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VARIFOCAL MIRROR DISPLAY OF ORGAN SURFACES FROM CT SCANS

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Abstract

A means will be presented of constructing a powerful varifocal mirror 3D display system with limited cost based on an ordinary color video digital display system. The importance of dynamic interactive control of the display of these images will be discussed; in particular, the design and usefulness of a method allowing real-time user-controlled motion of the 3D object being displayed will be discussed. Also, an effective method will be described of presenting images made of surfaces by the straightforward, automatic calculation of 3D edge strength, the ordering of the resulting voxels by edge strength, and the 3D grey-scale display of the top voxels on this ordered list. The application of these ideas to the 3D display of the intimal wall of the region of bifurcation of the carotid artery from 12-24 CT scans of the neck will be discussed.

Varifocal Mirror Display Principles

As indicated in Figure 1, 3D display can be accomplished using a flexible mirror, suspended like a drumhead and made to vibrate by placing it in front of a 30Hz loudspeaker. The observer looks into the mirror at the reflection of a screen. A few mm vibration of the mirror makes the screen appear to sweep across a few tens of cms of depth, and the rate of vibration makes the swept image fuse into a single 3D image. The image is constructed by presenting on the screen each 2D slice of the 3D image at the time that the screen appears to be at the depth corresponding to this slice. The result is a "true" 3D translucent image, i.e. one with all depth cues (including head-motion parallax) except hiding -- one sees simultaneously the slices at all depths.

In fact, if a CRT is the screen producing the images reflected in the mirror, one cannot display all of the pixels in a slice simultaneously. Rather, at any time one is displaying a single pixel, a point, and the 3D display strictly consists of a collection of points, each successively deeper than the one before. Today's technology allows approximately 200,000 points to be displayed in a full cycle of the mirror's vibration, with each point able to have its intensity specified, but over a small perceivable range.

A system for producing a 3D display using this method then consists of a 2D image presentation component made from a CRT with fast electronics and a fast phosphor; a vibrating mirror component made from a mirror, speaker, and stand; a component for producing one cycle of a 30Hz sine wave at a specified time; a memory for holding in some representation the position and intensity of each image point to be displayed; a component to produce the signals specifying display point position and intensity to the CRT from the information in the memory; and a control to cause the beginning of the point sequence and the beginning of the sine wave to occur at the same time. The system may also include a processor to transform the memory information in response to user interaction. Further details of general system design issues may be found in [Fuchs, Pizer, et al, 1979].

