Walk-up VR™: Virtual Reality beyond Projection Screens

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Introduction

The advent of Virtual Reality (VR) technologies promised a revolution of processes in the workplace and *of* the workplace itself. Despite the envisioned opportunities, only research labs and major manufacturers in the automotive and aerospace industry frequently employ VR technologies today, and then only in highly specialized applications or phases of the working process.

One main reason for the detached existence of VR techniques is the lack of easy-to-use, unencumbered interfaces, and robust and non-obtrusive interaction devices. Even while communications technologies have enabled a plethora of internetworked VR applications, such as DIS, MASSIVE, DIVE, etc., these are all essentially distributed yet isolated islands of technology - suffering from a scarcity of well-developed, natural, interactive user interfaces. This difficulty is further exacerbated by the absence of a viable integration of the familiar desktop user-interface and evolving VR paradigms.

Today, VR research and development efforts are often limited to the continual innovation of interaction styles and metaphors for Virtual Environments (VEs). New tools and interaction devices are coming forward, aiming at ever increasing the immersive experience of the users, rather then supporting seamless integration with real work scenarios. Even though users may soon be able to perceive smells within VEs, real, task-oriented interaction within these environments will continue to lag behind.

Taken together, the combination of these efforts can result in new user interfaces that reduce the cumbersome barriers prevalent in VEs today, finally unleashing the latent impact of this technology in everyday life. To realize this vision, an interdisciplinary and applied approach is needed to integrate VR into the everyday workplace. Mixed-reality display capabilities, useful multi-modal interaction and perceptual, intuitive interfaces are major components of such an application-oriented and human-centered approach, for which we coined the term *Walk-up VR*.

Augmented and Virtual Reality as Contributing Technologies

Augmented Reality (AR) allows the superimposing of computer-generated graphics (i.e. the virtual scene) onto the user's view of the real (physical) world. In contrast to VR, AR techniques allow both virtual and real objects to coexist within the same space. Comparable to VR, the display technology that is employed for AR has its own inherent limitations. The display characteristics of Head Mounted Displays (HMDs) for example, such as resolution and field-of-view, greatly effect the ergonomics of its use. HMDs in general have reduced resolution and focal length capability when compared to large-surface VR –display characteristics that are essential elements of user perception. Optically translucent display systems additionally lack in image brilliance, since contrast and brightness of the displayed graphics is tightly coupled to the lighting conditions of the surrounding real environment. Finally, high performance see-through HMDs available today, which approach the resolution necessary for immersive perception, must sacrifice field of view and are cost prohibitive for widespread use.

Conversely, VR display devices fill a large portion of the user's field of view. While perceptively immersive, filling the user's field of view also isolates him from the surrounding physical environment. It is this isolation of the user from the real world that prevents the prevalent use of VEs in the workplace. Table-like display devices and wall-like projection systems—despite their limited viewing space—seem in this regard more promising since they allow the user to simultaneously perceive the surrounding real world while working with a virtual environment. The "Office of the Future" vision by the University of North Carolina at Chapel Hill (UNC) is a consequent extension of this concept.

The current employment of VR display technology is not readily suitable for mixed-reality (MR) applications. In the case of rear-projection display systems, real-world objects are always located between the observer and the projection plane, thereby occluding the projected graphics and consequently obstructing the virtual environment. Front-projection has the advantage in that physical models can be augmented with projected graphics directly onto the surface of those objects, instead of displaying them in viewer's visual field. This technique, known most commonly as spatially-Augmented Reality (SAR), is still limited insofar as the user obstructs projected imagery when approaching the physical objects. This limits the use of the SAR concept to visualization, making it unsuitable for complex interaction with virtual and augmented real objects.

Project Goals and Approach

The previous discussion highlights the divide between AR and VR, mainly caused by restrictions imposed by the employed display technologies onto the respective applications. Consequently, there is a common tendency to constrain applications to either AR or VR based upon their particular displays. Similarly, the integration of real and virtual work environments in useful applications is a rarity. The *Walk-UP VR* initiative has as its main objective the integration of real and virtual world objects, models and data into useful VE applications for the everyday workplace. In addition, the initiative aims at developing and adapting the interaction technologies and devices required to meet this goal.

