STEREOSCOPIC COMPUTER GRAPHICS FOR SIMULATION AND MODELING

John A. Roese
Lawrence E. McCleary
Naval Ocean Systems Center
San Diego, CA

ABSTRACT

A visually effective stereoscopic CRT display technique has been developed which uses continuous tone computer graphics in combination with electro-optic shutter viewing devices. The technique involves the generation of left and right perspective views of an object model using continuous tone computer graphics. The perspective views constitute stereo pairs and are displayed in an alternating manner on the even and odd field scans of a conventional 2:1 interlace raster scan CRT display. When viewed with electro-optic shutters operated synchronously with the CRT field scan rate, the alternating perspective views are perceived as stereoscopic images with strong binocular depth-of-field sensations. Lightweight stereoscopic viewing glasses have been developed which use lead lanthanum zirconate titanate (PLZT) ceramics as electronically controlled shutter elements. Representative applications of the stereoscopic display technique to dynamic flight simulation and complex molecular modeling are presented. The flight simulation illustrates a landing sequence on an aircraft carrier while the modeling application shows complex three-dimensional structures of double helix DNA and bacterial ferredoxin molecules. The stereoscopic display technique has been shown to be highly effective for adding binocular depth-of-field to computer graphics displays with a resulting enhancement of object model realism.

KEY WORDS AND PHRASES: computer graphics, stereoscopic displays, PLZT electro-optic shutters, simulation, flight simulators and trainers, modeling, molecular modeling

CR CATEGORIES: 8.1, 8.2

INTRODUCTION

The combination of continuous tone computer graphics used with electro-optic shutter viewing devices has resulted in visually effective stereoscopic CRT displays with strong binocular depth-of-field sensations. Stereoscopic computer graphics display techniques are ideally suited for the creation of realistic simulations which give true or exaggerated depth-of-field effects and for computer modeling applications which require unambiguous visualizations of complex structural features.

The use of continuous tone computer graphics algorithms to generate stereoscopically complementary left and right perspective views of object models is straightforward. These algorithms are parametric in terms of object viewing orientation and can be used to generate stereo pairs of left and right object model perspective views. The stereo pairs are displayed on alternate field scans of a conventional 2:1 interlace raster scan CRT display. Stereoscopic viewing of the sequence of alternating perspective views is accomplished with the use of electro-optic shutters which are mounted in lightweight stereoscopic viewing glasses. Synchronous operation of the electro-optic shutters with the display of alternating left and right computer generated perspective images results in highly effective stereoscopic computer graphics displays.

Two major areas of applications for stereoscopic continuous tone computer graphics displays are simulation and modeling. Representative of display problems in these areas are dynamic flight simulations and the visualization of complex three-dimensional molecular structures.

STEREOSCOPIC DISPLAY SYSTEMS

Many different methods for producing stereoscopic displays have been devised dating from the invention of the familiar parlor stereoscope in the nineteenth century. For display applications involving computer driven CRT devices, two major classes of stereoscopic viewing systems have evolved. These are: systems which simultaneously present both left and right perspective views in a side-by-side manner on the CRT display (or on adjacent CRT displays) and use reflective or refractive optical means to superimpose the two perspective views; and systems which rapidly alternate the left and right perspective views on a single CRT display for viewing with synchronized shutter mechanisms.

A recent innovation in the latter class of alternating image stereoscopic CRT displays has been the use of lead lanthanum zirconate titanate (PLZT) ceramic wafers as electronically controlled optical shutters mounted in a stereoscopic viewer (6,7). Use of PLZT electro-optic ceramics represents a highly desirable alternative to earlier electromechanical shutter viewing mechanisms.

In PLZT steroscopic viewers, pairs of PLZT shutters are used as electronically triggered light valves which operate 180° out of phase with 50% duty cycles. As illustrated in Fig. 1, each PLZT shutter assembly contains front and rear linear polarizers with an electroded PLZT ceramic wafer in between. The axes of polarization of the front and rear polarizers are at right angles and are oriented at 45° with respect to the electric field applied to the PLZT ceramic wafer by the set of interdigital electrodes.