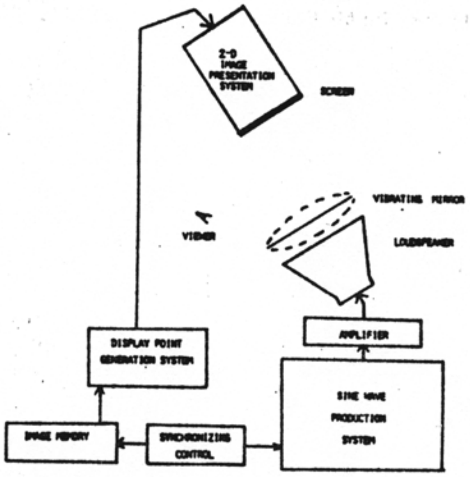

Figure 1

GENERAL VARIFOCAL MIRROR SYSTEM STRUCTURE

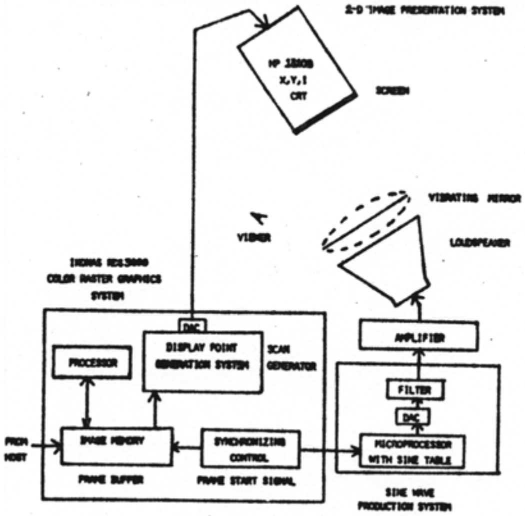

Figure 2

UNC VARIFOCAL MIRROR SYSTEM STRUCTURE

UNC Varifocal Mirror Display System Structure

Whereas all other systems for varifocal mirror display that we know of have special-purpose electronics for memory and image point generation and thus are quite expensive (the one system commercially available carries a price of $100,000), our system (see Figure 2) is based on a general purpose color raster graphics system. The result is that anyone with a need to produce digital color video images can add on a varifocal mirror display for under $10,000. For varifocal mirror display the frame buffer words that normally are interpreted as holding intensities of red, green, and blue at a point on a video display are now interpreted as holding x position, y position, and intensity information for a CRT accepting x,y,i signals. The same "scan-generation" circuitry and digital-to-analog converters used for color video display are used when the system is utilized for 3D display. The "frame-start" (vertical synch) signal used in video display is used to signal the beginning of each sine-wave cycle. In our system the sine-wave is produced by a microprocessor holding a sine table. Upon the receipt of the frame-start signal as an interrupt, the processor transfers these table values through a digital-to-analog converter, smoothing filter, and audio amplifier to the speaker.

Interactive Control for Translucent 3D Display

Varifocal mirror display is exceptionally effective in having the viewer perceive displayed objects as three-dimensional. However, complicated scenes on such 3D displays are not always easy to interpret: the displayed 3D image is translucent and thus objects in front of and behind an object of interest obscure the visualization of that object, the 3D volume inherently contains more spatial information than a 2D plane, and a viewer's depth resolution is lower than his in-slice resolution. In fact, it is a fair generalization that the display is exquisite at displaying dots and lines, good at displaying surfaces, and has weaknesses in displaying space-filling grey-scale images (although it can be quite useful in radiology even for this [Baxter, 1981]). We have found that the understanding of complex scenes is often enhanced by allowing the user to change dynamically the orientation of the image. This capability is, of course, in addition to the ability of the user to view the object from a limited range of orientations by moving his head. The rotation of the image is of special use in allowing the user to view from a direction in which obscurations are minimized or object properties such as bifurcations are made most apparent. Also of use, but perhaps harder to provide at interactive speeds, is the ability temporarily to remove (or dim) obscuring objects from the image.

In what we believe is a first, we have implemented real-time user-controlled rotation of 3D images. To do this, part of the frame buffer memory of the raster graphics system is used to hold a list of points and line endpoints to be displayed, each with its corresponding intensity. These are in order of their importance in visualizing the scene. The list elements are read, 16K at a time, into the system's fast processor, and for each the following is done: by appropriate matrix multiplication it is transformed into the co-ordinate system corresponding to an orientation indicated by the user with an interactive device; then the location within the list used for refreshing the display is calculated based on the computed depth value; finally the computed values of the other two position co-ordinates together with the intensity is placed within the refresh list in an empty slot near the calculated location. This continues, in groups of 16K points and line endpoints, until the source list is exhausted or the user indicates a new orientation. The result is that we can rotate 16K points and line endpoints in real time. If the image contains more than 16K points and line endpoints, the first 16K are rotated in real time, and the remainder do not appear until the movement is stopped, when they are added into the image.

We have also implemented a scheme of dimming all but an ellipsoidal region of 3-space so as to reduce obscuration. The center position and size in each dimension of the ellipsoid are under user control. This modality has not been used enough to evaluate it well, but it appears that dimming an image object, rather than an image region of some general shape, will be preferable, though much more difficult.

3D Surface Display from CT Scans

As implied above, if the source image data consists of grey-scale information but the information of interest is the surfaces making up the edges between regions, for varifocal mirror display it is preferable to present only the edges rather than all of the grey-scale information. We have found, based on only a few test cases, that this can be done effectively by applying a 3D edge-strength calculation operator, such as a 3D extension of Sobel's method, to the source 3D image (collection of slices), ordering the resulting voxels by decreasing edge strength, selecting the top few thousand elements of this list, and displaying these on the varifocal mirror, with edge strength determining intensity. A major advantage of this approach over other schemes requiring edge detection, such as shaded graphics, is that no edge tracking needs to be done.

The application to which we are applying this technique is the viewing of the intimal wall of the carotid artery near the region of bifurcation in the neck. The source data is obtained from injection of an iodinated substance followed by the collection of 12-24 CT scans spaced 1.5mm apart. Our initial results are very intriguing, but we are too early into our study to predict the degree of success.

REFERENCES

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