

***Through-The-Lens* Techniques for  
Motion, Navigation, and Remote Object  
Manipulation  
in Immersive Virtual Environments**

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## Abstract

In this paper, we present a set of techniques for interaction with, navigation through, and manipulation within virtual environments. The proposed techniques are based on a *through-the-lens* model, extending existing techniques like the *eyeball-in-hand* and the *scene-in-hand*. The significant improvement consists of an intuitive preview displayed on a hand-held personal interaction panel (pip), which acts like a *magic lens*. This allows for a better orientation, and adequate and precise adjustment of the virtual camera position. Once the desired target position is set, the user can 'beam' himself/herself to the new location moving the hand-held pip to her/his face. In this way, an illusion of entering a new world through the provided window is created.

Furthermore, we describe another application of these techniques: the manipulation of distant objects. Instead of 'beaming', after the virtual camera is set appropriately, the user can use his/her dominant hand to manipulate objects as if he/she is standing in front of them. Thus, (1) no flying, or walking to the object's location is necessary and (2) no confusing (automatic) scaling of the surrounding environment is performed.

Finally, the navigation tool we describe in this work is a significant extension and improvement of the well-known *world-in-miniature* (WIM) paradigm. The proposed technique allows for the user to perform rather a controlled change of his/her position and view-orientation in the virtual world, than to really travel there. This is especially useful for navigation within large virtual worlds. In addition, when a tabletop display system is utilized this provides an useful tool, since walking is rather limited possible in such setups.

We conclude the paper with a presentation and discussion of some preliminary usability studies, performed with the presented techniques.

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## 1 Introduction

The main step towards making the virtual perception real and letting the participants feel completely within or even a part of a virtual environment is enabling him/her to interact with the latter and to move through it. Unfortunately, the initial enthusiasm about virtual reality (VR) was soon quelled by the inability to provide adequate interaction techniques, which are intuitive to use, while offering sufficient functionality and powerful, while still easy to use.

Even though, many of the natural navigation abilities of the human are understood, it is hard, often impossible to use this knowledge to design tools and techniques for virtual world scenario. Furthermore, the aim of many virtual worlds is to offer exploration capabilities, which do not have a counterpart in the real life. Hence, new manipulation and exploration techniques have to be developed and studied.

In this paper, we introduce three *through-the-lens* techniques for remote object manipulation, navigation, and travelling within virtual worlds. The remainder of the work is organized as follows: In the next section, we discuss previous work in the related areas of two-hand interaction with virtual worlds. Section 3 briefly describes our hardware setup and configuration. In Section 4 we discuss the common concepts of the the proposed techniques. In the three following sections, we describes in detail the contribution of this work. Afterwards, we report on preliminary usability tests. In Section 9 we compare the proposed tools with other related approaches. Then, we conclude the paper pointing out some of our future research topics.

## 2 Related Work

Here we review previous work on two-hand interaction in general and its application in virtual environments. Afterwards, we focus on the navigation and object manipulation in virtual worlds.

### 2.1 Two-Hand-Interaction

The first contributions on two-handed interaction we know of, are the work of Buxton and Myers [BM86] and Guiard [Gui88]. Buxton reported on significant performance increase when bimanual navigation/selection is applied compared to accomplishing the task unimanually. Guiard's work showed, how a prop in the non-dominant hand is used to define a (coarse oriented) coordinate system, a kind of a reference frame, while the dominant hand is used for fine positioning relative to that coordinate system. Kabbash [KBS94] evaluated two-hand interaction techniques and compared them with unimanual interaction. The conclusion of his work is that bimanual interaction can improve overall performance, especially when asymmetric partition of labor is possible.

Exploiting the above observations on the asymmetric use and coordination of human hands, several research groups developed two-hand interaction techniques for different virtual environments. The resulting tools are known under various names like *pen and palette* [SRS91], *pen and tablet* [AS95], *physical clipboard* [SCP95], *3D-Palette* [BBMP97], *personal interaction panel (Pip)* [SG97, SES99], and the *virtual palette and remote control panel* [CW99]. The idea is quite simple: the user is provided with a tracked pad used as a frame of reference for the interaction with computer generated widgets. In addition, a tool for manipulating these interface elements is provided, e.g. a virtual pen. The virtual tool is a visual duplicate of a six-degrees-of-freedom input device, providing tactile feedback, similar to Wloka and Greenfield [WG95]. This two-hand interaction concept turned

out to be very intuitive to use and suitable for various kinds of virtual environments (augmented, immersive, CAVE-like, tabletop displays, and head mounted displays). Further work in the area of interaction techniques and systems applying bimanual interaction are described in [TGS96, CFH97, Bro88].

