New Developments for Virtual Model Displays

Ian E. McDowall and Mark T. Bolas
Fakespace, Inc.

Abstract
This article introduces two new technology developments in the field of virtual model displays (VMD). Projection-based stereo systems have typically only been able to produce a single head-tracked image and have been constrained to non-adjustable surfaces.

The first new technology, the Duo, allows two simultaneous and individually head-tracked stereo pairs to be displayed. This brings the virtual models to life, as two people can now share the workspace by pointing at the model and sharing virtual props to manipulate the model just as if it were sitting in front of them. The motion of either viewer does not impact the view of the other.

The second new development in the field of VMDs is the ability to adjust the angle of the projection surface to provide a natural workspace depending on the application and associated virtual models.

Introduction
Systems such as the Immersive Workbench are ideally suited to collaborative applications. A virtual model effectively sits on the Workbench and people naturally come over to look at the models. Using the Duo, recently developed by Fakespace, it is now possible for more than one person to see the virtual model correctly. This means that the collaborative virtual model space exists simultaneously for several viewers.


Figure 1: The Immersive Workbench at Fakespace.


Figure 2: Researchers at NRL.

The Responsive Workbench developed at GMD, the Immersive Workbench and other projection-based displays such as the Cave were typically restricted to a single interactive viewer and a number of passive participants. The interactive user wears both flicker stereo glasses (typically from StereoGraphics) and a head tracker. Software updates the perspective view to account for the motion of the viewer. Other people looking at the same display also wear stereo glasses and see the same stereo pair as the person with the head tracker. Unfortunately the stereo illusion works for the non head-tracked viewers only when their viewpoint is substantially the same as the head-tracked person.

One of the key issues cited in research on virtual projection displays is the effect of tracker error on the perceived quality of the environment. Of course, any error correction and measurements are performed relative to the participant who is wearing the head tracker. Even the errors in current tracking technology cause concern for creating a good quality virtual display. Issues such as calibration and lag are deemed essential items for future work. The errors for those participants who do not have the head tracker are enormous. The views they are seeing are calculated for a point of view which is several feet from their actual position! Issues such as tracker lag are totally irrelevant to the passive participants. This reduces the true utility of these systems which have been touted as collaborative design spaces even though there is only one good view.

Given that systems such as the Immersive Workbench and Responsive Workbench are so well suited to collaborative design applications in principle, Fakespace has released the Duo for the display of multiple stereo pairs on a single projection surface. Thus, a number of stereo views are projected onto the work surface, and using special shutter glasses, the correct views are seen by the various participants. Initially, this technology has been implemented to support two independent stereo views.


Figure 3: An easy to share workspace at Stanford University.

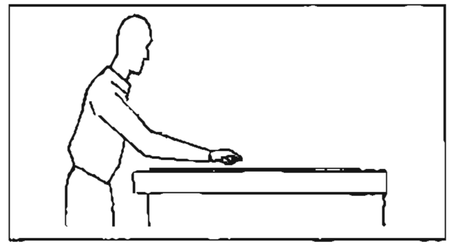


Figure 4: A natural work envelope.

The position and location of the workspace are also critical design decisions in these projection-based systems. The workspace should invite you to reach out into the model to point things out to a co-worker and interact with the model. Basically, the workspace needs to accommodate one's natural inclination to reach out and touch the model.

Adjustable Work Surface
The Immersive Workbench includes the ability to adjust the work surface from flat like a table to near vertical. In practice, angles from flat to about 20 degrees inclined are preferred. A surface any steeper than this tends to interfere with the workspace because one's hands start to bang into the projection surface when trying to reach out into the virtual model.

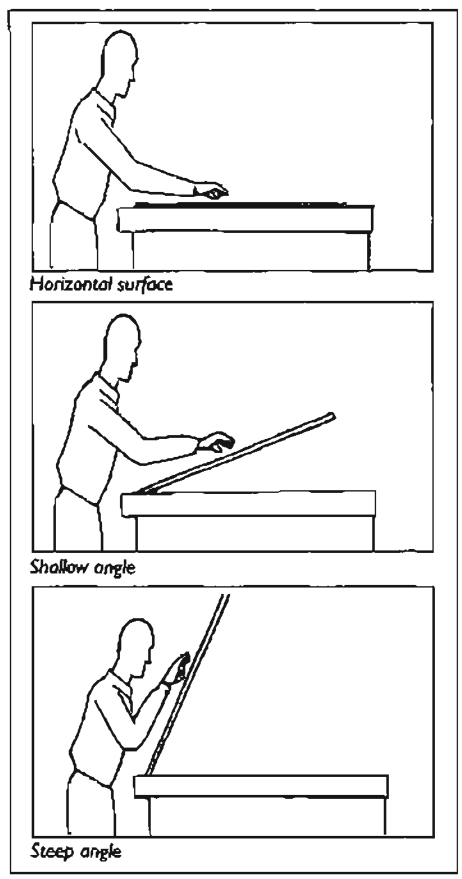
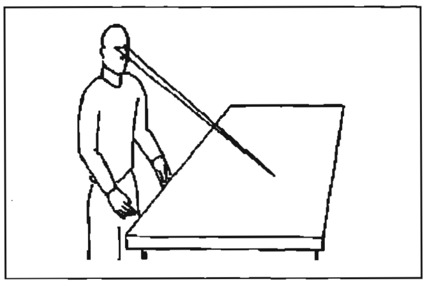
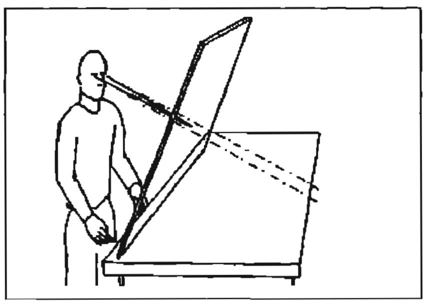


