



The MagicBook: a transitional AR interface

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Abstract

The MagicBook is a Mixed Reality interface that uses a real book to seamlessly transport users between Reality and Virtuality. A vision-based tracking method is used to overlay virtual models on real book pages, creating an Augmented Reality (AR) scene. When users see an AR scene they are interested in they can fly inside it and experience it as an immersive Virtual Reality (VR). The interface also supports multi-scale collaboration, allowing multiple users to experience the same virtual environment either from an egocentric or an exocentric perspective. In this paper we describe the MagicBook prototype, potential applications and user feedback. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

As computers become smaller and more powerful, researchers have been trying to produce a technology transparency that significantly enhances human–computer interaction. The goal is to make interacting with a computer as easy as interacting with the real world. There are several approaches for achieving this. In the field of Tangible User Interfaces [1], real world objects are used as interface widgets and the computer disappears into the physical workspace. In an immersive Virtual Reality (VR) environment, the real world is replaced entirely by computer-generated imagery and the user is enveloped in the virtual space. Finally, Augmented Reality (AR) blends elements of the real and virtual by superimposing virtual images on the real world.

As Milgram points out [2], these types of computer interfaces can be placed along a continuum according to how much of the users environment is computer

generated (Fig. 1). On this Reality–Virtuality line, Tangible User Interfaces lie far to the left, while immersive virtual environments are placed at the right-most extreme. In between are Augmented Reality interfaces, where virtual imagery is added to the real world, and Augmented Virtuality interfaces, where the real world content is brought into immersive virtual scenes. Most current user interfaces can be placed at specific points along this line.

In addition to single user applications, many computer interfaces have been developed that explore collaboration in a purely physical setting, in an AR setting, or in an immersive virtual world. For example, Wellner's DigitalDesk [3] and Brave's work on the InTouch and PSyBench [4] interfaces show how physical objects can enhance both face-to-face and remote collaboration. In this case, the real objects provide a common semantic representation as well as a tangible interface for the digital information space. Work on the DIVE project [5], GreenSpace [6] and other fully immersive multi-participant virtual environments have shown that collaborative work is also intuitive in completely virtual surroundings. Users can freely move through the space, setting their own viewpoints and spatial relationships, while gesture, voice and graphical information can all be

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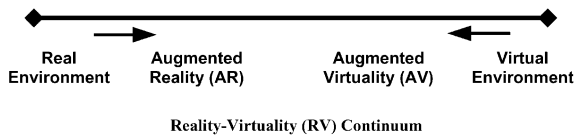


Fig. 1. Milgram's Reality-Virtuality continuum.

communicated seamlessly between the participants. Finally, collaborative AR projects such as Studierstube [7] and AR² Hockey [8] allow multiple users to work in both the real and virtual world, simultaneously, facilitating computer supported collaborative work (CSCW) in a seamless manner. AR interfaces are very conducive to real world collaboration because the groupware support can be kept simple and left mostly to social protocols.

Benford [9] classifies these collaborative interfaces along two dimensions of Artificiality and Transportation. Transportation is the degree to which users leave their local space and enter into a remote space, and Artificiality the degree to which a space is synthetic or removed from the physical world. Fig. 2 shows the classification of typical collaborative interfaces. As can be seen, Milgram's continuum can be viewed as the equivalent of Benford's Artificiality dimension. Again, most collaborative interfaces exist at a discrete location in this two-dimensional taxonomy.

However, human activity often cannot be broken into discrete components and for many tasks users may prefer to be able to easily switch between interfaces types, or co-located and remote collaboration. This is particularly true when viewing and interacting with three-dimensional (3D) graphical content. For example, even when using a traditional desktop modeling interface users will turn aside from the computer screen to sketch with pencil and paper. As Kiyokawa et al. point out, AR and immersive VR are complimentary and the type of interface should be chosen according to the nature of the task [10,11]. For example, if collaborators

want to experience a virtual environment from different viewpoints or scale then immersive VR may be the best choice. However, if the collaborators want to have a face-to-face discussion while viewing the virtual image an AR interface may be best. Similarly, in a collaborative session users may often want to switch between talking with their remote collaborators, and the people sitting next to them in the same location. Given that different degrees of immersion may be useful for different tasks and types of collaboration; an important question is how to support seamless transitions between the classification spaces.