## 2.2 Navigation

In their work [DS93], Darken and Sibert present a toolset for navigation in virtual environments, applying principles extracted from real world navigation aids. Furthermore, they compare the strengths and the weaknesses of the latter.

The 2D maps proposed by Darken and Sibert were extended into the third dimension by Stoakley et al. [SCP95]. He defines navigation as a term covering two related tasks: movement through a virtual space and determining the orientation relative to the surrounding environment. Considering these two items, Stoakley introduced the WIM-technique. WIM stands for *World In Miniature* and is a miniature copy of the virtual world displayed on a hand-held panel. Originally, the WIM was applied for manipulating objects in the 3D space. Pausch et al. [PBBW95] extended the WIM concept to provide a navigation tool. However, he also reports, that despite the intuitive and useful application of the WIM, manipulating the viewpoint was confusing to many users. This was caused by the fact that the world surrounding the user moves simultaneously with the manipulation on the WIM.

Mine et al. [MBS97] describes the application of the scale-world grab metaphor for locomotion. It enables the user to transport himself/herself by grabbing an object in the desired travel direction and pulling herself/himself towards it. The main advantage of this technique is, that the user can reach any visible location in only one grab operation.

Another set of navigation metaphors is discussed by Ware and Osborne [WO90]. They evaluate three metaphors for exploration and virtual camera control: *eyeball-in-hand*, *scene-in-hand*, and *flying-vehicle-control*. They conclude that: "None of the techniques is judged the best in all situations, rather the different metaphors each have advantages and disadvantages depending on the particular task".

Another pioneer work in this area is the paper of Bier [Bie86]. He discusses interaction techniques, primarily geared towards scene composition, emphasizing precise object placement in the 3D-space. In his work Mine [Min95] discusses in detail the fundamental forms of interaction in virtual environments, including movement, manipulation, and menu interaction. Finally, Usoh et al. [UAW<sup>+</sup>99] compares different motion techniques.

## 2.3 Remote Object Manipulation

The remote manipulation of objects in a virtual environment has been addressed by the work of many researchers. Poupyrev et al. [PBWI96] reports on a technique for extending the user's virtual arm with a nonlinear function (the *go-go-technique*). A mapping with 1:1 is applied closed to the user's body, while a nonlinear function is used further out. A brief evaluation of this and other existing techniques for grabbing and manipulating remote objects is given by Bowmann and Hodges [BH97]. In their work, they report on a user study and compare the go-go-technique, other arm extension techniques, and a ray-casting technique. The paper concludes that none of the tested techniques is a clear favorite, because none of them were easy to use and efficient throughout the entire interaction consisting of grabbing, manipulating, and releasing.

Mine et al. [MBS97] describes another technique for remote manipulation: the *scaled-world grab*. When an object is grabbed, the scaled-world grab automatically scales the

surrounding environment down about the user's head and scaled back up when it is released.

Pierce et al. [PFC<sup>+</sup>97] describes a technique for interacting with 2D projections of 3D objects: the *image-plane* interaction. Stoakley et al. [SCP95] describes how objects are brought into reach in the form of a scaled down copy of the original, enabling the user to manipulate the miniatures. Finally, Pierce et al. [PSP99] utilizes hand-held object replica, for remote manipulation.

### 3 Hardware and Software Setup

The hardware used in our setup consists of a 6DOF tracking system (*Ascension, Flock of Birds*) and a table top display (*Barco, Baron* or *Virtual Table*). The screen has an approximate size of 53"x40" and is tilted about its *x*-axis (see Figure 1). The tracker data is

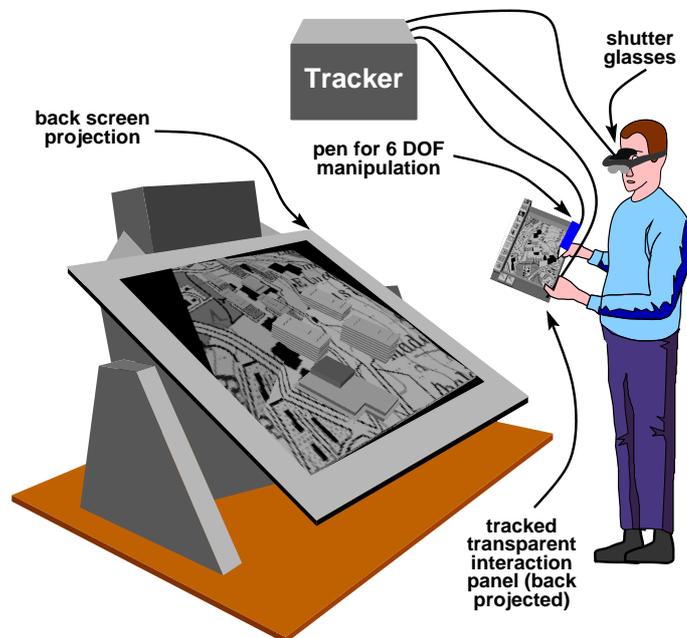


Figure 1: Hardware setup of the virtual environment. The images on the hand held panel are back-projected via the table display.

