A Geophysical Outlook—Part 7

Will true 3D display devices aid geologic interpretation?

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20-second summary

The earth is three-dimensional; hence, it is logical that 3D display devices will become aids to subsurface interpretation. Technological advances are providing a new generation of display systems and techniques that provide a true 3D view of data volumes. Many of these methods have been developed for application in other fields such as chemistry and medicine, however, active research is still underway in search of the best approach to displaying computer generated geophysical/geological data.

This article, the seventh in a series on new exploration technologies, goes beyond today's state of the art in computer graphics display[1] to describe true 3D display devices and techniques that are being evaluated in various research laboratories around the world. These advances are closely tied to the expected application of 3D display devices as interpretational tools for explorationists.

Fig. 1—In this simple 3D imaging device, called the Mirage, two parabolic mirrors face each other and are separated by the distance of their common focal lengths. Note that the hole being pointed to acts as a mirrored surface, and that even the imaged object, the knob also pointed to, is actually resting in the bottom of Mirage although it appears to be reflected on the mirror. (See Fig. 2).

THE THREE-DIMENSIONAL display of data sets is needed in many different scientific projects. Research areas, which the author is aware of, that are seeking true 3D display techniques include: medicine, with applications such as the displaying of data from ultrasound echo scanners,[2] computed tomographic scanners (cat scans) like the Mayo Clinic Dynamic Spacial Reconstructor,[3] radiographs,[4] shadowgraphs[5] and nuclear emmision;[6] chemistry, through the displaying of molecules and molecular interactions;[7] biology, through reconstructing nerve cell interconnections;[8] meteorology, by illustrating multidimensional meteorological data fields;[9,10] traffic control, by displaying radar and sonar images in 3D for air traffic control or submarine location; mathematics, by illustrating multidimensional mathematical information like curves and surfaces; geology, through studying earthquake epicenter locations in 3D;[11] and, of course, seismology, by evaluating volumes of seismic data in relation to well and geologic information.[12]

Similarly, there is great interest in using this technology for the entertainment and advertising industries. Possible applications range from 3D movies, to 3D home TV, to 3D video arcades or even 3D photography.

In the early 1970s, the field of holography seemed to offer spectacular promise for meeting these more general applications as well as the scientific needs. However, there are basic characteristics of laser holography that limit widespread application.[13] For instance, laser holography produces a one-color scene. There is also the speckle effect, which the Hungarian-born inventor Dennis Gabor once called "holographic enemy number one."[14] That is, at the wavelength of visible light, even the smoothest surface appears bumpy, and the result is a speckle that dazzles the eye and further detracts from the realism of the image. Further, display size is a problem, because a large hologram requires a large, expensive laser, and these can damage the human eye. However, the biggest problem from the scientific side is that holograms are a photographic plate, meaning that the display cannot interact with a digital computer data base. All in all, there will need to be major breakthroughs before holography will provide a method of interactively working with a volume of seismic data. Currently an active participant in the advancement of holography is Dr.

Stephen A. Benton,[15] senior scientist at Polaroid Corp.'s Research Lab, Cambridge, Mass., who has put together a history of the conceptual evolution of 3D imaging techniques, called "Similar Visions," for the New York Museum of Holography.

While the search for a true 3D display device for interactive analysis of seismic data volumes has not yet provided a satisfactory answer, a whole range of devices exists that have the potential of helping to solve the problem. These methods range from a $35 pair of parabolic mirrors to computer driven systems with unlimited price tags. The remainder of this article summarizes these developments and describes how they are presently being implemented.