In this effort we focus on the extension of semi-immersive display devices such as virtual workbenches, display walls, etc. The confined dimensions of these display types allow the user to manipulate objects at an arm's-length distance, supporting the notion of seamless integration with the habitual workspace. Our work extends the human-centered and portable character of these 'traditional' VR display devices in a number of ways. Visual display extensions have been developed using so-called 'optical combiners', physical props that allow for the fusion of light reflected by real objects and light emitted by virtual ones. Fully integrated AR supports mobility and extends the application range. Tele-collaboration functionality provides features that support common work practices. Cost-efficiency and a task-centered approach to interaction in Virtual Environments are of additional interest. This work is also fostering the application and integration of VR and AR technology in common settings by employing objects of utility used in human-human communication to further the adaptation and development of display and interaction devices.

Designing Perceptive Interaction

While the desktop metaphor is well understood and represents an effective approach to human-computer interaction for document-oriented 2D tasks, transplanting it to 3D reveals inherent limitations. Interfaces that incorporate true 3D input and output technologies (e.g., six degree of freedom (6DOF) sensors and stereoscopic displays) seem more promising, yet using advanced interface devices still does not guarantee a superior user interface. In our work, we are most interested in capturing natural interaction modalities and transforming them into highly intuitive interfaces.

Transparent Tools and Augmented VR

In 1998, we developed a system that uses transparent props for two-handed interaction with a Virtual Table (VT) [1]. The hand-held transparent props are a pen and a pad, related to earlier research in augmented reality interface design called the Personal Interaction Panel (PIP). Our system overlays transparent physical props onto the back-projected display of the VT to achieve a kind of inverse augmented reality, which we call *augmented VR* (patent pending). The VT thereby provides an enhanced workspace with capable multipurpose tools. A key feature is the tactile feedback that the physical props provide, making the tools feel real (cf. Figure 1).

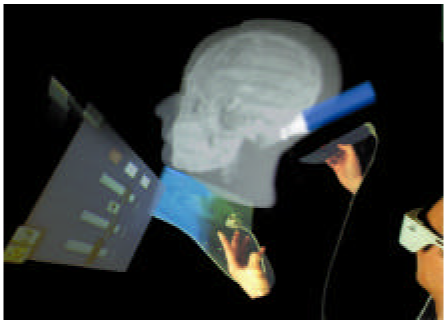

Figure 1: The transparent pen and pad props.

Our system unifies several previously isolated approaches to 3D user-interface design, such as two-handed interaction, the use of multiple coordinate systems (i.e., of the table and the pad), and the use of transparent tools. Specialty features further include windowing and through-the-plane tools, each of which allows the design of distinct forms of interaction.

Since the pad is directly controlled by the user's non-dominant hand it can additionally be used as an active tool. It therefore represents an embedding of 2D in 3D, but its possibilities extend far beyond that by *combining* several individual metaphors:

- *Tool and object palette and Virtual Remote Control*: The pad can carry tools and controls, much like a dialog box works in the desktop world. It can also offer collections of 3D objects to choose from.
- *Window tools*: As the user can see through the pad into the scene, the pad becomes a see-through tool.
- *Through-the-plane tool*: The user can orient the "window" defined by the pad and then manipulate objects as seen through the pad, i.e. manipulate the 2D projections of objects on the pad.

- *Volumetric manipulation tool*: The pad itself can be used for active object manipulation, exploiting the fact that the pad has a spatial extent (unlike the point represented by the pen tip).

These options co-exist in the design space of our user interface and together form a very powerful and general framework for 3D interaction. Because the physical and geometric properties of the pad are of very basic nature, it is possible to use all the metaphors mentioned above for application tasks without confusing the user.

Transflective Tools

Two fundamental problems of semi-immersive rear-projection devices are the limited viewing that is caused by relatively small projection planes, and their inability to combine real objects with displayed virtual ones. This is due to the fact that real objects always occlude the projection planes and consequently the displayed virtual environment, thus prohibiting traditional augmented reality tasks from being supported by such devices. To overcome both problems, we developed the transflective pad –a hand-held half-silvered mirror that, on the one hand, allows a user to interactively increase the limited viewing volume [2] and, on the other hand, enables rear-projection devices to support basic augmented reality tasks [3].