processed by a *tracker-server* responsible for the transformation of the received sensor position and orientation into the world coordinate system (for details see [SES99]). The Flock-of-Birds unit is tracking three receivers, providing information about their position and orientation in the space. One receiver is attached to the users head, the other two are attached to the transparent prop and the virtual pen. In this way, the system knows where the pip and the pen are and enables us to project various virtual tools on the pip. The latter are now manipulated with the virtual pen.

Our implementation is based on the Studierstube framework [SFGS96]. This is an object-oriented library extending the standard Open Inventor functionality, allowing for transparent processing of tracker events. These are propagated through the Open Inventor scene-graph and can be used to define virtual 3D interface elements like buttons, sliders, etc.

Moreover, the Studierstube provides many useful additional classes, which were applied for our implementation. For instance, every time we talk about the *second world*, we mean a SEAM-like window, in which the current scene preceded by an appropriate transformation node is rendered. A SEAM is defined by Schmalstieg and Schaufler [SS99] as a “door into another world” and stands for a *Spatially Extended Anchor Mechanism*. Thus, the *second world* is the world, the user is viewing, while not being in it. Applying this metaphor, the concepts described in this work are implemented without using any special purpose hardware or additional software.

## 4 Through-The-Lens Techniques

Beside the two-hand nature, the common feature of the proposed tools is that all of them make use of the *through-the-lens* display technique. Conceptually, this is similar to the *magic lenses* introduced by Bier et al. [BSP<sup>+</sup>93] and extended for the 3D case by Viega et al. [VCWP96]. Schmalstieg et al. [SES99] further improved this tools in two ways. First, by implementing a real 3D tool, which allows for the user to gain an insight into the 3D world through a sort of a window. Second, by allowing two-hand interaction of objects seen through the lens. Unfortunately, interaction is here limited to displaying context sensitive information on the panel and selecting objects seen through the panel with a “lasso tool”. Hence, no manipulation of objects in the second world, or of the world itself is possible. Even when a “snapshot” of an explored scene is made, only the *current* view can be frozen. Furthermore, no manipulation of objects in this copy of the scene is supported.

The contribution we make in this paper, is a significant extension of Schmalstieg’s SEAM-concept for travelling, distant object manipulation, and navigation as will be described in the next sections. May be the most important advantage of our technique is that the environment surrounding the user remains unchanged. Thus, no disorientation can be caused at all. Furthermore, the through-the-lens techniques can be even extended and applied for remote viewing and freezing views, and as a magic lens.

## 5 Through-The-Lens Remote Manipulation

One of the most important issues considering the illusion of being surrounded by a real-feeling virtual world is the ability to manipulate objects in it. Unlike in the real world, in which one can only interact with objects in the hand’s reach, a virtual environment can provide various techniques for manipulating distant objects.

The approaches described in Section 2.3 proved to work well, however, they still have various drawbacks. In Table 1, we have briefly compared them. The aim of our development was to provide an intuitive technique, lacking the above limitations: the *through-the-lens manipulation*. In order to manipulate a remote object with this technique, the user first has to locate the object in the space. In case the target object is in user’s sight, the transparent pip can be used to display a magnified (not a copy but a) reference of the scene, as shown in Figure 2. With the virtual pen, which is used as a grabbing tool in this case, the scene seen through the pip is grabbed and adjusted such that the target object is in hand’s reach. This task can also be accomplished using a scalable WIM-like approach (see Section 7). Once the scene seen through the pip is adjusted, the tool in the dominant hand can be set to the one we want to manipulate the object with. Figure 3 shows a sequence of snapshots visualizing this process.

As stated above, the main advantage here is, that the world surrounding the user remains unchanged. The user can manipulate the target object, without travelling to it, while enabling him/her to perform very precise manipulations as if he/she is standing

Technique	Drawbacks
<i>scaled-world grab</i> [MBS97]	<ul style="list-style-type: none"> <li>– the user has to keep the grabbing button pressed during the manipulation;</li> <li>– the automatic scaling may confuse the user;</li> </ul>
<i>go-go-technique</i> [PBWI96]	<ul style="list-style-type: none"> <li>– difficult grabbing of objects at great distance;</li> <li>– may require adaptive scaling functions depending on the virtual world and user position in it;</li> </ul>
<i>image-plane</i> [PFC <sup>+</sup> 97]	<ul style="list-style-type: none"> <li>– works only if the physical hand or a finger-tracked detailed virtual counterpart is visible in the virtual world;</li> <li>– difficult to apply in stereo environments;</li> </ul>
<i>WIM-interaction</i> [SCP95]	<ul style="list-style-type: none"> <li>– fine manipulations are difficult to perform;</li> <li>– in miniaturized large worlds details may disappear.</li> </ul>