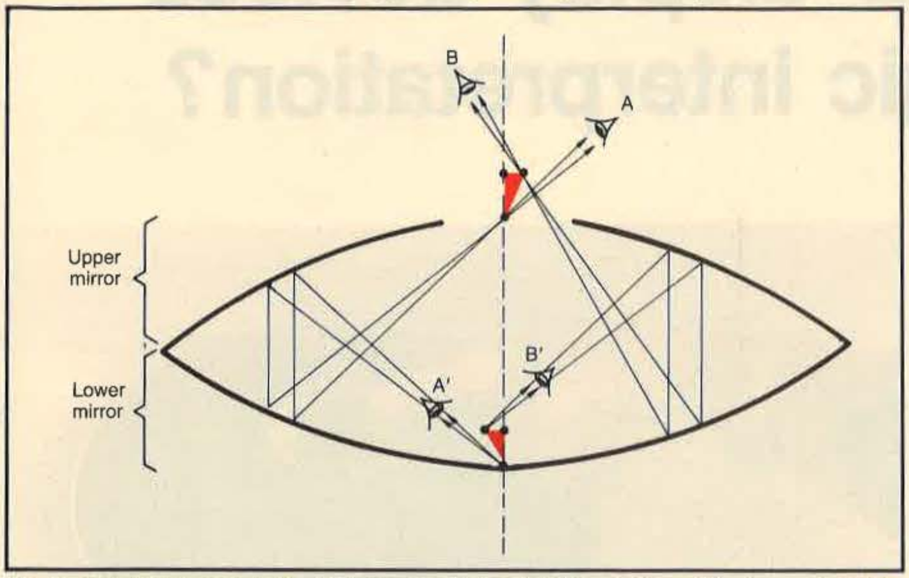


Fig. 2—The real triangular object to be imaged is located at the bottom of the lower mirror. An upgoing cone of rays issuing from the bottom point of the triangle takes the path shown and reconverges at the exact center of the upper mirror parabola. Because the mirror allows the viewer at A to see the same diverging ray cone as a viewer at A', there is a 180° rotation of the image.

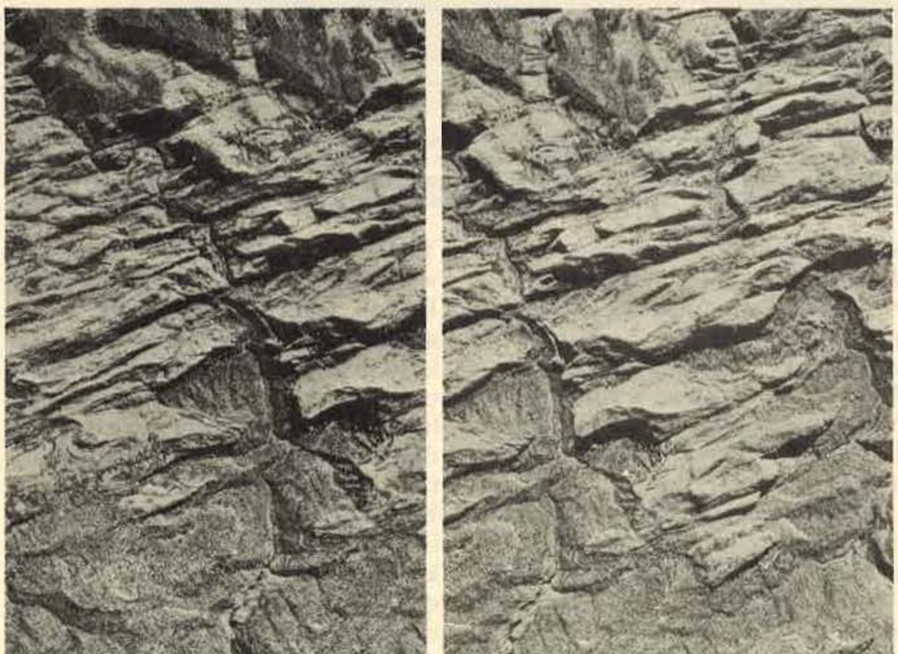


Fig. 3—Stereo aerial photograph of Zion National Park in southwestern Utah.[17] To the trained eye the plateaus seem to be above the printed page when the pictures are fused together by the brain. A simple stereoscope helps untrained eyes fuse these pictures.

PARABOLIC MIRRORS

Mirage is the trade name of a novelty toy made by Opti-Gone Associates, Woodland Hills, Calif. This simple imaging device consists of two identical parabolic mirrors facing each other and separated by a distance equal to the common focal length (Fig. 1). The imaging principle involved is illustrated in Fig. 2. The image in the base of the mirrors appears to be sitting in space.

Most other 3D display devices are more complicated than Mirage and create images in virtual, or non-invadable, space. However, by displaying a computer-created virtual image at the base of a set of parabolic mirrors, the image is moved into real space where it can be interacted with.[16]

Dr. Simpson, at the University of Houston's Cullen Image Processing Lab (IPL), has started working on one practical application for Mirage. This has involved installing it in a box with its top flush with the viewing hole. Stable pointers are then inserted into the image, in order to determine an individual's accuracy in depth positioning as a function of viewing distance. This may help to design 3D interaction algorithms, as well as in selection of personnel for work with data volumes.

For many years, earth scientists have worked with similar "illusions" in the form of air photo stereo pairs. An example of stereo air photos is shown in Fig. 3. The relief of Zion Canyon is southwestern Utah appears to come out of the flat page, when these two pictures are fused in the viewer's mind.[17] A fair percentage of the population cannot fuse stereo pairs to see a three-dimensional picture. Simple stereoscopes, that can be picked up in most university bookstores, help in fusing stereo pairs. (The principle is the same as that used in the stereo movies that come out every so often.) It is interesting to note that if there is rotational movement of the data volume, there is little problem visualizing 3D because of the accompanying motion parallax.[18,19]

PROJECTION IMAGING

It seems that medical researchers have been attacking the problem of true 3D display of data volumes longer than geoscientists. At least many of the 3D display techniques developed have been for studying medical data volumes.