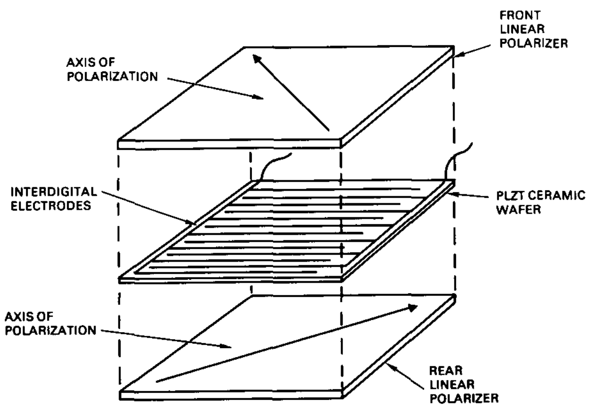

Figure 1. PLZT electro-optic shutter assembly.

In present implementations, the PLZT ceramic wafers are cut and polished to a thickness of 15 mils and chrome-gold electroded on one or both surfaces. Typical electrode width is 2 or 3 mils with interdigital electrode spacing of 40 mils.

Operation of the shutter assemblies as light valves stems from the birefringent nature of PLZT materials in the transverse mode due to the presence of an applied electric field. Birefringence is the difference in the index of refraction for light polarized parallel and perpendicular to an applied electric field vector. The value of the refraction index difference is related to the square of the applied electric field magnitude. This property is used to electronically control the amount of light transmitted or blocked by the PLZT shutter assemblies.

With no electric field applied to the PLZT wafer, light penetrating the front polarizer and PLZT ceramic is blocked by the orthogonal rear polarizer, resulting in minimum light transmission. However, with the application of a sufficient voltage potential, light traversing the front polarizer is rotated 90° by the PLZT wafer and can then pass through the rear polarizer to achieve maximum light transmission. Light exiting the rear polarizer of the PLZT shutter in the maximum transmission state maintains the linear polarization introduced by the front polarizer although it has undergone a 90° rotation by passing through the shutter assembly. Determination of the significant electro-optic parameters in the PLZT shuttering process has been described previously (2-4).

Pertinent operational characteristics of the PLZT electro-optic shutters for use in the stereoscopic viewer include: switching times between maximum and minimum light transmission states of less than 1 msec; optical contrast ratios exceeding 1000:1; and a 500 VDC operating voltage with a peak transient switching current of 30 ma. Spectral transmission characteristics for the PLZT shutters are approximately constant at 15 to 17% for wavelengths from 460 to 750 nmi but decrease rapidly at shorter wavelengths. Improved levels of operation and reliability have been achieved with the use of double sided electroding and plastic or glass polarizers bonded to the PLZT ceramic wafers.

Two implementations of the PLZT electro-optic shutter stereoscopic viewer including switching circuitry, power supplies, etc., are available commercially. A prototype PLZT stereoscopic viewer is shown in Fig. 2. As illustrated in this figure, the viewer housing is of a plastic design which can be attached to standard eyeglasses frames in the same manner as clip-on sunglasses. Normal display operations, such as seeing auxiliary readouts and operating control devices, are possible in average to bright ambient lighting conditions without removing the PLZT stereoscopic viewer.