Table 1: Comparison of interaction techniques.

just in front of it. The *through-the-lens* object manipulation is a very powerful technique, which can be even combined with well-known approaches like the go-go-technique, the image-plane manipulation, and the scaled-world grab. When the object in the second world is brought in a reach convenient for direct manipulation with one of these techniques, the *through-the-lens* manipulation can be easily applied. Furthermore, since the second world can be arbitrarily adjusted, this technique allows for an extraordinary fine positioning and manipulation. Our approach separates in a simple way the grabbing and the manipulation tasks, as was proposed by Bowmann and Hodges [BH97].

Unfortunately, since the pip is used to project the second world, no interaction tools can be mapped on it. We solve this problem by using the snapshot concept described in [SES99]. With its help, one can detach the SEAM window with the second world from the pip and position it in the space. Afterwards, the pip and all available tools on it can be applied for object manipulation in this frozen window. The difference between the original snapshot tool and the one proposed in this work is that we enable the user to manipulate the frozen scene.

As introduced above, in our implementation the second world is a reference of the surrounding world, preceded by the appropriate transformation node in the scene-graph. Thus, the position of the current tool is easily mapped back into the primary world, where the objects are manipulated. For avoiding equivocal manipulation, the grabbing of an object is only allowed if the pen is within the SEAM window displaying the second world.

## 6 Through-The-Lens Travelling Tools

Virtual worlds are often too large to be viewed from one virtual camera location. This introduces the problem of travelling through such environments. Many VR-applications nowadays provide a motion paradigm, enabling the user to explore the virtual space. The most popular ones are the “flying” and the “walking” concepts, giving the user the freedom of movement. Unfortunately, users who have this freedom often become lost, or disoriented, or miss important features of the environment.

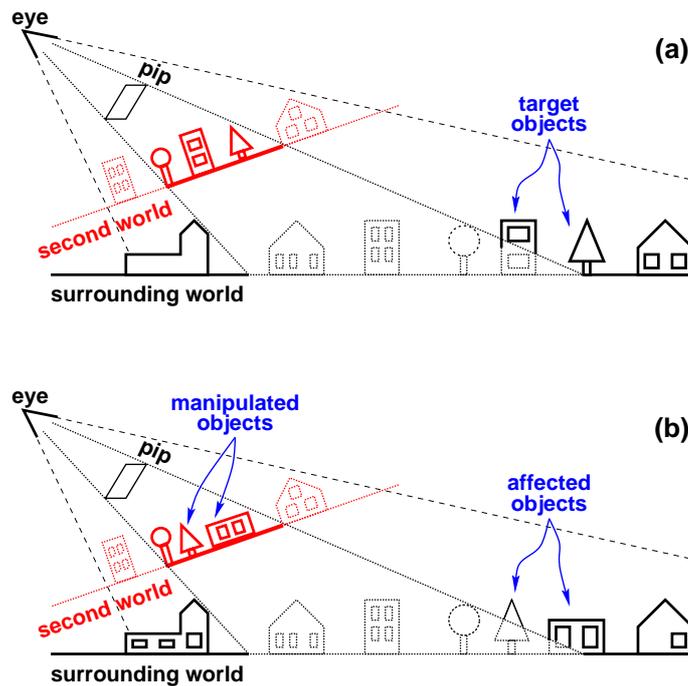


Figure 2: Through-the-lens manipulation. In (a), the two superimposed worlds are shown. The objects drawn with dotted lines are invisible for the user. Manipulations on objects in the second world seen through the pip, appear as manipulations of the corresponding objects in the surrounding world (b).

### 6.1 Through-The-Lens Scene-In-Hand Motion

The *scene-in-hand* metaphor originally introduced by Ware and Osborne [WO90] is widely used in desktop applications and provides a very useful tool for scene manipulation. Nevertheless, sometimes it is difficult to determine the current position when virtual worlds are explored. Furthermore, when implemented in a virtual environment, such a metaphor can be rather confusing and unintuitive, or even cause fatigue and perception illness. This is mainly due to the fact, that when the world is grabbed and moved, the user has no fixed point to look at.

In order to make the *scene-in-hand* metaphor applicable in VR-applications, we propose an extension of the SEAM-concept [SS99]. Instead of sewing together worlds which are fixed to each other, we enable the user to manipulate the scene seen through the transparent panel. In this way, the world surrounding the user remains unchanged and the problems addressed above are solved.

