Proceedings, SPIE Conference on Processing and Display of Three-Dimensional Data. San Diego, 1982 367-21

Interactive Three-Dimensional Computer Space

Christopher Schmandt

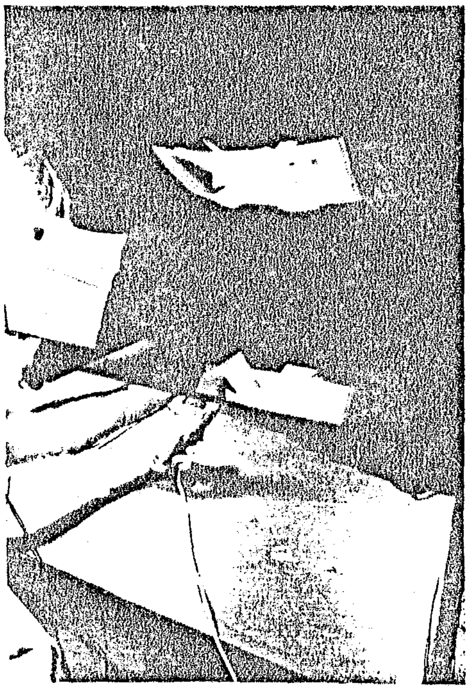
Architecture Machine Group, Massachusetts Institute of Technology
Room 9-516, 107 Massachusetts Avenue, Cambridge, Massachusetts 02139

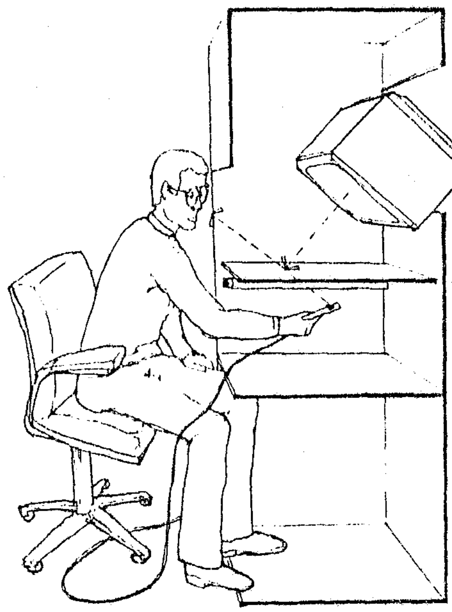
Abstract

Work is described which merges 3-D input and display technologies to implement a real-time interactive computer graphics environment, generating a stereoscopic image that one creates by reaching directly into it. The display is an ordinary video monitor, reflected off a half-silvered mirror, and viewed through PLZT opto-electrical shutter glasses. For input, an electromagnetic six degree-of-freedom digitizer is mounted in a small wooden "magic wand", with a pushbutton mounted in the handle.

Introduction

The last several years have seen the growing acceptance and application of computer graphic hardware to a variety of discplines, such as image processing and computer aided design. Simultaneously, a smaller but more adventuresome body of research uses graphics to represent database abstractions or aid interacitve computing systems to more accurately communicate with their users. As processing has become cheaper, there has been rising interest in displaying three dimensional solids. Although this usually is taken to mean planar projection, perhaps with features such as shading and spectral reflection, there is a growing desire among computer graphic circles to work with true stereoscopic display systems.





Figures 1 and 2. The three dimensional work station in use and a cutaway view. The CRT screen above the user's head is viewed through the half-silvered mirror. The user is wearing what appears to be welders' goggles, which house the PLZT glasses. The digitizer is mounted at the end of the wand in the user's hand.

One of the obvious attractions of computer generated graphics is the possibility of making them interactive, responding through a variety of input devices. The work described in this paper represents the partial fruition of desires to design computer systems which incorporate both stereo displays and interactive graphics. This particular project explores spatial mapping of a true 3-D video display into an instrumented, position-sensitive work area. The result is an image which appears to occupy the same space as one's hand; one can reach into the image, modifying it or drawing in it precisely where one is touching.