Several researchers have conducted work in this area. Kiyokawa et al. [11,12] explored the seamless transition between an AR and immersive VR experience. They developed a two-person shared AR interface for face-to-face computer-aided design, but users could also change their body scale and experience the virtual world immersively. Once users began to decrease or increase their body size the interface would transition them into an immersive environment. This ability of users to fly into miniature virtual worlds and experience them immersively was previously explored by Stoakley et al. in the Worlds in Miniature (WIM) work [13]. They used miniature worlds to help users navigate and interact with immersive virtual environments at full-scale. The WIM interface explored the use of multiple perspectives in a single user VR interface, while the CALVIN work of Leigh et al. [14] introduced multiple perspectives in a collaborative VR environment. In CALVIN, users could either be *Mortals* or *Deities* and view the VR world from either an egocentric or exocentric view, respectively. CALVIN supported multi-scale collaborative between participants so that deities would appear like giants to mortals and vice versa.

The MagicBook interface builds on this earlier work and explores how a physical object can be used to smoothly transport users between Reality and Virtuality, or between co-located and remote collaboration. It supports transitions along the entire Reality-Virtuality continuum, not just within the medium of immersive VR, and so cannot be placed as a discrete point on a taxonomy scale. In the remainder of this article we describe the MagicBook interface in more detail, the technology involved, initial user reaction and potential applications of the technology.

2. The MagicBook experience

The MagicBook experience uses normal books as the main interface object. People can turn the pages of these books, look at the pictures, and read the text without any additional technology (Fig. 3a). However, if they look at the book through an AR display they see 3D virtual models appearing out of the pages (Fig. 3b). The

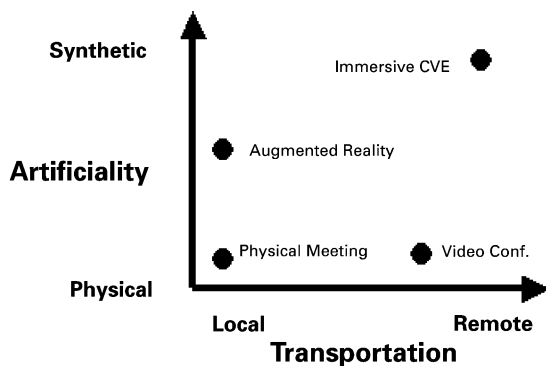


Fig. 2. Benford's classification of collaborative interfaces.

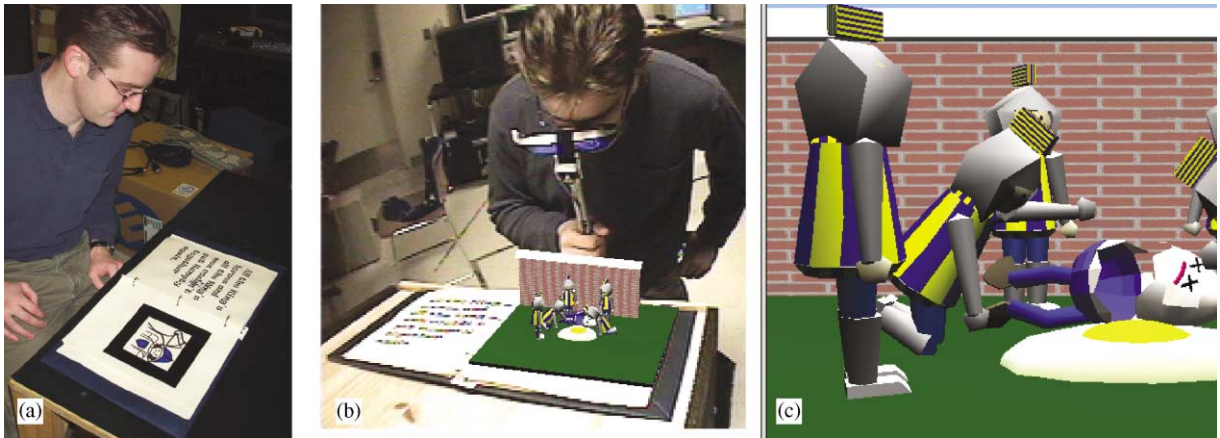


Fig. 3. Using the MagicBook to move between Reality and Virtual Reality.