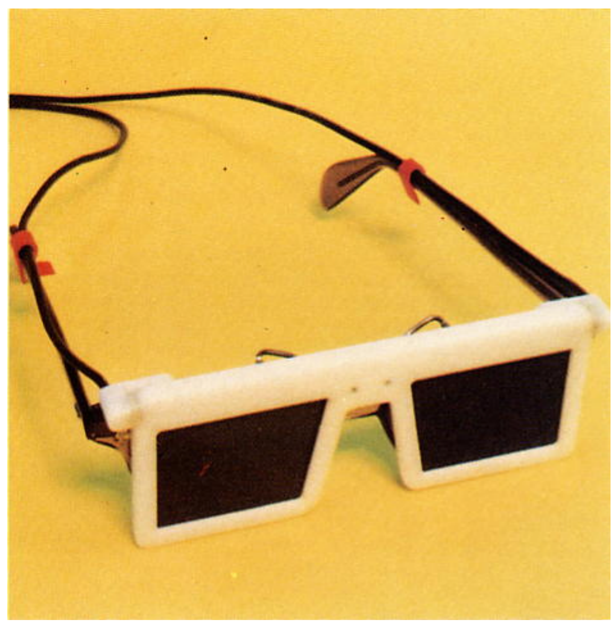

Figure 2. PLZT electro-optic shutter stereoscopic viewer.

An advantage of shutter type viewers is that the observer is essentially unconstrained in terms of normal head and body movements while looking at a stereoscopic computer graphics display. For prolonged periods of viewing, this can be of major importance for reducing observer fatigue. By way of comparison, conventional reflective or refractive stereoscopic devices typically impose severe observer viewing orientation limitations in order to continuously merge pairs of perspective images. In addition, multiple observers can view a single stereoscopic CRT display. The only requirement for simultaneous viewing is that each observer have his own stereoscopic viewer.

STEREOSCOPIC COMPUTER GRAPHICS

In order to produce realistic computer generated stereoscopic images, computer programs are used which produce continuous tone images of three-dimensional object models on raster scan CRT displays. These programs are parametric in terms of the viewing angle and permit complementary left and right image pairs to be generated and combined for stereoscopic displays. Two programs which are well suited for this task are MOVIE-BYU (1) and the Spherical Shading Program developed at the National Institutes of Health (5).

MOVIE-BYU is a highly user oriented program which can be used to produce perspective displays of two- and three-dimensional models of static images as well as dynamic animated sequences of line drawing or raster scan displays. The program works with polygonal representations of the object model and uses the Watkins algorithm (8) for performing hidden surface removal. In order to build a computer model to be displayed, a MOVIE-BYU preprocessor called UTILITY is executed on an interactive computer terminal. The user inserts X, Y, Z coordinate values for each nodal point of the object model and provides connectivity information in order to build triangular and/or quadrilateral panels (polygons) which define the surfaces of the object model. Panels are then grouped together to form major object parts which are displayed using various MOVIE-BYU options. A powerful feature of the package for many applications is the ability to assign translational displacements and scalar functions to individual object model nodes. MOVIE-BYU can be invoked from the user terminal to display the entire object model or subsets (parts) of the model as it is being developed. Parameters which are easily changed in an interactive mode by the user include:

- o field of view, object viewing distance, and near and far Z clipping planes;
- o rotation and translation of the entire object or separate parts;
- o geometric distortions based on nodal displacements or scalar functions;
- o selection of line drawing mode for vector displays or continuous tone mode for raster displays;
- o color assignment by parts for raster displays;
- o amount of ambient light for each part for raster displays;
- o type of shading for raster displays including flat and uniform for a faceted appearance and smooth shading for a curved surface effect; and
- o color assignments for encoding a fourth variable on a three-dimensional object model.

The Spherical Shading Program has also been used very successfully to produce color shaded surface displays of intersecting spheres. The techniques used for representing spheres provide speed and storage improvements over the polygonal approach of MOVIE-BYU. The Spherical Shading Program provides orthographic views of the object model and is implemented on a frame buffer with memory large enough to retain the entire image. Additional features of this program are the ability to soften the effects of aliasing around the sphere silhouettes and the ability to display scenes with both opaque and partially transparent spheres.