Initially, when the *scene-in-hand* tool is activated, the primary world and the second world are aligned as shown in Figure 4 (a). Thus, there is no difference between the content of the panel and the scene occluded by the panel. Now the user is free to grab the scene seen through the pip and manipulate it (see Figure 4 (b)-(c)). In order to provide a sufficient space for manipulation of the second world, it can be grabbed at any position and not only within the part of it, projected through the pip. Furthermore, the pip can be used as a magic lens. Because the second world is not attached to the pip, moving the pip allows to take a look at different areas in the second world (see Figure 4 (d)-(e)).

Once the user adjusted the second world as desired, he/she can get “beamed” there

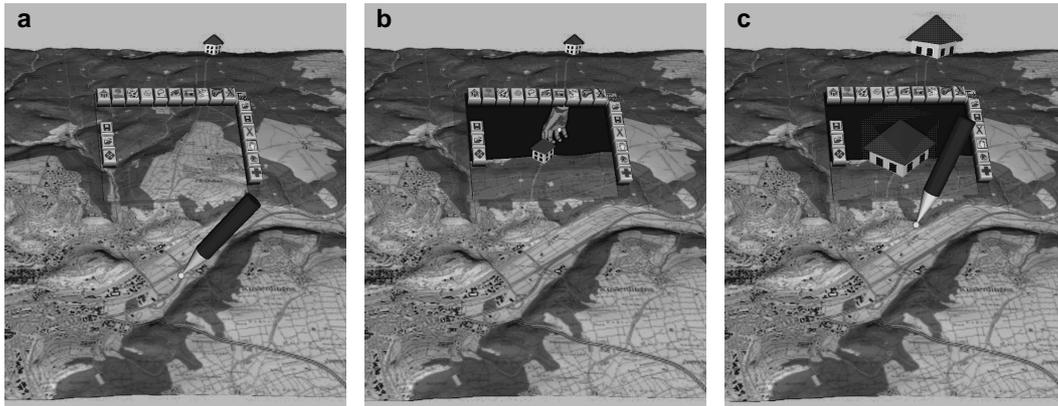


Figure 3: Manipulating a remote object: (a) shows a reference of the virtual world, aligned with the original one; (b) shows the through-the-lens grab and drag-tool, used to bring the target object in hand's reach; (c) manipulating the object in the scene seen through the pip affects the original object.

through moving the panel towards his/her face. As soon as the image of the second world is large enough to cover the whole screen, the second world becomes current (similar to Figure 4 (e)).

This concept is powerful enough to enable reaching any arbitrary location in the explored environment. The only disadvantage is that, even though one can travel controlled through the virtual space, it may be difficult for an user to determine his/her current location with respect to the entire world. The lack of such global orientation is circumvented with the navigation tool discussed in Section 7.

## 6.2 Through-The-Lens (local) Virtual Camera Motion

The motion of the virtual camera is a metaphor suitable for viewing the virtual world from various perspectives. Although, it is conceptually possible to implement a technique for travelling the complete virtual world with this metaphor, it is a rather circumstantial task. The problems arising with this approach are pointed out by Ware and Osborne in [WO90].

Instead of allowing to position the virtual camera arbitrary in the scene, we propose another concept: The virtual camera is moved only in the hand's reach. This provides the following advantages:

- the camera sees always a part of the scene, which is close to the current user position;
- the risk of getting lost in the scene is reduced;
- the user is enabled to zoom in/out the view from a particular camera position.

Since it has been pointed out [WO90], that the *eyeball-in-hand* concept can be hard to understand and may even destroy the user's mental model of the scene, we provide a preview of what the camera sees. As soon as this tool is activated, the user can position the virtual pen somewhere in the space. By pressing the button of the pen, the appropriate part of the scene is then displayed on the pip's surface (see Figure 4 (f)). When the virtual camera is adjusted to see the second world as desired, the user can "beam" himself/herself as described above.