models appear attached to the real page so users can see the AR scene from any perspective simply by moving themselves or the book. The models can be of any size and are also animated, so the AR view is an enhanced version of a traditional 3D “pop-up” book. Users can change the virtual models simply by turning the book pages and when they see a scene they particularly like, they can fly into the page and experience it as an immersive virtual environment (Fig. 3c). In the VR view they are free to move about the scene at will and interact with the characters in the story. Thus, users can experience the full Reality–Virtuality continuum.

As can be seen, the MagicBook interface has a number of important features:

1. The MagicBook removes the discontinuity that has traditionally existed between the real and virtual worlds. VR is a very intuitive environment for viewing and interacting with computer graphics content, but in a head mounted display (HMD) a person is separated from the real world and their usual tools, or collaborators.
2. The MagicBook allows users to view graphical content from both egocentric and exocentric views, so they can select the viewpoint appropriate for the task at hand. For example, an AR viewpoint (exocentric view) may be perfect for viewing and talking about a model, but immersive VR (egocentric view) is better for experiencing the model at different scales or from different viewpoints.
3. The computer has become invisible and the user can interact with graphical content as easily as reading a book. This is because the MagicBook interface metaphors are consistent with the form of the physical objects used. Turning a book page to change virtual scenes is as natural as rotating the page to see

a different side of the virtual models. Holding up the AR display to the face to see an enhanced view is similar to using reading glasses or a magnifying lens. Rather than using a mouse and keyboard based interface, users manipulate virtual models using real physical objects and natural motions. Although the graphical content is not real, it looks and behaves like a real object, increasing ease of use.

2.1. Collaboration with the MagicBook

Physical objects, AR interfaces and immersive VR experiences have different advantages and disadvantages for supporting collaboration. As shown by Benford’s classification, there has been a proliferation of collaborative interfaces, but it has traditionally been difficult to move between the shared spaces they create. For example, users in an immersive virtual environment are separated from the physical world and cannot collaborate with users in the real environment. The MagicBook supports all these types of interfaces and lets the user move smoothly between them depending on the task at hand.

Real objects often serve as the focus for face-to-face collaboration and in a similar way the MagicBook interface can be used by multiple people at once. Several readers can look at the same book and share the story together (Fig. 4a). If these people then pick up their AR displays they will each see the virtual models superimposed over the book pages from their own viewpoint. Since they can see each other and the real world at the same time as the virtual models, they can easily communicate using normal face-to-face communication cues. All the users using the MagicBook interface have their own independent view of the content so any number of people can view and interact with a virtual model as easily as they could with a real object (Fig. 4b).

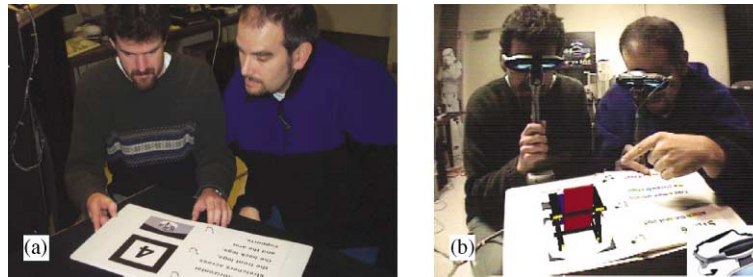


Fig. 4. (a) Collaboration in the real world, (b) Sharing an AR view.