With the generation of left and right perspective views of an object using continuous tone computer graphics techniques, a composite image is produced which is suitable for stereoscopic viewing. This is accomplished by displaying the pair of images on a 2:1 interlace raster scan CRT using one view on the odd line field scan and the stereoscopically complementary view on the even line field scan. Stereoscopically complementary images are two views with a rotation about the vertical axis which will produce an effective depth of field sensation when viewed. Typically, the vertical axis rotation is about a point near the center of the object so that the front of the object will appear to extend out from the screen, while the rear of the object will appear to extend into the screen. Also, the amount of rotation is an important consideration. In general, the horizontal viewing orientation specified for generation of the left and right views should increase with decreasing object viewing distance.

The stereoscopic computer graphics technique is illustrated in Figs. 3 through 5 for an idealized submarine hull model data set. MOVIE-BYU was used to produce the perspective views with smooth shading for the curved surfaces. Fig. 3 shows the left perspective view on one field scan with the interlaced field scan blanked. The right perspective view is contained in the other field scan as shown in Fig. 4. The composite image in the form required for stereoscopic viewing is shown in Fig. 5. Here the greatest horizontal displacements are at the bow and stern with little or no displacement near the center of the body. Points with no horizontal displacement will appear to be at the surface of the CRT screen while the bow will extend outward and the stern inward from the viewing surface.

The visual sensation of a three-dimensional image is achieved when the composite image is displayed on a 2:1 interlace CRT and viewed with the PLZT stereoscopic viewer. The electro-optic shutters in the stereoscopic viewer are operated synchronously with the CRT vertical retrace sync pulse such that the perspective view for one eye is seen during one field scan while the other eye's view is blocked. The process is reversed during the subsequent field scan to accommodate the perspective view for the other eye. Repetition of this sequence at or near normal 30 frames/sec (60 fields/sec) rates causes the observer to merge the rapidly alternating perspective views into a composite three-dimensional image. Losses in vertical resolution are inherent in this technique because the perspective view seen by each eye is contained on a single field scan. However, since the odd and even field scan lines are interleaved when written on the CRT, the resulting resolution loss as perceived by the observer is minimal. When used with newer 60 frames/sec CRT displays, each perspective view is presented at full resolution and, consequently, there is no loss in resolution when viewing stereoscopic images.

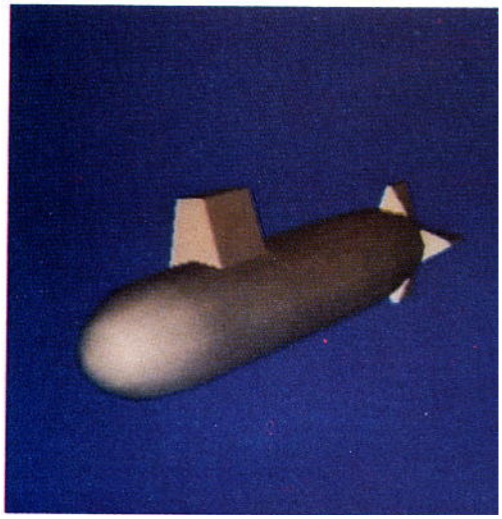

Figure 3. Single field scan left perspective view of submarine hull model.

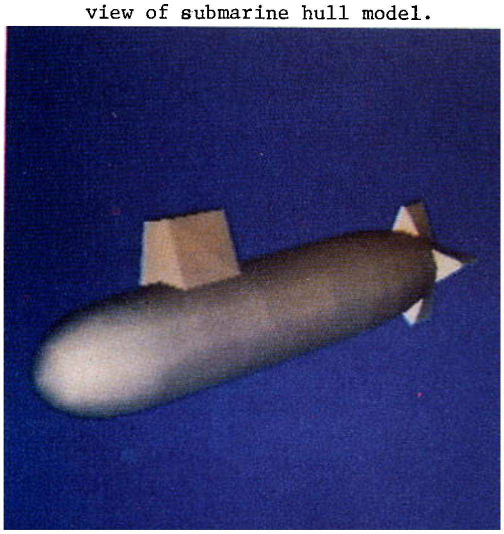

Figure 4. Single field scan right perspective view of submarine hull model.