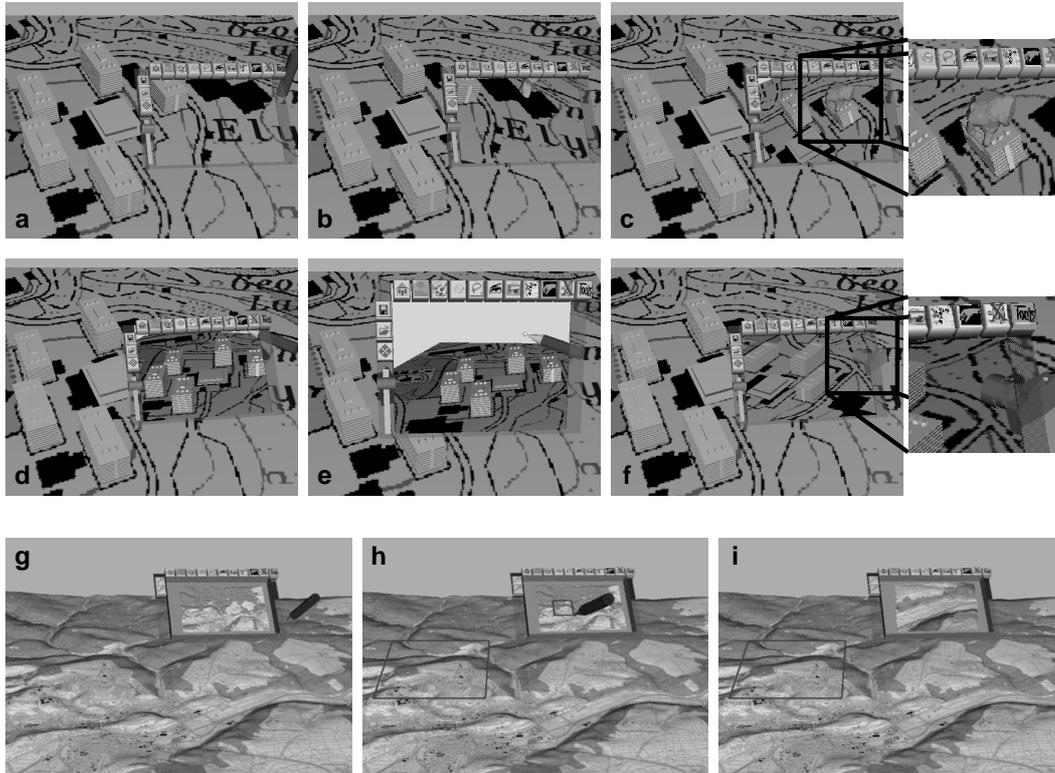


Figure 4: (a)Initially, the surrounding and the second worlds are aligned. In (b) and (c), the user has grabbed the scene seen through the pip and manipulates it. Moving the pip allows to take a look at different areas in the second world in (d) and (e). By pressing the button of the pen, the appropriate part of the scene is then displayed on the pip's surface, as seen with a camera on the pen's tip(f). In (g) and (h), the virtual pen is applied to select a region of interest on the miniaturized map of the world. Afterwards, the user can use the pip for previewing the selected location (i).

Unlike the *scene-in-hand* metaphor, providing a tool for global movement, the virtual camera motion is rather useful for adjusting the viewpoint at a given location. Hence, this tool does not support the “grab-and-move” feature. It turned out that using this option, the participants often lose orientation, after performing several grab-and-move operations. Although, the grab-and-move feature would allow us to extend the operation radius of the virtual camera motion tool and to travel to places in the second world, which are far away from the current virtual camera position, we did not implement it in our system. If the user desires to move further away than this tool allows, the more intuitive and easy to use *scene-in-hand* metaphor has to be used.

The described motion-techniques proved to be useful and easy to use in their current implementation and to complete each other. The *scene-in-hand* metaphor is more appropriate for travelling to far destinations, while the *eyeball-in-hand* metaphor is more suitable for adjusting the viewpoint at the current location. In addition, the proposed motion concepts can be even combined with the go-go-technique, the image plane technique, and the scale-world grab technique in order to provide even more convenient travelling tools.