For example, when an x-ray is taken, a "radiograph" is made on photographic film. Each point on the radiograph is the integral of the x-ray density (the linear attenuation coefficient) along the path connecting the x-ray source and the point on the detector. These projection "pictures" cannot be interpreted when the image of the structure cannot be distinguished from the background. One method of removing this superposition is to selectively opacify the desired anatomy.

Another procedure is to use computed tomography (CT). CT uses projection information from many angles of "view" around the body to numerically generate a 2D slice through the body. Because superposition is minimized in CT scans, this method is useful in distinguishing hidden structure, even though the spatial resolution and noise characteristics of cross-sectional images are inferior to that of radiographs.[20] A stack of these CT scans results in a data volume that needs to be evaluated, very similar to a volume of seismic data.[21]

Lowell Harris, at the Mayo Clinic, developed one method of accomplishing this using numerical reprojection of data from a volume of CT scans to create a projection image. Fig. 4 summarizes this procedure. By making 2D digital "radiographs" of the reconstructed volume at different viewing angles, the volume can be viewed as a stereo pair, or put on video and rotated for motion parallax.[18] Because the CT data volume is digital, it can be manipulated to overcome superposition prior to being reprojected. These enhancement methods are referred to as selective "tissue dissolution" and non-effacive numerical "dissection."[20] In other words, the radiologist is able to use numerically those fundamental medical procedures used by pathologists to cut, peel and dissect the data volume for detailed analysis.

Explorationists face a similar problem. To study the application of these procedures, a volume of physical model data[22] was evaluated using these techniques.[23] Fig. 5 is a stereoscopic photograph of that physical model taken from an overhead position. The model consists of five thin plexiglass lenses at various heights above a plexiglass base plate. The model was placed in the Seismic Acoustic Laboratory (SAL) modeling tank and a volume of common-offset seismic traces collected. The trace spacing and line spacing was the same so that each trace represented one square on a surface grid.

The raw data was projected at two different viewing angles to form the stereo pair shown in Fig. 6. Notice how the diffractions make the data appear to be out of focus. After the 3D migration of this raw data volume, the image projection results in Fig. 7.[24] This is a projection of the amplitude envelope from the Hilbert Transformation of the migrated data set, and is a good example of how 3D migration will "focus" a data volume. If these were sand lenses in an oil bearing sequence, it would be easy to specify a drilling site.

A video rotation sequence of projections of the same data volume gives an even clearer view of the 3D relationships. However, this movement cannot be reproduced on the printed page. The rotation sequences do give additional credence to the use of vector refresh graphics as a tool for evaluating 3D data volumes.[1,19,20] It is interesting that the Department of Biological Sciences at Columbia University has been using vector graphics systems since the early 1970s to visualize biologically

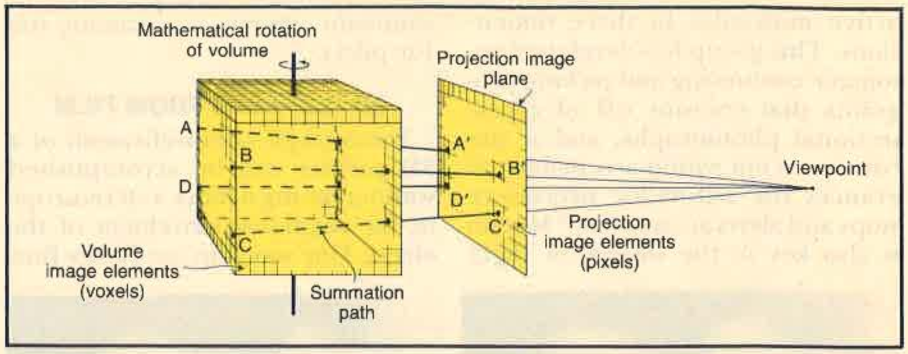


Fig. 4—Picture elements (voxels) of the volume on the left are numerically summed along projection paths (four representative paths shown) to form the picture elements (pixels) of the two-dimensional projection image in the center. When the resulting digital image is displayed, it is as though the observer views the volume image from the viewpoint on the right. [Reproduced from SEG Reprint,[22] Courtesy L.D. Harris: Identification of the Optimal Orientation of Oblique Sections Through Multiple Parallel CT Images. *Journal of Computer Assisted Tomography* (In Press).]