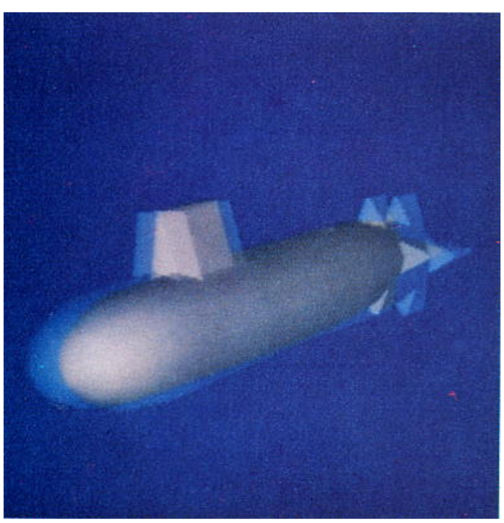

Figure 5. Composite left and right perspective views with 2:1 interlace field scans.

SIMULATION AND MODELING APPLICATIONS

The enhanced realism resulting from stereoscopic depth-of-field effects is a highly desirable perceptual cue for many computer graphics applications. These applications include the generation of realistic static and dynamic simulations of real-world objects and modeling of physical phenomena and abstract mathematical relationships. Automotive design, architectural studies and flight trainer simulations are representative of real-world computer graphics applications which would benefit from the use of stereoscopic display techniques. Other categories of computer graphics applications include dynamic models for air traffic control, visualization of mathematical defined sonar or radar cross correlation surfaces and molecular structure analysis.

A conceptualized multiple viewing screen flight trainer is illustrated in Fig. 6. In this trainer configuration, the geometric relationships between the subject and the viewing aspect for each screen are factored into the computer graphics software for simultaneous generation of the multiple views. In a truly interactive environment, the computer graphics software would generate new images in a near real-time fashion according to the subject's responses. The use of video projectors as shown in Fig. 6 is a candidate method for generating large screen images for added realism. An alternative method would be to use conventional CRT monitors at a closer viewing distance. In either case, the use of standard 2:1 interlace raster scan display technology with the perspective views displayed on alternate field scans will result in stereoscopically induced depth-of-field sensations. In Fig. 6, the subject is shown wearing PLZT stereoscopic viewers. Of major importance is the fact that the viewers do not unduly constrain the subject's field of view or head movements. Thus, a greatly enhanced sense of realism can be incorporated into present day flight trainer/simulator technology with minimal impact to the subject or to the system designer.

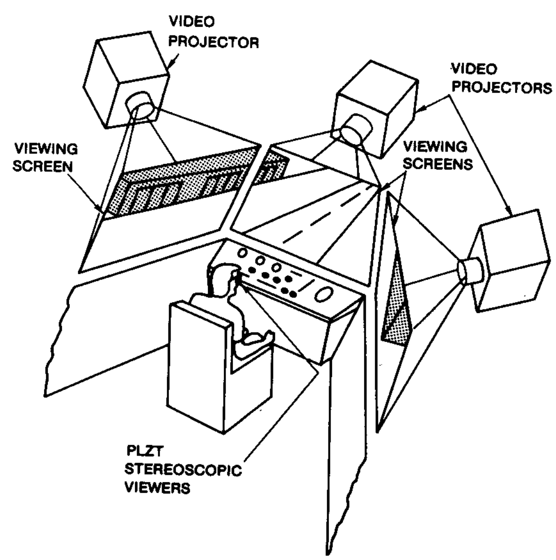

Figure 6. Multi-screen trainer configuration for stereoscopic flight simulator.

As an illustration of a simulation sequence as it might be seen from the center viewing screen of the flight trainer configuration, a computer generated aircraft carrier landing sequence has been developed. This sequence begins with the acquisition of the carrier at a large distance, the approach and maneuvering to obtain a proper landing orientation, and the final approach. Figs. 7 through 12 show selected scenes from the landing sequence. Each scene presents a single perspective view of the aircraft carrier model at full 512 X 512 spatial resolution.