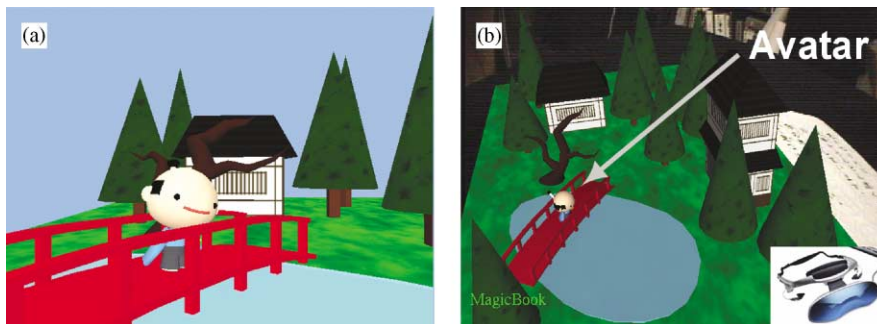


Fig. 5. Collaboration in the MagicBook.

In this way the MagicBook technology moves virtual content from the screen into the real world, preserving the cues used in normal face-to-face conversation, and providing a more intuitive technology for collaboratively viewing 3D virtual content.

Multiple users can also be immersed in the virtual scene where they will see each other represented as virtual characters in the story (Fig. 5a). More interestingly, there may be situations where one or more users are immersed in the virtual world, while others are viewing the content as an AR scene. In this case the AR user will see an exocentric view of a miniature figure of the immersed user, moving as they move themselves about the immersive world (Fig. 5b). Naturally, in the immersive world, users viewing the AR scene appear as large virtual heads looking down from the sky. When users in the real world move, their virtual avatars move accordingly. In this way people are always aware of where the other users of the interface are located and where their attention is focused.

Thus the MagicBook interface supports collaboration on three levels:

- *As a Physical Object:* Similar to using a normal book, multiple users can read together.
- *As an AR Object:* Users with AR displays can see virtual objects appearing on the pages of the book.

- *As an Immersive Virtual Space:* Users can fly into the virtual space together and see each other represented as virtual avatars in the story space.

The interface also supports collaboration on multiple scales. Users can fly inside the virtual scenes (an egocentric view) and see each other as virtual characters. A non-immersed user will also see the immersed users as small virtual characters on the book pages (an exocentric view). This means that a group of collaborators can share both egocentric and exocentric views of the same game or data set, leading to enhanced understanding.

3. The MagicBook interface

The MagicBook interface has three main components; a hand held AR display (HHD), a computer, and one or more physical books. The books look like any normal book and have no embedded technology, while the display is designed to be easily held in one hand and to be as unencumbering as possible (Fig. 6).

Each user has their own hand held display and computer to generate an individual view of the scenes. These computers are networked together for exchanging information about avatar positions and the virtual scene each user is viewing. The HHD is a handle with a Sony

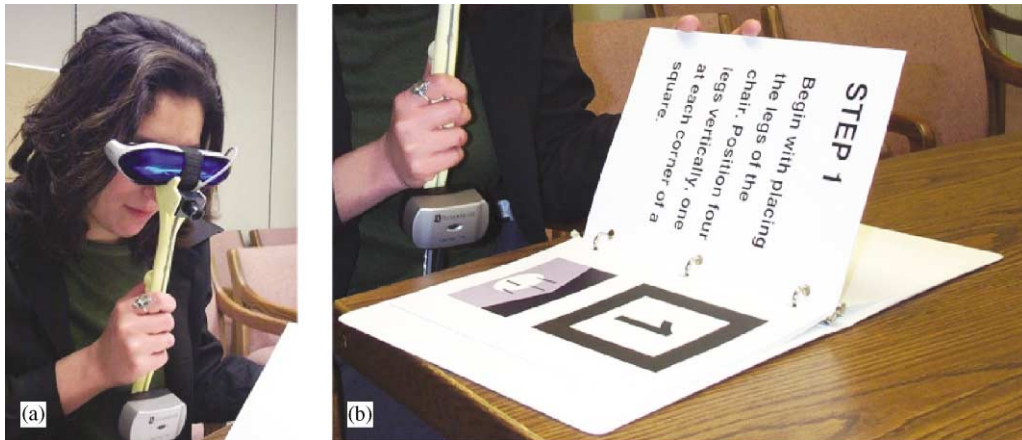


Fig. 6. Components of the MagicBook interface.