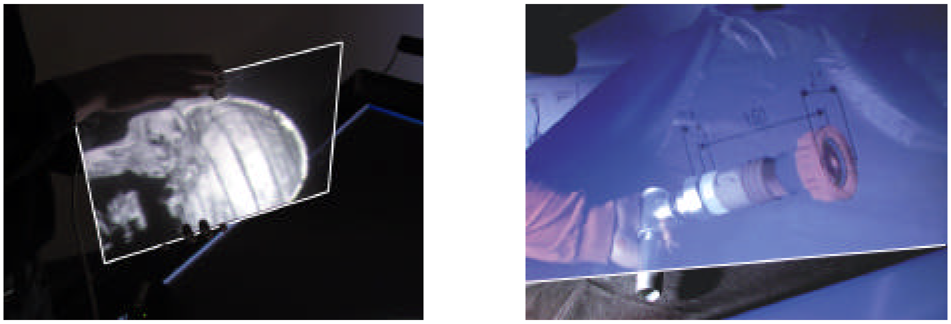

Figure 2: The transflective pad used in an opaque mode (left) to observe CT-based volume data, and in a see-through mode (right) to superimpose a real object.

While holding the tracked transflective pad (patent pending) in such a way that the viewer physically sees the reflection of the projection plane in the mirror, the rendering concept differs slightly from traditional viewpoint-driven stereo-rendering: Instead of using the actual viewpoints of the observer's eye, the corresponding *reflected* viewpoints (with respect to the mirror plane) are employed to project the virtual environment and to render the resulting stereo-images. Since the stereo rendering now depends on the *reflection* of the observer's viewpoints rather than on his *actual* viewpoints, he perceives the virtual environment stereoscopically and perspectively correct – as a reflection – in the mirror. Additionally, all graphical elements that are virtually located on the side of the mirror plane that is adverted from the observer are inversely reflected. This inverse reflection, however, is neutralized by the physical reflection of the mirror. Thus, the observer perceives a non-reflected virtual environment by looking at the mirror and the transflective pad behaves more like a transparent see-through window rather than a mirror – offering to interactively extend viewing beyond the boundaries of the projection planes (cf. figure 2, left) and to take up difficult-to-reach inspection points (e.g. a birds-eye view, etc.)

If the area behind the transflective pad is illuminated, the half-silvered mirror represents an interactive image plane that folds the observer's optical path and optically combines the transmitted image of the surrounding real world with the reflected image of the projected virtual environment, thus creating an AR display (cf. figure 2, right). Note, that the transflective pad is also the first hand-held device that offers stereoscopic see-through functionality.

Projection-Based Mixed Reality

To achieve seamless integration of virtual reality into habitual workplaces, simultaneous and equivalent handling of both the virtual and the real environments must be supported. Working with a combination of virtual and real objects and tools at the same time should be possible without leaving the workplace or alternating between two or more environments. Current AR technology (such as see-through head-mounted displays or video-mixing) is still too cumbersome and its application unfit for our habitual work activities. To overcome this virtual/real-world separation, we are extending the viewing and the interaction range of workbench-like projection-systems into the surrounding real environment. The transflective pad is one implementation of this more general concept that we call "Projection-Based Mixed Reality (MR)". This technique enables rear-projection systems to support basic augmented reality tasks, while maintaining the advantages of projection-based MR technology.

The Extended Virtual Table

As another implementation of the projection-based MR concept, our current efforts focus on developing an Extended Virtual Table (cf. figure 3) as a link between real and virtual workplaces (patent pending).

In contrast to the transflective pad, a large half-silvered mirror is used that is placed at a *constant position* between the Virtual Table and a neighboring real workbench. However, the same rendering techniques are still applicable. Although the mirror represents a physical barrier between the two environments, a variety of new and effective interaction metaphors are supported.

Switching between the immersive virtual environment and the augmented real environment is handled on a gaze-directed basis (i.e. whether the user is looking at the Virtual Table, or through the mirror at the real workbench).