Figure 5: Work surface angle.

Another aspect of the virtual workspace is visual comfort. The stereo image generated to make the virtual models pop out of the table relies on the disparity between the eyes to generate the stereo effect. The eyes of the viewer will have an easier time fusing the two images, and thus seeing stereo, if the visual cues can be matched as well as possible. This factor also leads to a preference for a more horizontal work surface. Virtual models sitting on a table require the user to consistently accommodate and converge in the vicinity of the table surface. A more vertical surface implies a metaphor of looking out into the depths of virtual space and in this case, there is a rivalry between accommodation and convergence as shown (see Figure 6).



Accommodation and Convergence with horizontal surface



Accommodation and Convergence with steep angle

Figure 6: Accommodation and convergence.

The Duo — Multiple Stereo Views

Field sequential stereo is the typical way in which workstation graphics have been presented in stereo. The computer renders right and left eye views which are sent to a display sequentially in time. The display is viewed through special glasses. These glasses contain shutters which are switched in synchrony with the image going to the display. When the left eye image is on the screen the left eye lens is opened and when the displayed image switches over to the right eye view, the right eye is opened. The other eye is dark. Thus over time, the left and right eyes of the viewer see only their respective image. This method for generating stereo generally produces fairly good results. The vertical rate used for these systems is generally from about 96 to 120 hertz. Thus the frame rate from a graphics point of view is on the order of 48 to 60 pairs of images per second. In order to minimize visual artifacts from the shutter glasses, these images are best viewed under subdued lighting conditions. This is also beneficial since the shutter glasses filter out more than half the light even in the open state.

The field sequential stereo technique does have shortcomings. There is a very slight bleed-through between the eyes of the shutter glasses, but a more significant problem is phosphor latency. In color monitors particularly, the image does not completely decay to black in the time that the sequential stereo images change from displaying the previous image. This results in ghosting which can be mitigated by reducing the overall scene contrast. In projection systems, the phosphors used in the CRTs of the projector are faster. In fact, there is a special phosphor for the green tube (P43) which greatly reduces the latent image problem. Thus, in a projection-based system, it is possible to get high quality stereo images to the viewer at frame rates of 48 to 60 hertz.

The Duo system Fakespace has released for producing two stereo views requires the display of four separate images to the screen in a time sequential manner. A stereo pair of images are calculated independently for each viewer. Over a short interval of time, the following sequence of images is drawn on the projection surface.

Left Eye	Right Eye	Left Eye	Right Eye
Person A	Person A	Person B	Person B

Figure 7: Image display sequence.

Note that each person wearing the Duo glasses sees a pair of images. Each eye sees the screen approximately 25 percent of the time. For the remaining 75 percent of the time, the shutter is opaque and the eye sees nothing. Each interval is on the order of eight milliseconds. In order to reduce perceived flicker, custom shutter glasses were developed and bright projectors are used in order to achieve the best results due to the decrease in light which occurs via the time sequential technique.

Techniques other than time sequential (such as time sequential in conjunction with different polarization states) are also possible, however they typically result in increased bleed-through between images.

The Duo system works well. When two people are wearing the special glasses and each is head tracked, they can both reach out to point at something in the virtual world, and they are both pointing to the same place in space above the table. This enables collaborative design and interaction between the participants and with the virtual model.

Applications

With the capability for different people to share a virtual model, the model becomes much more real. It's one thing to watch someone else reaching out to touch a virtual model when you either can't see the model yourself (as with an HMD) or it's distorted and you can't tell exactly what they are pointing at (single viewer systems). However, when two people can independently point into thin air and they both see the model there, the degree of presence one can attribute to the model is quite surprising.

The first test of the system was to draw a simple virtual cube on the Immersive Workbench. As Figure 8 illustrates, even when both participants are standing next to each other, the difference between their two perspectives is enormous.

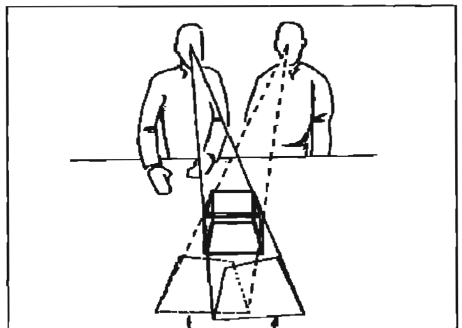


Figure 8: Difference in perspective views.