This work, performed at the Architecture Machine Group of M.I.T, is part of an ongoing exploration of interactive and user-sensitive displays, with concern for realism and immediacy. Neither the input nor CRT display technologies were developed in the Laboratory; the novelty of the project consists of creating a display station and graphic software to allow the combination of technologies into a spatially correspondent visual environment

INPUT TECHNOLOGY

Numerous devices are now used commonly as two dimensional graphical input peripherals, such as tablets, touch screens, trackballs, and mice. They have found wide application, especially in computer aided design, for entering and manipulating databases representing real world objects. There are, however, obvious limitations to this 2-D interaction; real solids are three dimensional. The common practice of mapping the two degrees-of-freedom of input into three dimensions is awkward, requiring frequent remapping of axes to manage 3-D manipulations. True three (or higher) degree-of-freedom input devices have been demonstrated but are still not in wide use. Surprisingly, and perhaps a partial answer to its lack of acceptance, such hardware has rarely been used in conjunction with stereo display interaction. Additionally, many of these devices suffer from limitations due to reliance on mechanical linkages or use of optical paths which can easily be occluded by a user's hand.

We have attempted to provide true three dimensional input in a comfortable manner with a magnetic position sensing technology developed by Polhemus Navigational Sciences of Essex Junction, Vermont. [1] This six degree-of-freedom digitizer returns the position (x, y, and z) and attitude (azimuth, elevation, and roll) of a small sensor relative to a larger radiator 40 times per second (see figure 3). Three mutually orthogonal dipole antenna coils in the radiator generate a nutating magnetic field, which is picked up by the sensor, a plastic cube about 1.5 cm. on edge which also contains a similar array of receiver coils. A small minicomputer controls the radiator currents and processes the sensor signal to calculate location quite accurately.

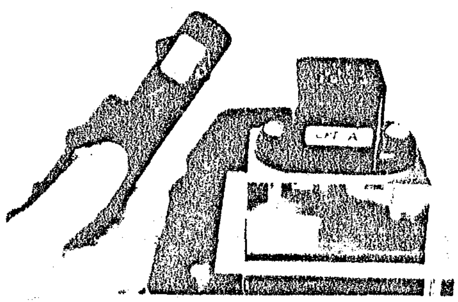


Figure 3. The digitizer, showing the radiator and sensor in the "magic wand".

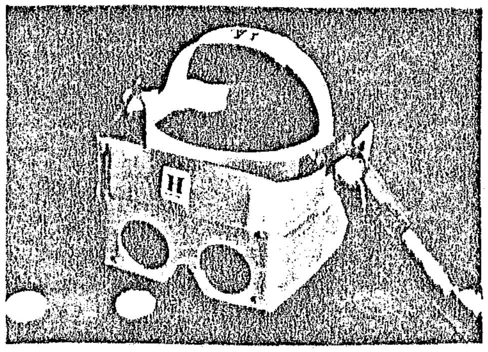


Figure 4. The PLZT shutter glasses and and wand.

The sensor is small and light, connected to nearby preamplifiers by a thin, flexible cable. Because it senses by magnetic fields, a human body using the device doesn't interfere with or block its operation, although, as discussed below, color television monitors cause significant problems. For the purposes of this work station, a sensor has been mounted at the end of a small wooden "magic wand" which also has a pushbutton switch placed within the handle. The wand, switch, and cable are black, while a white spot on the sensor indicates the "active" portion of the wand. The radiator is mounted out of sight behind the work area.

Stereoscopic Display

Stereoscopic display technology is much more widely appreciated than 3-D input hardware. For the purposes of interactive computer generated stereo imaging, the display must be capable of changing in something near real time and communicating with a host computer. Additionally, we desired to project the display into the work area to create the direct spatial mapping of input to image. for these reasons, we chose video as the display medium; color video computer displays are commonly available, easy to interface, and relatively inexpensive.

Single screen stereo CRT display can be accomplished using the 2:1 interlace of conventional video combined with special opto-electrical shutter glasses.[2] Left and right eye views of stereo pairs are displayed on the even and odd scan lines, effectively time multiplexing them. The screen is then viewed through wafers of a lead lanthanum zirconate titanate (PLZT) ceramic which functions as an electrically operated shutter (see figure 4). Running in synchronization with the video signal, these glasses allow one eye at a time to view the proper phase image on the CRT. Simple calculations of the left/right (even/odd scan line) disparity allow the computer generated graphics to be displayed in a manner such that they occupy a visual volume both in front of and behind the screen.