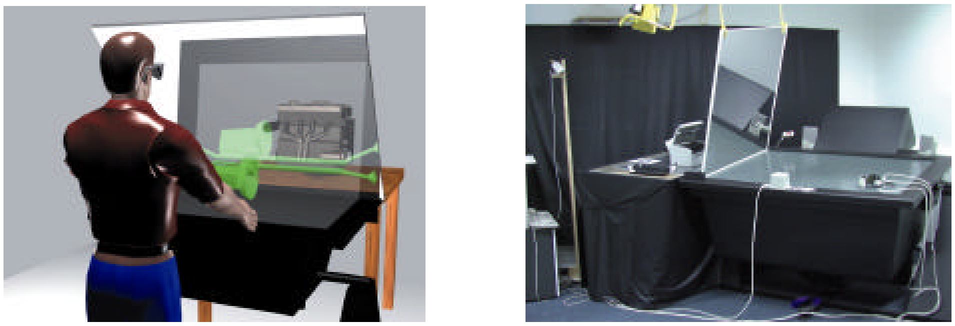

Figure 3: A hybrid assembly scenario (right) with the extended virtual table (left).

The combined (virtual and real) workplace, for instance, allows users to combine virtual mock-ups (VMUs) that exist within the virtual environment and physical mock-ups (PMUs) that are placed on the real workbench. VMUs, for example, can be modeled above the Virtual Table's surface and can then be assembled to their corresponding PMU within the real environment (e.g. for design review purposes). Rather than handling PMUs and VMUs separately during the entire product design process (as it is the case today), these hybrid mock-ups offer an early reference between VMUs and existing PMUs, thus supporting a more efficient and more realistic early design-stage review and possible rework.

Our extended workspace can also be used for remote cooperative tasks and opens new dimensions of telepresence. While looking at the Virtual Table, users can work within the local virtual design space displayed on the table's projection plane. By looking at the mirror (the real workbench is not illuminated), however, one would see the life-size video-stream of their collaborators and their local design spaces that is mixed with graphical elements (displayed on the Virtual Table and reflected by the mirror). Since this scenario is the same for each of the collaborators, it creates the impression of being present in the same environment for all participants. With appropriate rich interaction techniques, viable tasks other than just collaborative design review are supported by taking direct actions within the shared design space. Collaborators can simply exchange virtual components by picking them up from their local design space and pushing them through the mirror to the opposite environment. The component's information (such as geometry, product data, etc.) would immediately be transmitted over a network.

Virtual Showcases^{TM}

Another example of our projection-based MR concept is the Virtual Showcase^{TM} (patent pending). In the Virtual Showcase^{TM} we introduce a medium that allows users to superimpose any kind of graphical information onto real exhibits, or to display exclusively virtual exhibits. Virtual Showcases^{TM} are built from four transflective surfaces. To achieve an optimal ratio between reflection and transmission, the geometry of Virtual Showcases^{TM} differs slightly from familiar rectangle showcases – for example, they might resemble a frustum of a pyramid (cf. figure 4 –left). Based on such a configuration, we can envision a large variety of different Virtual Showcase^{TM} setups, ranging from small and cost-efficient screen-based devices to large projection-based constructions. In addition, Virtual Showcases^{TM} allow for a number of visual effects by changing the lighting conditions of their interior and the brightness of the displayed graphics. Real exhibits and virtual information, for instance, can be alternately highlighted or can be simultaneously visible.

On the one hand, real exhibits can be superimposed with virtual supplements by displaying stereoscopic 3D or monoscopic 2D computer graphics that are reflected by the Virtual Showcase^{TM}. If stereoscopic 3D graphics is used, virtual and real objects can be optically combined in such a way that they appear three-dimensionally conjunct to the observers. On the other hand, an empty Virtual Showcase^{TM} can be filled with an exclusively virtual exhibit (cf. figure 4 –right). This allows the display of artifacts that aren't physically located in the museum, and gives users the ability to interactively exchange the artifacts.

In some setups, the projection devices themselves can be used for interaction (e.g. if touch-screens are applied) to display information without interplaying with the Virtual Showcase^{TM}. Virtual Showcases^{TM} also allow a number of observers to see and to interact with different or the same graphical content within the same physical space.