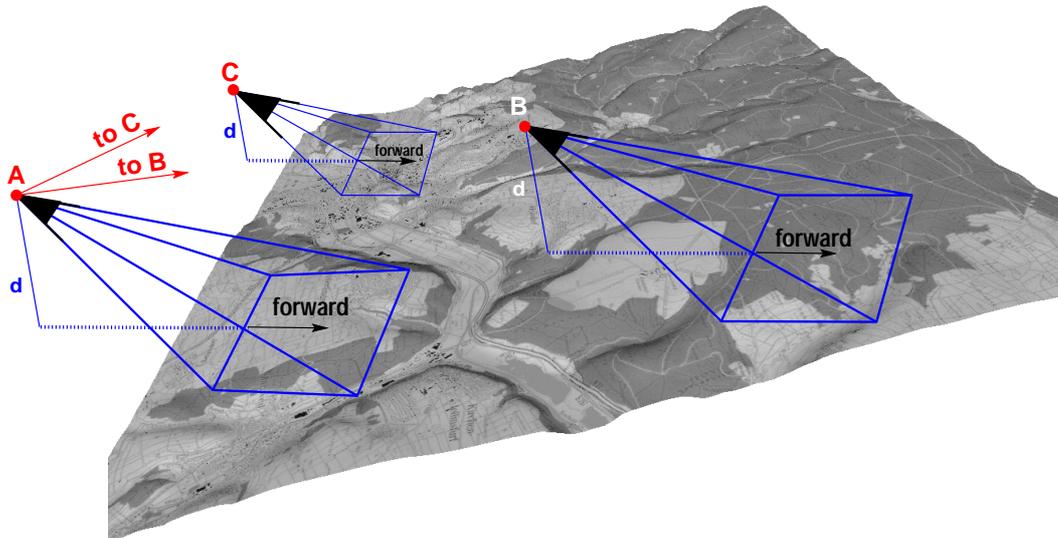


Figure 5: If the size of the new ground window is the same as the one currently viewed, the distance between the virtual camera in B is the same as the distance in A. Otherwise, it is appropriately scaled.

## 7 The Navigation Tool

In contrast to travelling tools, a navigation tool should allow the user to gain a view of the entire world. Travelling itself does not assume that the user knows where she/he is, concerning the entire scene. A navigation tool is in general an aid for a well directed travelling.

The navigation tool we describe here, exploits the WIM metaphor introduced by Pausch et al. [PBBW95]. As reported by Pausch, the original WIM has several drawbacks when applied for navigation and travelling. It turned out, that manipulating the viewpoint was confusing to many users. This was mainly due to the fact, that the virtual world surrounding the user moves when the user moves its position in the miniaturized world.

In our implementation, the user does not *travel* from one location to another in terms of motion. He/she can rather apply a controlled “beaming” in order to get at a desired destination. For this, the virtual pen is applied to select a region of interest on the miniaturized map of the world, as shown in Figure 4 (g)-(i). This area is used either to define a new region displayed on the panel in finer resolution, or to define the participants new position. In the first case, a technique similar to the well-known desktop “zoom-in” metaphor is implemented (we call it *zooming*). In the second case, the new position is derived from the clip currently seen by the user and the current distance between the virtual camera and the ground, as shown in Figure 5 (we call this *tele-moving*). The size of the new region selected on the pip defines the visible scene at the new location. The distance  $d$  shown in Figure 5 is scaled appropriately to achieve the designed zoom factor. Note that the forward direction is always parallel to the initial forward direction. Sibert and Darken [SD96] have shown that this is an important issue, considering the user’s orientation in the virtual world as a whole.

On the other hand, it has been often reported in the literature, that an automatic “beaming” from one location to another may cause disorientation. Therefore, when the user is tele-moving, we first offer a preview of the new location selected on the map (see

Figure 4 (i)). This prevents sequences of tele-moving actions immediately followed by an undo-action, which is typical for the case when the result does not match the expectations of the user. If this is not the case, say, if the new location is the targeted location, the pip can be used to immerse the world seen through it, as this is done with the motion tools discussed above. Finally, the viewing angle can be fine-tuned with the *eyeball-in-hand* approach, if the desired view direction is not parallel to the initial view direction.

## 8 Usability

The tools proposed above are implemented and integrated in an terrain visualization and exploration application. Although, we have not performed intensive usability studies yet, the evaluation of preliminary tests with 10 users (graduate and undergraduate students) have shown, that the proposed tools are very intuitive to use even for users with limited or no VR experience at all.

For the evaluation, we explained the participants the functionality of the tools, and made a short demonstration. Afterwards, they were asked to accomplish the following task: They had to manipulate the world seen through the scene such that a particular object is viewed, which is invisible from the default user position. Then, they had to rotate the object about its  $y$ -axis.

After evaluating the results, we found out that most of the users were familiar with the tools within couple of minutes. Moreover, none of them reported disorientation or confusion while using the proposed tools. Asked about the usability, most of the participants stated, that it was rather easy to apply the tools for accomplishing the given task.

## 9 Discussion

In this work, we present a set of *through-the-lens* tools. A similar technique based on transparent props, the through-the-plane technique, is introduced by Schmalstieg et al. [SES99]. Unlike Schmalstieg, who describes an object selection tool and a tool for superimposing context sensitive information, we present a set of tools, including a tool for remote manipulation, two travelling tools, and a navigation tool. Our work is more related to Schmalstieg's "snapshot"-tool. However, this approach is limited to *viewing* and *freezing* a view of the current scene. No further interaction is possible with this tool. In contrast to Schmalstieg, we implement the interaction through the transparent prop and apply it for manipulation, navigation, and traveling.