When presented on a 2:1 interlace display, the landing sequence is viewed stereoscopically by displaying the pair of perspective views generated for each scene on alternate field scans. Fig. 7 shows the aircraft carrier soon after it has been acquired visually. Since there would be no perceived depth-of-field sensation at this extreme viewing range, the two perspective views generated by the computer are essentially identical. Figs. 8 and 9 illustrate the approach to the aircraft carrier and circling maneuvers. The effects of decreasing altitude and final alignment adjustments with the flight deck are shown in Figs. 10 through 12. Increasing horizontal displacements are introduced between the perspective views for the latter scenes of the sequence to heighten the depth-of-field sensation corresponding to smaller distances to the aircraft carrier model. This sequence was produced using MOVIE-BYU and serves to highlight the capabilities of this software package for changing the object viewing distance and orientation.

Two examples of idealized molecular structures are used to illustrate the application of stereoscopic computer graphics to object modeling. These examples are presented in Figs. 13 and 14 and show a complex double helix DNA structure and a bacterial ferredoxin molecule. These molecular structure models were generated by the NIH Spherical Shading Program and represent isolated scenes taken from a sequence of views generated by rotating the molecular models at fixed intervals. Models such as these have proven to be valuable interactive laboratory tools and training aids for molecular biologists in order to visualize complex molecular structures. For example, the double helix nature of the DNA structure of Fig. 13 can be determined by careful examination of individual scenes. However, this structure becomes immediately apparent when viewed stereoscopically.

For stereoscopic viewing, 4° rotations of the models about their centers were generated. The two views serve as left and right perspective image pairs. The perspective images are displayed on alternate field scans in the fashion described previously for viewing with the PLZT stereoscopic viewers. By proper handling of the data, lines deleted to form the right perspective view of one scene are used to generate the left perspective view for the next scene. In this manner, n-1 stereoscopic scenes can result from n full resolution views as generated by the computer. In the case of a rotation sequence covering a full 360°, all n views can be utilized to generate n stereo pairs.

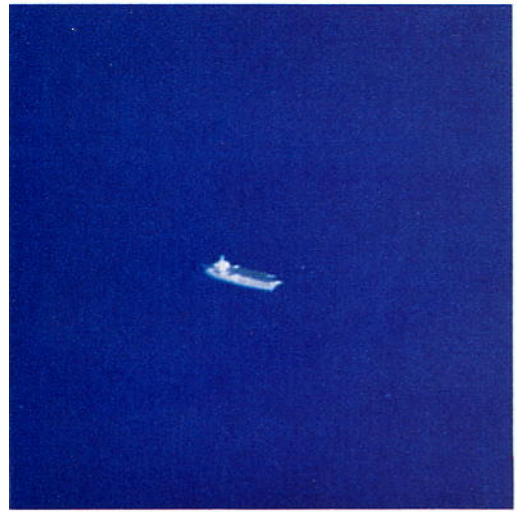

Figure 7. Long range visual acquisition of aircraft carrier.

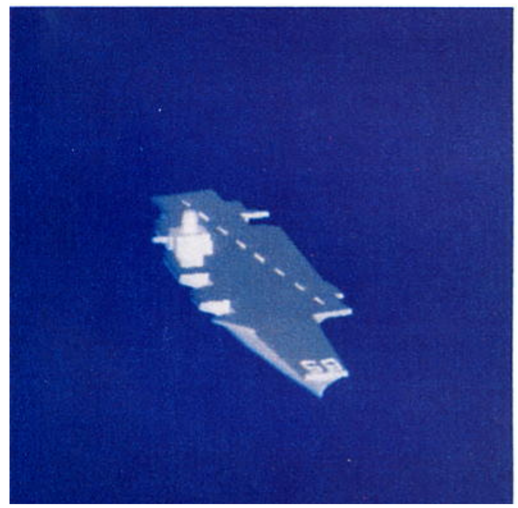

Figure 8. Bow aspect approach and circling maneuvers.