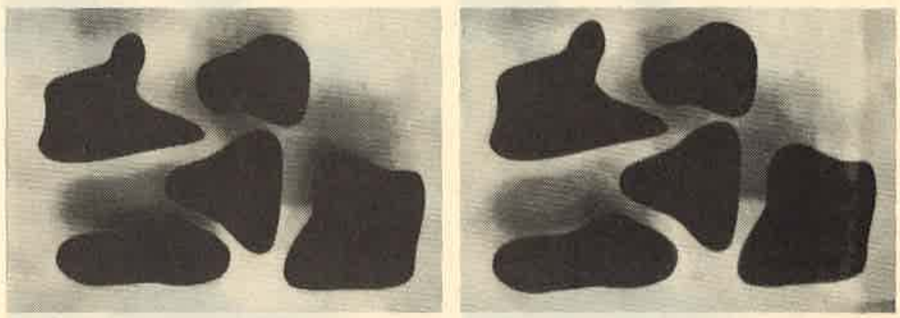


Fig. 5—Stereoscopic photograph of a physical model with five plexiglass lenses raised above a plexiglass base. The highest lens is in the bottom right corner, they stairstep down to the top left corner lens, and the bottom left and top right lenses are lowest and are at the same elevation.[22]

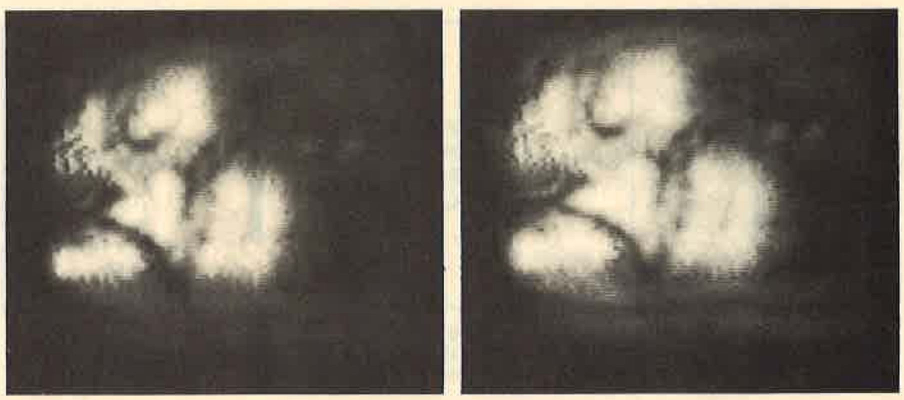


Fig. 6—A stereoscopic projection of a volume of unprocessed seismic data over the physical model from Fig. 5. Note the unfocused appearance caused by the diffractions.[22]

active molecules in three dimensions. This group has developed automatic contouring and picking programs that contour off of cross-sectional photographs, and if the contour is not within acceptable tolerances the automatic procedure stops and alerts an operator.[8] Motion is also key in the success of flight simulator systems as a training tool for pilots.

3D DISPLAYS FROM FILM

Stereoscopic comprehension of a 3D picture can be accomplished without having to have a stereoscope or the rotational movement of the object. One way is to use James Butterfield's Autostereoscopic Film Display. In this system, cameras are used to record a stereo pair on film. The two pictures are projected by separate projectors onto a Fresnel lens screen, which is optically equivalent to a large diameter convex lens. The viewer positions his head so that each eye perceives only one of the images. The brain fuses these images as a single 3D picture. With a 2½-in. diameter projector lens, the viewer has a viewing window of 2½ in. left, right, up-and-down, and about 18 in. in-and-out of the screen. This viewing window can be greatly increased using a screen made of lenticular lens, as is shown in Fig. 8a. This configuration will repeat the stereo view for every 2½-in. movement of the observer.[25] This same procedure can be expanded for group viewing by using multiple cameras to film an object (Fig. 8b). The same number of projectors is used to create a 3D image that can be viewed by several people simultaneously (Fig. 8c). It seems reasonable that the same procedures can be used with multiple computer-controlled CRTs (cathode ray tubes).