From the computer graphics standpoint, the major advantage of the PLZT video display is simply that it uses ordinary video components, including computer frame buffers and monitors, allowing a range of implementations. The glasses allow close to full color image transmission, which is not dependent on particular head attitudes, as with polarizing techniques. The image resolution is halved in the vertical direction due to the use of interlace to multiplex stereo pairs. Image brightness is also reduced significantly, even with the shutter fully opened,which can be only partially compensated for by increasing CRT gain. Additional problems occur with video projectors.

The Work Station

A 19 inch CRT is mounted at a 45 degree angle above and in front of the operator's head, and viewed through a half-silvered mirror parallel to the floor. This projects the image into a region, unobstructed by the screen, that one can reach into with the input wand. This is the active work area. The region under the mirror was painted black and is illuminated, resulting in the visual mix of the computer generated image and the hand that is working on it. This lighting is driven by a computer controlled dimmer.

left right

Figure 5. A stereo pair of photographs showing the work station. To view in stereo, position the head so the left eye is looking at the left picture, and the right eye to the right, relaxing the eyes.

The user sits in a comfortable chair in front of the work station, looking down into the active region through the half-silvered mirror. This allows his hand to appear in the midst of the reflected image from the CRT. The digitizer's radiator is hidden behind the wooden walls of the work station. As the digitizer is accurate over a larger region than the projected graphics, menu buttons are placed in the work area where they can be seen but don't overlap with the display. Of course, additional "soft" buttons can be projected in the image as well. These menu items are selected by touching them with the wand and pushing the button in its handle. Visual feedback is provided for each menu function selection.

Implementation

The user sits in front of the work station and sees the wand in the midst of a true 3-D video image (see figure 6). He can touch and change the image using the button and the wand. It is the task of system software to determine the position of the digitizer and insure that the resulting change in the image is mapped correctly into the viewer's visual field so it appears to occur exactly where the wand is seen. As the goal of the interaction is such a successful spatial correlation, no cursor should be necessary.

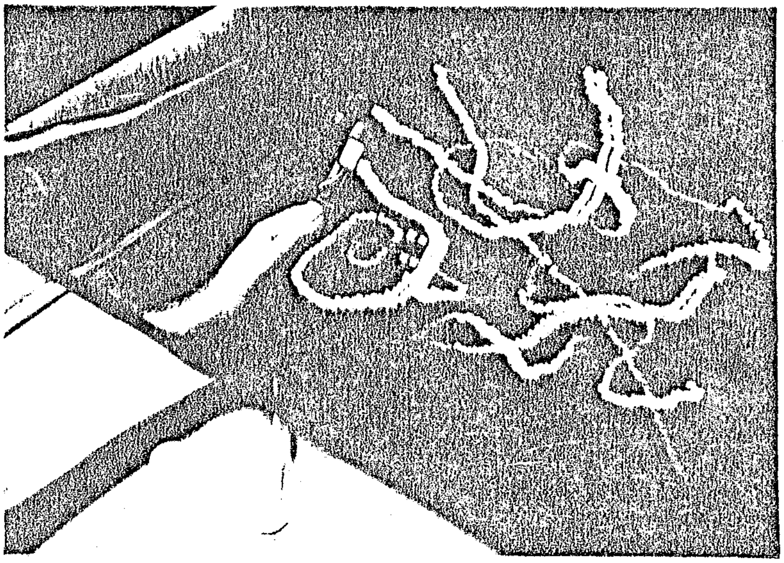


Figure 6. Looking through the mirror into the work area. The graphics appear as double lines without the PLZT viewing glasses; the distance between the double images determines the depth at which they are seen.

Indeed, the effectiveness of the integration of the various components of the system may be measured by how well the graphics function without any cursor. In the initial application of the system, the wand became a paint brush, and the user was given the ability to draw 3-D colored images in space. When the button is pushed, color dribbles out of the white spot on the wand which marks the digitizer's location.

Several calculations determine the position of the paint. First, the digitizer's location, in its own coordinate system, must be rotated, translated, and scaled into the screen coordinate system (actually, that of the projected image of the screen). Then the point of intersection of the projected screen and the line of sight from the eye to the digitizer is determined. This gives the (x, y) coordinate in screen space at which to draw the image. Finally, the depth of the wand (z in screen space) is used to determine the disparity of the even/odd, left/right views with which to draw the graphic.