If both people were to see the same image, their perception of the cube would be quite incorrect. Geometric errors of this magnitude are simply not acceptable for many applications — particularly those that require an analysis or judgment of form or shape.

Given the ability for each viewer to have their own correct perspective view, there are a number of different avenues to pursue using this capability and a number of software issues to contemplate.

Two Viewers Share a Common Virtual Model

Each viewer wears the Duo glasses and a head tracker. Images are presented on the projection surface which appear correct for each person. In an Immersive Workbench application for instance, one user may stand on one side of the table and the other person may be located on another side of the table. Each person will see the objects "on/in" the table from their own perspective. If the model is common for the two viewers, they each see it correctly rendered and can both point into the model when discussing it.

This is the most obvious form of collaboration and involves a common virtual model. Annotations on the model will appear the same to both participants. Physical props and their virtual representations such as 3D styluses or tracked pointers may be passed between the participants and shared. The registration of the model space to each tracker will determine the accuracy of alignment between the two viewers.

Multiple Viewers Share a Single Model

Another scenario in which one researcher is trying to communicate a design or idea to a group of others could be accomplished with one tracked view and a single untracked view. Thus, one viewer has a head tracker and the Duo glasses and sees the images on a stereo projection screen as one normally does with head tracking. The other people also have Duo glasses but no head tracking. The view for the head-tracked individual is live — the view for the other people is updated periodically and is a "generic" viewpoint so that all participants see an acceptable view.

For example if one were showing a model of a particular simulation to a group of people, the researcher could select views to be discussed with the group. With the active view and interaction tools, the researcher could answer questions about the data and show the group at large what was going on without having to worry that his head movements were leading to disorientation of the part of the passive viewers.

Two Viewers Share Different Models

Since each participant is seeing the model from his own perspective, it is also possible for them to see different models. Each participant uses the Duo glasses and a head tracker. The application software may share some elements of the scene graph between the participants and restrict others. This technique may well lead to the most revolutionary collaborative applications. The two participants may share some portion of the data and restrict the visibility of other parts. In the simplest case, the underlying model can be the same and the annotations different for each viewer. At the other extreme, the models themselves might be different.

Imagine being part of the design team on a new mechanical pump design. You are discussing the design with someone on the Immersive Workbench — you might want some information the other person does not need to see. For instance you may be wondering what the dimension of the inlet port is, and in your view you may bring up the measurement tool. The other person does not see this tool — it's only visible to you. This would be very useful for people looking for different things in the same model — the other person may be interested in the material used in the inlet port and has brought up a text window which has the material information.

There is also the possibility of working in a collaborative setting where the participants are working on a common problem but need to be able to work on part of the problem independently and then regroup to discuss how to proceed. The military often needs to have different disciplines working together but independently to reach a conclusion as to an overall strategy. For example, if the marines are trying to establish a beachhead, there are a myriad of disciplines involved. At some points, the person responsible for supplies might want to zoom out from a low level view to see where the various aircraft are in relation to the immediate area. In his case, the local view being used by the person in charge of the operation does not want to be disrupted. However, when they need to discuss where a particular delivery will be made and when, they may share the same virtual model of the local area and point at landmarks and so on. Even in this case where the model is being shared, the data overlaid for each viewer might well be specific to their portion of the mission. Naturally, in a real scenario like this it would be desirable to have more than two simultaneous views.

In a teaching scenario where a designer is trying to explain to a mechanic how to perform some tricky maintenance procedure on a piece of equipment, they may both look at the model as if it were on the table. When the designer says "you line up these two marks like this, then insert the screw with your other hand," the mechanic may not be able to see what the designer is talking about. At this point, the mechanic might want to see the exact view the designer has. When the mechanic has seen what the designer has in mind, he may switch back to his own tracked view. In this way the student can see the world through the teacher's eyes. When the switch takes place, the offset from the teacher's head position to the student's head can be measured. By using the offset, the image drawn for the student can be through the teacher's eyes but the student may still have a live perspective view.

Future Directions

This technology will improve as the artifacts become better understood and can be mitigated. The current system will be developed so as to reduce the amount of flicker. The possibility exists also for doing more than two viewers. The next round of innovations will take place as this technology is applied in areas where people are writing unique and powerful application software.

Conclusions

In conclusion, a system has been developed that allows two independent viewers to share a virtual model. This system has been implemented on a Fakespace Immersive Workbench but might be applied to other projection-based systems. The shared virtual model space gains a great deal of presence in light of the ability of two participants to really share the workspace. The types of interactions which may be performed on the virtual model space are greatly enhanced since the viewers may elect to share all or part of the space, and any physical props may be simply passed from one person to the other. Work surface angles have been explored ranging from horizontal through vertical. A "sweet spot" between flat and 20 degrees inclined was found.

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Ian E. McDowall and Mark T. Bolas
Fakespace, Inc.
Mountain View, CA 94043
Tel: +1-415-688-1940
Fax: +1-415-688-1949
Email: *ian@well.com* and *bolas@well.com*
http://www.fakespace.com