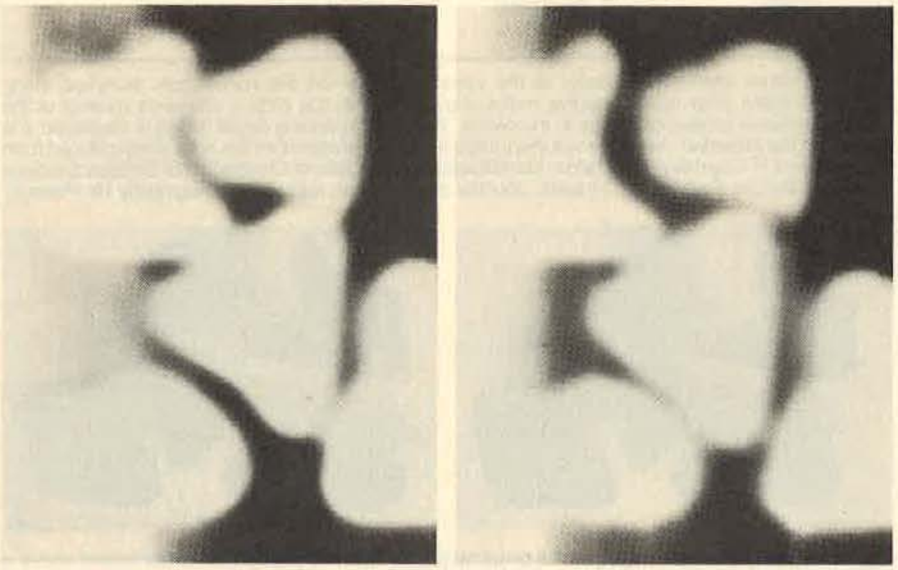
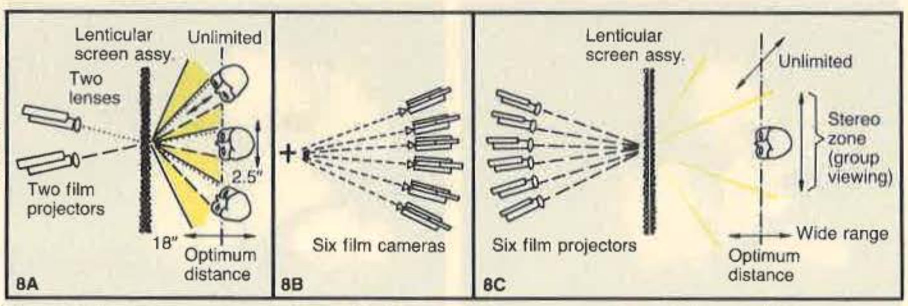
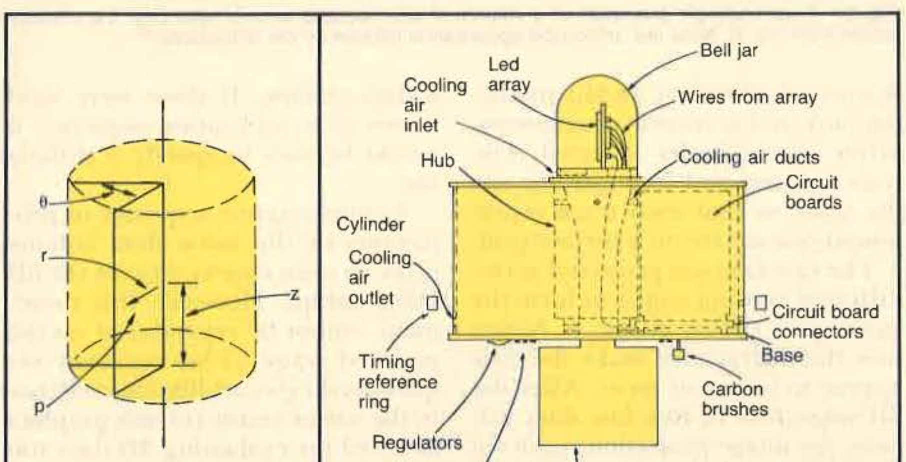


Fig. 7—A stereoscopic projection of a volume of Hilbert Transformed 3D migrated data from the physical model in Fig. 5. Note the focusing effect of migration compared to Fig. 6.[24]



Courtesy Jim Butterfield

Fig. 8—The autostereoscopic film projection of a stereo pair on a lenticular screen (8a). Note that the viewer can move his head and still see the stereo pair. Using multiple cameras (8b) and the same number of projectors (8c), the stereo zone can be expanded for group viewing.



Courtesy M.I.T. Innovation Center

Fig. 9—In 9a the cylindrical coordinate system used to locate a point, p, with the M.I.T. rotating diode display device: r is the radius; z is the height; and θ is the angle from a reference plane. Fig. 9b shows the mechanical assembly of the device.

Another device that uses film to produce a 3D display is called the synthalyzer.[26] This system uses a set of 60-70 coordinated sections of a specimen recorded on a 16mm film strip. The film is mounted on a transparent drum that revolves at about 1,200 rpm. A strobe light freezes the projected image above a stepped cylinder with translucent Archimedes spiral segments. The result is similar to that observed with the parabolic mirrors. There are also two main sets of controls, as described by de Montebello, that are used to study hidden details of a reconstructed specimen. The first is an optical dissector that basically blocks portions of the display. The second is an electronic chopper that allows successive removal and isolation of the projected layers. These can be used independently or in conjunction. Dr. Budinger, Donner Laboratory and University of California at Berkeley, described an interesting variation of this concept, assuming money is no problem.[27] A shutter could be rapidly moved in front of a set of 18 images on two CRTs. As the shutter passes, each image is passed through a series of glass lenses and is reflected off of a rotating silvered cylinder. The optics is set up so that a real image is created under computer control.