Our remote manipulation tool exploits the more general SEAM-mechanism introduced by Schmalstieg and Schaufler [SS99]. In our context a SEAM-like window is applied for manipulating a copy (or a reference) of the scene, currently explored by the user. Unlike the original SEAM utilization, which is applied for sewing two *fixed* worlds together, in our system only the world the user is in, is fixed. The *second world* can be arbitrarily manipulated, thus, enabling him/her to precisely work with distant objects without having to travel to them. In contrast to the *scaled-world grab* technique described by Mine [MBS97], with the proposed manipulation tool no automatic scale-down of the world is needed. The problem of the *scaled-world grab* method is that it can be confusing for the user when the system automatically scales up and down the world around him/her. This may distort the mental object or scene model in terms of size and distance to the manipulated target. Furthermore, it can be hard to manipulate the object, since when released, the world is scaled up back.

The proposed travelling tools are a significant improvement of the original *scene-in-hand* and *eyeball-in-hand* metaphors introduced by Ware and Osborne [WO90]. The

main weakness of the *eyeball-in-hand*-technique is the user's disorientation when the viewpoint (virtual camera) is manipulated. This holds also for Ware and Osborne's *scene-in-hand*-manipulation. In order to circumvent this problem, we extended the original SEAM functionality and allowed the user to manipulate a copy of the virtual camera, while displaying the result not directly, but through a SEAM mapped on the personal interaction panel. Thus, allowing a precise camera adjustment and observation of the result *before* setting the user's view to the new virtual camera. The *scene-in-hand*-technique we extended in a similar way.

Their only drawback is the doubling of the rendered data. Each time the second world is manipulated, we use intern a reference to the original data, preceded by the appropriate transformation in the scene graph. Although, in this way the data is not doubled in the memory, the complete geometry passes the rendering pipeline an additional time. In our setup, this was not a problem, however, we can imagine that large scenes can significantly slow down the rendering performance on slower machines. In order to circumvent this obstacle, we are currently working on image-based approaches which will replace the geometry rendering and make the time requirements independent on the scene's complexity.

Finally, the navigation tool is an extension and improvement of the WIM-technique [PBBW95]. In our implementation we paid special attention to the application and usability in large virtual environments. Therefore, we initially map the complete virtual world on the personal interaction panel of the user, aligning the user's forward direction with the up-direction of the scaled down virtual world. As shown by Sibert and Darken [SD96], this is important to ease the user's orientation. Afterwards, the user can select a region of interest directly on the scaled down world, defining the scaling of the aimed view volume. This action is not immediately followed by a 'beaming there', but a preview of the selected area is possible through a SEAM mapped on the personal interaction panel (see above). Additionally, a fine adjustment of the new position and orientation is possible during the preview phase. First when the user has finished the current adjustment of the virtual camera and view area, he/she can activate the 'beaming'. Hence, a precise travelling through the virtual world is possible without causing loss of orientation. Furthermore, an additional feature of the navigation tool is, that if desired, the map is not a static copy of the current world, but only a reference of it. This implies, that all changes of the virtual world, e.g. object manipulations, newly created objects, and textures, are displayed on the scaled down WIM.

## 10 Future Work

A hot topic of our current research in this area is the utilization of image-based rendering techniques for the proposed tools. This would in turn reduce the rendering time for the doubled geometry data in the current implementation. Furthermore, image based rendering techniques will make the rendering time for the second world independent on the scene complexity.

Another research direction will be to perform detailed usability studies with the proposed techniques. This will help us to discover eventual weaknesses of the latter and thus, to further improve them. We also intent to combine the proposed through-the-lens concept with some of the related approaches discussed above. This will impart the presented tools additional power and extend the range of their application in terms of utilization purpose and working scope.

## 11 Conclusions

In this paper, we presented a set of novel through-the-lens techniques for remote object manipulation, motion, and navigation in virtual environments. They exploit the SEAM-metaphor described in the literature, while providing a powerful toolset for interaction. The main features of the proposed tools are:

- the supported two-hand interaction;
- the suitability for combining them with other techniques described in the literature (like go-go, scale-world grab, and image plane approaches);
- the provided easy to understand *second world*-concept offering a kind of a live 3D preview;
- and the utilization of well-known desktop techniques like the map zooming.

In particular, we described a navigation tool for travelling within virtual environments, a remote manipulation tool for distant object adjustment, and two motion metaphors. The latter extend the *eyeball-in-hand* and the *scene-in-hand* techniques, while significantly improving their usability. Furthermore, the proposed toolset supports another feature of great importance: the suitability for integration in immersive virtual environments based on back-screen projection like the CAVE and tabletop display systems (using transparent props), as well as in VR-setups utilizing head mounted displays.

In addition, we discussed the functionality and briefly introduced our hardware setup and some details about the software implementation of the proposed toolset. Finally, we reported on some preliminary usability tests, which have shown that the through-the-lens tools offer a promising extension of the interaction techniques currently utilized in virtual reality systems.

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