Planning Support for Navigation in an Immersive VRML Browser. *Proceedings of The Second Symposium on the Virtual Reality Modeling Language (VRML'97)*, 65-73, 1997. New York: ACM.
 22. R.P. Darken, and B. Peterson. Chapter 28: Spatial Orientation, Wayfinding, And Representation. In Kay M. Stanney (Ed.), *Handbook of Virtual Environment Technology*, 2001 (in press). USA: Lawrence Erlbaum Associates, Inc. On-line available: <http://vehand.engr.ucf.edu/handbook/Chapters/Chapter28/Chapter28.html>
 23. J. Nielsen. Usability Engineering. *Academic Press Inc.*, 195-200, 1993.



Figure 3c: Example of a ViP's information sheet.



Figure 4c: Example of interacting with a ViP.