BEAM SPLITTING TECHNIQUES

Dennis Ricks, of Ricks Research, Ltd., in Louisville, Colo., has demonstrated a new 3D television display that uses multiple CRTs and beam splitting mirrors to place the pictures in proper 3D space. Cross-sectional images are optically stacked by the beam splitters so that they appear one behind the other to form a composite three-dimensional image. Lenses are used to project the 3D image towards a viewing window. These lenses can also enlarge the image. More than five prototypes have been built, with image characteristics that range from medium resolution black and white to high resolution color.[28] A prototype system has been built with 16 backlighted transparencies illustrating a scene from the Apollo moon landing. The same type of lens configuration could be used with CRTs, but it is more expensive than using backlighted transparencies.

In working with a simple black and white version, it becomes obvious that with more than three unedited seismic sections it is impossible to recognize events because of superposition. If interactive terminals are incorporated, and numerical "pathology" techniques developed, this type of device has promise as a 3D interactive interpretation tool.

Dr. Stephen Pizer, at the University of North Carolina in Chapel Hill, had a similar research project. He used optical tunnels to multiplex hardcopy pictures and create a 3D image.[29] However, it was found that lenses provide a better solution than do the optical tunnels and that interaction with the display, not provided by the tunnels, is very important. Therefore, this research has been put on a back burner.

ROTATING LIGHT-EMITTING DIODES

One of the most unique 3D display devices was developed at the Massachusetts Institute of Technology Innovation Center. This system is based on rotating a two-dimensional array of red, light-emitting diodes (LEDs). The first tested and planned application for this device is to display x-ray tomographs in 3D. The intention is not to replace present 2D display techniques, but to provide a method to enhance the physician's interpretation of the data volume being worked with.[30] These are the same steps that must be followed in order to interactively interpret seismic volumes, i.e., to develop methods to work effectively with 2D slices on CRTs and then to add 3D display techniques to these procedures to enhance interpretation.