Glasstron PLM-A35 display mounted at the top, an InterSense InterTrax [15] inertial tracker at the bottom, a small color video camera on the front, and a switch and pressure pad embedded in the handle. The PLM-A35 is a low cost biocular display with two LCD panels of 260×230 pixel resolution.

The camera output is connected to the computer graphics workstation; computer graphics are overlaid on video of the real world and resultant composite image shown back in the Glasstron display. In this way users experience the real world as a video-mediated reality. One advantage of this is that the video frames that are being seen in the display are exactly the same frames as those drawn on by the graphics software. This means that the registration between the real and virtual objects appears almost perfect because there is no apparent lag in the system. The video of the real world is actually delayed until the system has completed rendering the 3D graphics. On a mid range PC (866 MHz Pentium III) with a virtual scene of less than 10,000 polygons we can maintain a refresh rate of 30 frames per second. This is fast enough that users perceive very little delay in the video of the real world and the virtual objects appear stuck to the real book pages.

Although commercially available hardware was used, the “Opera glass” form factor of the hand held display was deliberately designed to encourage seamless transition between Reality and Virtual Reality. Users can look through the display to see AR and VR content, but can instantaneously return to viewing the real world simply by moving the display from in front of their eyes. The hand held display is far less obtrusive and easy to remove than any head worn display, encouraging people to freely transition along the Reality–Virtuality continuum. It is also easy to share, enabling several people to try a single display unit and see the same content.

The books used in the MagicBook interface are normal books with text and pictures on each page.

Certain pictures have thick black borders surrounding them and are used as tracking marks for a computer vision based head tracking system. When the reader looks at these pictures through the HHD, computer vision techniques are used to precisely calculate the camera position and orientation relative to the tracking mark. The head tracking uses the ARToolKit tracking library, a freely available open-source software package, which we have written for developing vision based AR applications [16]. Fig. 7 summarizes how the ARToolKit tracking library works. Once the users head position is known the workstation generates virtual images that appear precisely registered with the real pages. Our use of 2D markers for AR tracking is similar to the CyberCode work presented by Rekimoto [17] and other vision based tracking systems.

When the users see an AR scene they wish to explore, flicking the switch on the handle will fly them smoothly into the scene, transitioning them into the immersive VR environment. In the VR scene, users can no longer see the real world and so the head tracking is changed from the computer vision module to the InterTrax inertial orientation tracker. The output from the InterTrax inertial compass is used to set the head orientation in the virtual scene. The InterTrax provides three-degrees of freedom orientation information with a high accuracy and very little latency. Readers can look around the scene in any direction and by pushing the pressure pad on the handle they can fly in the direction they are looking. The harder they push the faster they fly. To return to the real world users simply need to flick the switch again. The pressure pad and switch are both connected to a TNG interface box [18] that converts their output to a single RS-232 serial data signal.

The MagicBook application is also a client-server networked application. Each of the user computers are networked together for exchanging information about avatar positions and the virtual scene that each user is

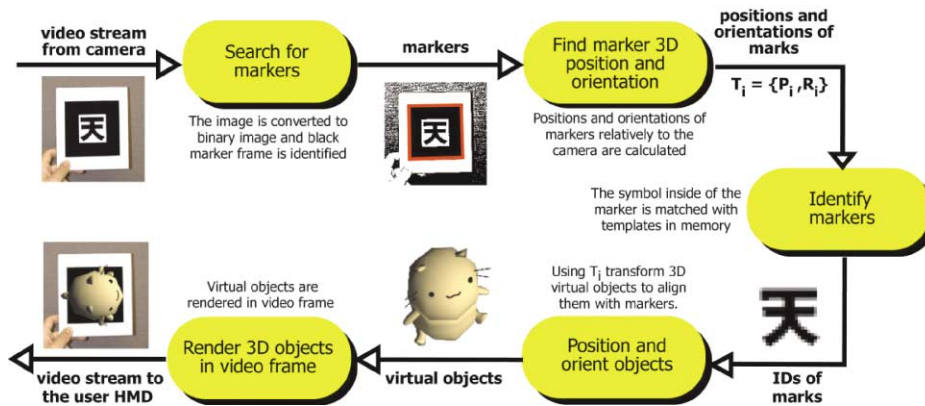


Fig. 7. The ARToolKit tracking process.