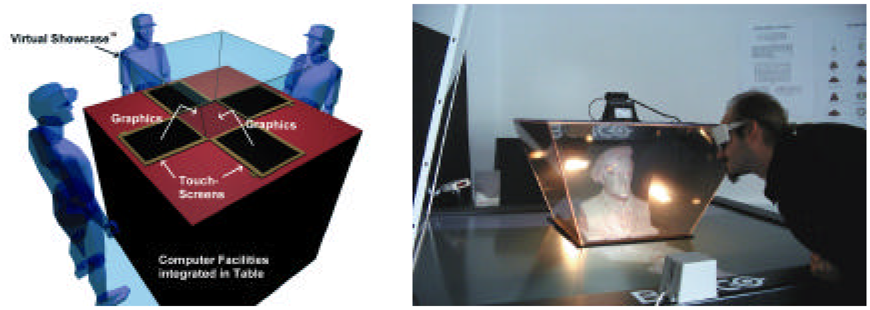

Figure 4: Virtual Showcase$^{\text{TM}}$: The concept (left) and an application exhibiting a 3D scan of a Wagner bust (right).

Challenges and Future Work

Many technological shortcomings are still hampering our vision of Walk-up VR$^{\text{TM}}$. The challenges range from real-time, multi-user capable, auto-stereoscopic display devices and accurate, precise, wireless, line-of-sight-independent and unencumbering tracking technology to the availability of effective and habitual interaction devices. Our work is facing the additional challenges of appropriately dealing with viewing distortions caused by the projection system, refraction by transparent display surfaces, and the bending of the reflection and refraction planes we use. Such viewing distortions must be accurately compensated for in order to effectively improve and extend our concept of projection-based MR. From an interaction point of view, the direct as well as indirect interaction using newly developed or extended interaction tools and devices are of major interest. Another great challenge for our vision of Walk-up VR$^{\text{TM}}$ is the registration of everyday (habitual) props with the projection-based MR system to allow for their seamless integration with the user interface design space of the virtual environment.

Currently, we are planning and implementing a general SceneGraph-based rendering architecture that extends the projection-based MR concept towards multi-sided projection environments, in combination with multi-faced transflective objects to allow for simultaneous interaction by multiple viewers.

While a Virtual Table or similar device is very well suited for 3D interaction, it is essentially a single-user device. Multiple users can wear shutter glasses and experience the same three-dimensional representation of virtual objects, but will be affected by space limitations around the table and perspective distortions. To overcome these restrictions, it is desirable to extend such a virtual environment beyond a single projection surface. Current research and development in the field suggests several possible configurations to achieve this:

- Multiple projection surfaces can be used, giving each user his or her own workspace (e.g., CAVE$^{\text{TM}}$, Stanford's L-Workbench, and UNC's Protein Interactive Theater).
- Time-interleaved displays such as Stanford/Fakespace's two-user Responsive Workbench present the stereoscopic images to (currently a maximum of two) different users during different phases of the refresh-rate cycle. These displays are therefore strongly dependent on the update rate that can be achieved since the refresh rate must not fall below 30 Hz per eye (i.e. 60 Hz per user) in order to avoid flicker.
- Rather than using projection surfaces, head-mounted displays (HMDs) can be used to experience the three-dimensional scene. If see-through HMDs are used, a conference using *collaborative augmented reality* can be established, which allows a shared experience of virtual objects, while at the same time retaining the benefits of face-to-face conversation (e.g., the *Studierstube* framework at Vienna University of Technology).
- A mixture of display devices can be used, comprising a *hybrid user interface*. For example, one user may use a Virtual Table, another one a conventional computer screen, while others may be using HMDs.
- Finally, *remote collaboration* allows users who are not co-located to experience a shared space. Face-to-face collaboration is no longer possible, but – as compensation – geographic distances between users can be overcome.

References

1. D. Schmalstieg, L.M. Encarnação, and Zs. Szalavári. *Using Transparent Props for Interaction with the Virtual Table.* In Proc. of the 1999 ACM Symposium on Interactive 3D Graphics (I3DG'99), April 26-28, 1999, Atlanta, GA, USA, pp. 147-153. ACM press, 1999.
2. O. Bimber, L.M. Encarnação , and D. Schmalstieg. *Real Mirrors Reflecting Virtual Worlds.* In Proc. of the 2000 IEEE-VR Conference, March 2000, New Brunswick, NJ, pp. 21-28. IEEE Computer Society, 2000.
3. O. Bimber, L.M. Encarnação, and D. Schmalstieg. *Augmented Reality with Back-Projection Systems using Transflective Surfaces.* In Proc. of the 2000 Eurographics Conference, August 20-25, 2000, Interlaken, Switzerland. Blackwell Publishers, 2000.