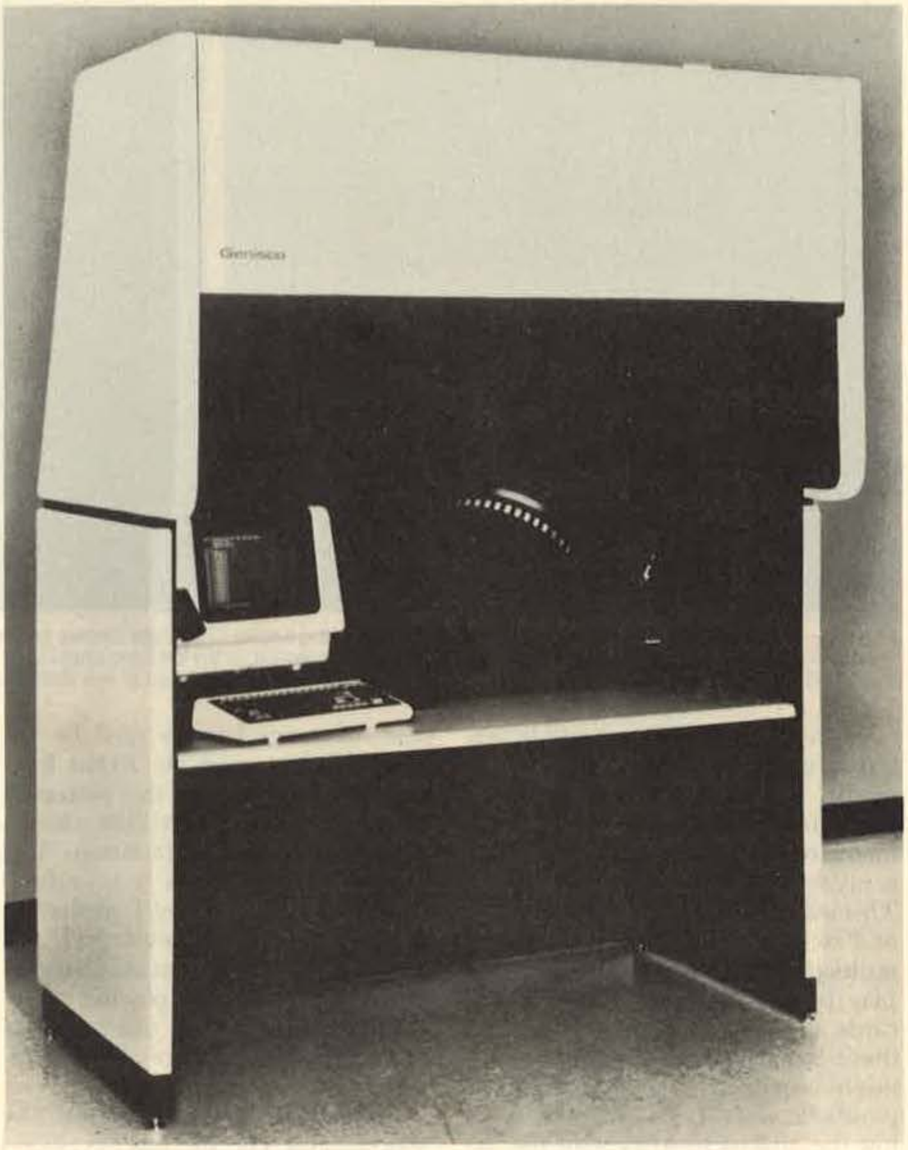


Fig. 10—The Genisco SpaceGraph vibrating mirror 3D display device. A 40-cm vibrating mirror is partially shown at the center of the display. A high-resolution CRT is housed within the overhead casing.

The concept is to use the motion of rotating a 2D image in space to create the third dimension. Static images result as the red LEDs are turned on at the same position in space while the array of lights is rapidly rotated. Each position, P, is defined in the usual cylindrical coordinate system as is shown in Fig. 9a. The three coordinates defining p are: r, the radius; z, the height; and θ, the angle from a reference plane. In the laboratory prototype, there is a two-inch square panel with 4,096 red LEDs, with a linear density of 32 diodes per inch. The array is visible from only one side. With the axis of rotation in the middle of the square array, the image volume swept out is a cylinder two inches high and two inches in diameter. Even with this small prototype, there is a large amount of data needed to construct a complete image. The number of points in the 2D array and the large number of discrete angular positions that images are to be displayed at for a flicker-free presentation requires large data transfer bandwidth.[30] The mechanical configuration is described in Fig. 9b. The electronics have been worked out and the patent assigned to Tri-Vi Corp.

In view of the potential applica-

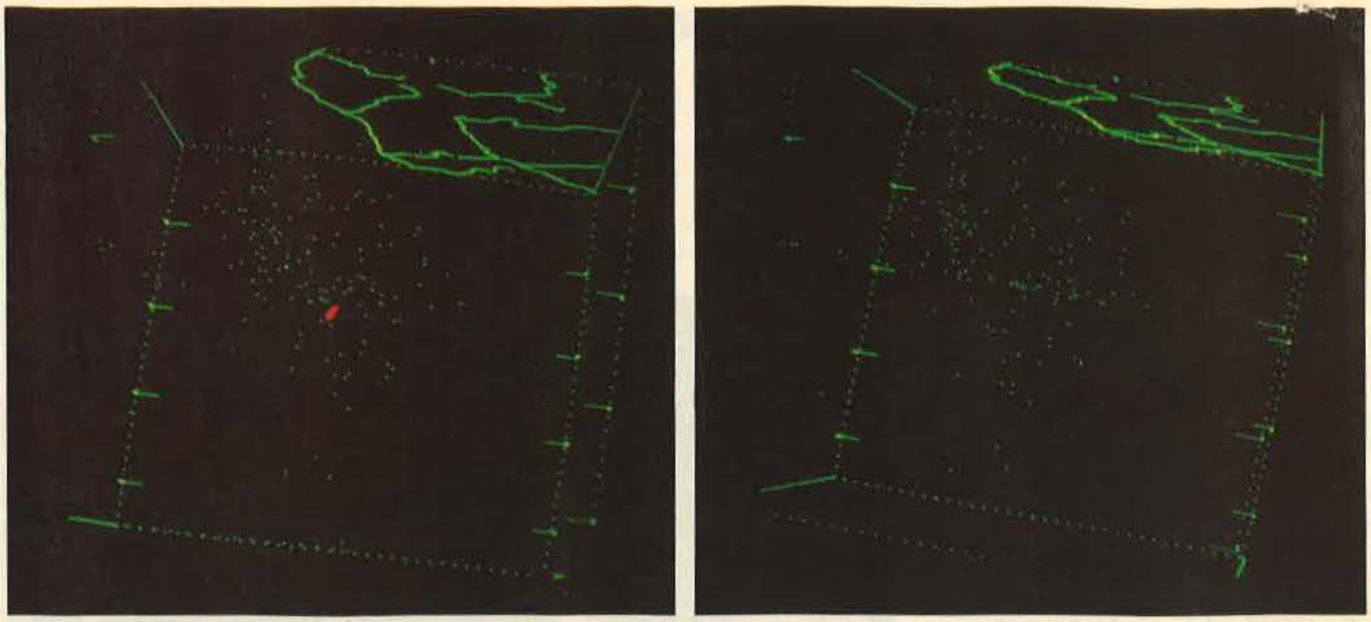


Fig. 11—These photographs were taken from different viewing angles of a single display on the SpaceGraph. The photos represent earthquake epicenters under an active Japanese fault belt. The red dot appearing on the left hand photo is an LED pointer that can be moved throughout the 3D image. While appearing 3D on the screen, any photographs taken from it appear two dimensional, as shown.