viewing. When users are immersed in the virtual environment or are viewing the AR scenes, their position and orientation are broadcast using TCP/IP code to a central server application. The server application then re-broadcasts this information to each of the networked computers and the MagicBook graphical client code. This is used to place virtual avatars of people that are viewing the same scene, so users can collaboratively explore the virtual content. Since each of the client applications contain a complete copy of the graphics code, only a very small amount of position information needs to be exchanged. Thus MagicBook applications can potentially support dozens of users. There is also no need for users to be physically co-located. The virtual avatars can be controlled by users in the same location or remote from each other. So the MagicBook technology supports both face-to-face and remote collaboration.

3.1. MagicBook applications

To encourage exploration in a number of different application areas we have developed the MagicBook as a generic platform that can be used to show almost any VRML content. VRML is a standard file format for 3D computer graphics. We use an open source VRML rendering library called libVRML97 [19] that is based on the OpenGL low-level graphics library. Since VRML is exported by most 3D modeling packages, it is very easy for content developers to build their own MagicBook applications. Once the 3D content has been developed, it is simple to make the physical book pages and the configuration files to load the correct content.

This ease of development has resulted in the production of nearly a dozen books in a variety of application domains. Among others, we have a Japanese children's story that involves the reader in a treasure hunt, a version of the Humpty Dumpty tale, a World War One History book, and a science fiction snowboard experi-

ence that allows the reader to ski Mt. St. Helens. These applications explore new literary ground where the reader can actually become part of the story and where the author must consider issues of interactivity and immersion.

The MagicBook technology has also strong application potential for scientific visualization. We have begun exploring using this technology for viewing geo-spatial models. Fig. 8 shows views of typical oilfield seismic data superimposed over a tracking card. Currently, petroleum companies deploy expensive projection screen based visualization centers around the world. The tracking systems used in the MagicBook interface are completely sourceless and so potentially mobile. In the near future it will be possible to run the MagicBook software from a laptop computer and so support a radically new way of presenting visualization data in a field.

One of the more interesting applications we have developed is an educational textbook designed to teach architects how to build Gerrit Rietveld's famous Red and Blue Chair (Fig. 9). After a brief introduction to Rietveld's philosophy and construction techniques, the readers are treated to a step-by-step instruction guide to building the chair. On each page is a 2D picture of the current stage of the chair construction. When readers look at this page in their hand held displays, they see a 3D model of the partially completed chair popping out of page. On the final page they see a virtual model of the completed chair that they can fly into and see life-sized. Being able to see the chair from any angle during the construction process as well as a life-sized model at the end is a powerful teaching tool.

3.4. User feedback

The MagicBook software was first shown at the Siggraph 2000 conference where over 2500 people tried the books in the course of a week. Siggraph is a

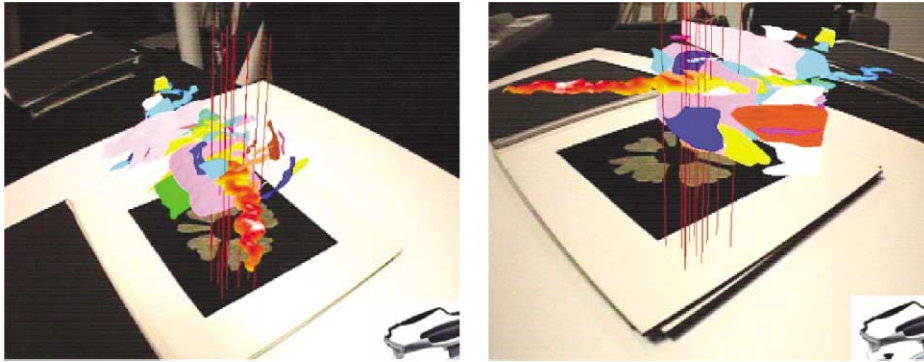


Fig. 8. Seismic data on a tracking marker.