This mapping allows the user to draw free-form, true stereo images, consisting of lines of colored paint suspended in space. Color is selected by touching colored dots used as menu buttons. Indeed, the image is quite well correlated with the wand location, and, when well calibrated (see below) really does support the illusion of the paint flowing out the end of the wand. In practice, the white target spot is about one centimeter square to indicate location uncertainty in the active volume, which measures approximately 50 by 30 be 25 centimeters deep.

Several additional cues aid the stereoscopic realism be reinforcing depth perception. A quick and dirty hidden surface algorithm automatically paints in front of or behind previously constructed lines. Similarly, the brightness and size of paint graphics decrease in a somewhat exaggerated manner with distance. The depth modulated luminance of the graphics is further used in conjunction with the illumination of the work area. As the user reaches closer, the lights under the mirror get brighter, so more of the graphic is obscured by the hand; as the hand moves futher away, the lights dim, with the reverse effect of making the graphics appear more dominant than the hand.

In another application under development at the time of this writing, the work station is used to build databases consisting of three dimensional polygons for solid modeling systems. The wand is used to enter sequential vertices, which are connected by stereo "rubber band" lines, and then filled with a selected color. Again, the disparity of even/odd scan lines place the polygons at the correct depth, and hidden surface removal deals with overlaps.

Limitations

Difficulties in the development of this interactive computer space fell into two catagories: effects on the magnetic digitizer by the CRT, and difficulties viewing projected video with the PLZT glasses.

The former is the most formidable problem. The strong local magnetic fields associated with the CRT severely disturb the digitizer in two ways: noise is introduced into the sensor signal, and the normally rectilinear digitizer coordinate space is severely warped. Noise is reduced with distance from the CRT, but as the screen is moved further away, its reflected image becomes smaller. Alternative display technology was not helpful (see below). Placing an ordinary metal window screen in front of the CRT screen helped reduce noise significantly, but digitizer points still needed to be low pass filtered, slowing system responsiveness. This trade-off was somewhat alleviated by using an adaptive filter which filters more heavily when the sensor is nearer the CRT.

Unwarping the digitizer space was done by a brute force, best fit simple curvature approximation, in combination with a calibration routine. Calibration was further necessitated by the fact that the digitizer coordinate system is relative to the radiator, which is frequently removed for other experiments in the Laboratory. Additionally, to insure spatial correspondence the system must be calibrated to a particular user's most comfortable viewpoint. Calibration is done by displaying a succession of dots which the user touches with the wand, giving inputs to build a transformation matrix.

The most bothersome limit with the PLZT glasses is their low (approximately 20%) transmission when fully open. This is further confounded when the CRT image is reflected off a half-silvered mirror! Although we attempted to use a video projector for a brighter image (and also to minimize the above mentioned magnetic disturbances to the digitizer), the decay characteristics of the General Electric Light Valve we used were such as to allow visual crosstalk over part of the display. After using the glasses for a few minutes, when the eyes have become somewhat more accustomed to the level of illumination, this reduced brightness is less noticed.

Conclusions

The most telling feature of this display system is that it is fun to use. It is simple yet fascinating to draw complex 3-D knots, spirals, etc. With the polygon drawer, we are getting closer to more real world applications. The low pass filtering does slow down the drawing more than is comfortable when very near the upper limits of the active volume, but speed is adequate further down. The depth adjuncts, especially the exaggerated dropoff of paint size and brightness, dramatically aid viewers not used to stereoscopic displays.

Acknowledgements

Foremost among those who deserve to share credit for this work are Jim Zamiska, who wrote most of the programs described, and Scott Fisher, for work with system design, optics, and who also took the photographs in this paper. Additionally, Carol Boemer drew the illustration on the first page. Honeywell and Megatek loaned the Laboratory PLZT glasses and controllers. This project was funeded by the Defense Advanced Projects Agency, Cybernetics Technology Division, under contract MDA 903-81-C-0097.

References

1. Rabb, F.H., Blood, E.B., Steiner, T.O. & Jones, H.R. Magnetic position and orientation tracking system. IEEE Transactions on Aerospace and Electronic Systems. No. 5, September 1979, pp 709-718
2. Roese, John A. and McCleary, Lawrence E. Stereoscopic Computer Graphics for Simulation and Modeling. Computer Graphics, Proceedings of ACM SIGGRAPH '79, Vol. 13, No. 2, August 1979, pp 41-47.