tions to seismic display, it will be interesting to watch the development of this system, as larger comercial versions are built. Plans are being made to build a larger device with an array diameter of six or eight inches. This will be rotated 20 times per second to decrease flicker. The use of multicolor LEDs to make a color display is also being evaluated.[31] Because the display is non-invadable, there has been talk that the system might be placed in the base of a set of parabolic mirrors.[16] This would allow the analyst to work with the 3D image.

VIBRATING MIRRORS

The most advanced, commercially available true 3D display devices are based on creating a volume of virtual images with a varifocal or vibrating mirror. This display volume is created by synchronizing the displays on a high resolution CRT with the movement of the mirror. The mirror is only moved about 4 cm (peak to peak) at its center, but the optics move the image position extremes about 35 cm.[32] Because of distortion, the normal virtual image volume evaluated with a 30-cm diameter mirror is an 18-cm cube.

There are two closely related methods of using the vibrating mirrors. The original patent was for a system that has a flexible mirror. This system, known as the Volume Viewer, has been worked on at the University of Utah Research Institute for several years now by Dr. Steve Johnson and Dr. Brent Baxter.[33] The mirror for this system is simply silvered Mylar film that is stretched over a large hoop. The mirror is moved by a standard woofer speaker. Several prototype systems have been developed and considerable software is available for the system to aid in displaying radiographs and other 3D medical data volumes. This software allows rotation of data volumes, etc.

The other system, called the SpaceGraph (Fig. 10), was developed by Dr. Larry Sher of Bolt, Beranek, and Newman, Inc., Cambridge, Mass., and has been licensed to Genisco computers. The first five systems, four of which will go to exploration research labs, should be delivered by the time this article is printed.

Besides the fact that additional software drivers are being integrated into the SpaceGraph during manufacturing, the biggest difference between the SpaceGraph and the Volume Viewer is that the SpaceGraph has a solid, and yet flexible mirror. Its display characteristics include a virtual image volume of up to 25 (X-axis) by 20 (Y-axis) by 30 (Z-axis) cm. There can be 32,768 points displayed in graphics mode, and 262,144 voxels displayed in image mode.[34] A voxel is a volume picture element, and was named by Dr. Sher.[18] Fig. 11 is a sequence of pictures taken off of the vibrating mirror. Unfortunately, the three-dimensionality of the display cannot be reproduced photographically.

Dr. Pizer at the University of North Carolina has developed another varifocal mirror system that is based on a standard color raster graphics display.[29] This system is routinely displaying CT images. Working with this system, Pizer found that there is still much to learn about gray scale before tackling the complex problem of color 3D display. The angle that a 3D object is viewed from turns out to be very important; therefore, an interactive procedure for continuous real time rotation of the displayed object has been developed.

Recently, the author has heard of other versions of this type of device. In this case, a projection device is used to put a sequence of pictures on a one-foot square translucent screen that moves through a one-foot volume. The screen performs the same function as the vibrating mirror. Another variation uses an electromechanical modulator to unscramble the same type of continuously deformed display that is being put up on a high resolution CRT to reflect on a vibrating mirror. New developments may be made that will allow a full-color true 3D display device. This is like adding a fifth dimension to x, y, z and motion. Given that mirrors can be used to overlay images, it seems feasible to put colored filters in front of different CRTs and merge the images to achieve a full-color 3D display. The phosphor persistence in color CRTs cause the image to streak in the Z-axis on a vibrating mirror. Therefore, a sufficiently fast phosphor needs to be filtered, or an aperture stop needs to be built that will cut off the image in the required time. The bottom line is that there is not a perfect 3D display device and a complete solution has yet to be developed.

SUMMARY

An interactive, high-resolution 3D volume display device is needed to help evaluate the volumes of geological and geophysical data being generated today. There have been 30 display developments in other scientific disciplines, even in the entertainment field, that may aid in the development of a workable 3D display system or technique for exploration; however, before geoscientists use true 3D display devices, effective methods must be developed for using high-resolution, two-dimensional computer graphics for interactive interpretation and processing. Experience developed in 2D can then be applied effectively to simultaneously evaluate an entire data volume on a 3D display device.

ACKNOWLEDGMENTS

There are certainly significant contributors to 3D display technology that have been missed in this cursory overview. The author apologizes in advance, and would be interested in any other information from readers on true 3D display devices. Thanks to Richard Verm and my wife for proofing the text.

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