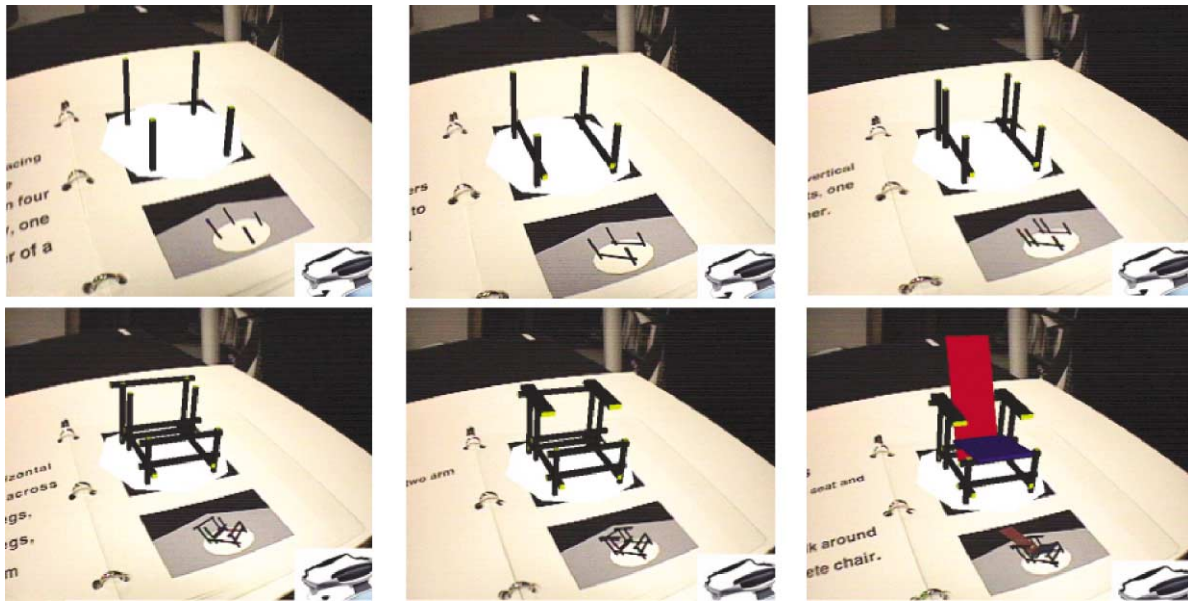


Fig. 9. Stages in building Gerrit Rietveld's red and blue chair.

demanding environment to display an interactive experience because attendees typically have only few minutes and need to be able to master the technology immediately. Although we did not have time for a rigorous user study, 54 of these people filled out a simple survey and were interviewed about their experience.

Feedback was very positive. People were able to use the interface with minimal training, they enjoyed the hand held displays, being able to view different AR scenes, and fly into the immersive VR worlds. Users felt that the interface was easy and intuitive to use. They were given two questions “Q1: How easily could you move between the real and virtual worlds?”, and “Q2: How easy was it to collaborate with others?”, and asked to respond on a scale of 1–7, where 1 was “not very

easy” and 7 “very easy”. Table 1 shows the average responses while Figs. 10 and 11 show the complete data sets.

Using a two tailed student's-*t*-test we found that the answers to question one were significantly higher than the expected mean of 4.0 ($t = 14.43$, $df = 53$, $p < 0.001$). This shows that users overwhelmingly felt that they could easily transition between the real and virtual worlds. However, with question two the user responses were significantly less than the expected mean ($t = -2.77$, $df = 53$, $p < 0.01$), showing they thought it was not as easy to collaborate with each other. This was probably due to some of the people trying the books by themselves, or when using it with another person not being aware of the avatars in the scene. In order for people to see each other as avatars they needed to be

Table 1
User feedback

Question	Average	Std. Dev.	Std. error
Q1: Ease of transition	5.87	0.95	0.13
Q2: Ease of collaboration	3.35	1.71	0.23

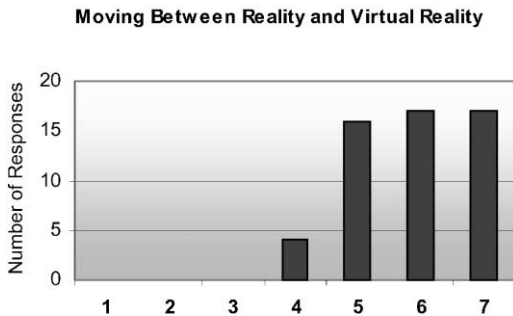


Fig. 10. How easy was it to move between Reality and Virtual Reality? (7 = very easy).

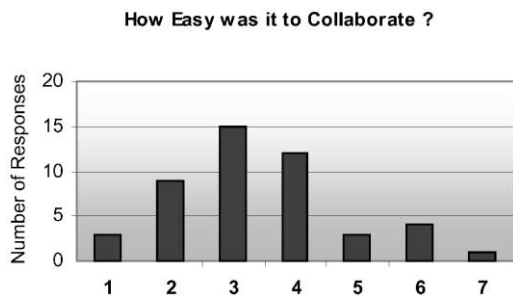


Fig. 11. How easy was it to collaborate? (7 = very easy).

immersed in the same virtual scene at the same time, which happened rarely.

4. Future improvements

Although users felt that they could easily transition between the real and virtual worlds there were also a number of shortcomings with the interface that they identified. Many people found it frustrating that they could not move backwards in the virtual worlds. We modeled movement in the immersive world after movement in the real world and assumed that users would rarely want to move backwards, since people rarely walk backwards. However, it seems that users expected more of a video game metaphor and a majority of people immersed in the VR scenes asked how they could fly

backwards. In the future we will explore different navigational metaphors.

Users also thought the realism and complexity of the graphics content could be improved. The ability to render and display complex scenes is a function of both the graphics cards that we were using and the hand held display properties. The current trend for rapid improvement in both graphics card performance and head mounted display resolution should remove this concern.

Interactivity is also limited in the current generation of the MagicBook. It is a compelling experience to be able to view and fly inside virtual scenes, but many applications require interaction with the virtual content that goes beyond simple navigation. For example, in architecture application users should be able to select and layout virtual furniture in the scenes that they are exploring. We are currently developing new metaphors based on tangible interaction techniques that could be applied in a MagicBook interface.

Another limitation is the use of a single marker for tracking by the computer vision based tracking system. If users happened to occlude part of the tracking pattern then the AR content would abruptly disappear. Recently, we have developed a multi-marker tracking method that uses sets of patterns [10]. Users can cover up one or more of these patterns without halting the AR tracking. We are in the process of incorporating this approach into the next generation of MagicBook interface.

Finally, more rigorous user studies need to be conducted to investigate how collaboration in this seamless interface differs from collaboration with more traditional interfaces. We need to explore how this interface affects communication and collaboration patterns and whether it forces users to change the way they would normally interact in a face-to-face setting. There are also unanswered questions in terms of what interface tools are needed to support multi-scale collaboration, and how to incorporate both face-to-face and remote collaborators. Our preliminary user feedback indicates that more explicit collaboration cues may be required for users to be aware of their collaborators when immersed in the virtual scenes or viewing AR content.

5. Conclusions

As computers become more ubiquitous and invisible there is a need for new interfaces that blur the line between Reality and VR. This can only be achieved by the use of Mixed Reality interfaces that span the Reality–Virtuality continuum. The MagicBook is an early attempt at a transitional Mixed Reality interface for viewing and interacting with spatial datasets. The MagicBook allows users to move between Reality and

Virtual Reality at the flick of a switch and supports collaboration on multiple levels. Although the MagicBook facilitates viewing of sophisticated computer graphics content, the computer is invisible. Rather than using a mouse or keyboard, interaction is focused around a real book and a tangible interface that makes it very intuitive.

Initial user feedback has been very positive and even complete novices feel that they can use the interface and become part of the virtual scenes. However, we are continuing to improve the interface. In the future we plan on exploring more intuitive ways for users to navigate through and interact with the virtual models. We are also working on ways of integrating the MagicBook approach into an environment with projective displays and so allow seamless transition between 2D and 3D views of a data set in a traditional office setting.

For more information about the MagicBook project and to download a free version of the ARToolKit software please visit <http://www.hitl.washington.edu/magicbook/>.

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