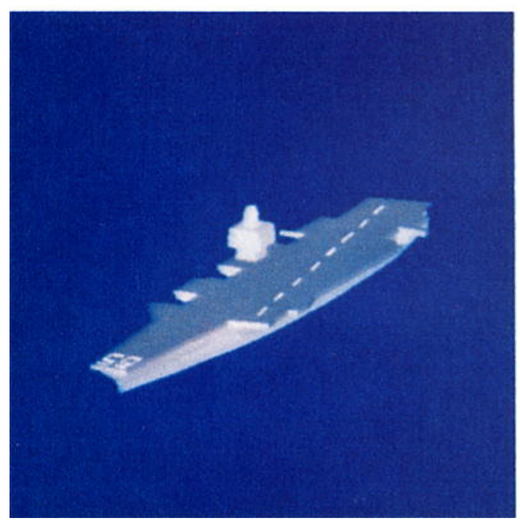

Figure 9. Bow aspect approach and circling maneuvers (Cont.)

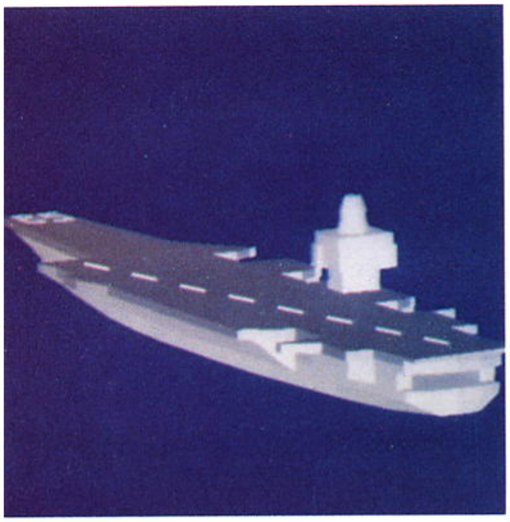

Figure 10. Stern aspect approach with decreasing altitude.

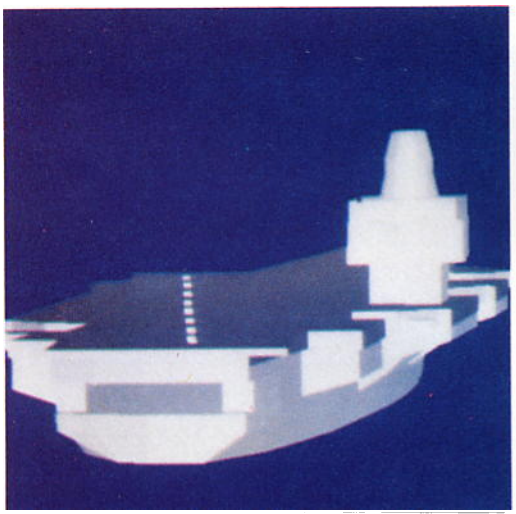

Figure 11. Stern aspect approach with proper runway alignment.

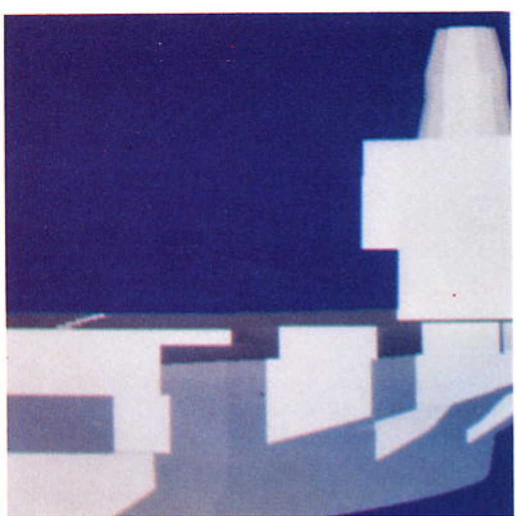

Figure 12. Final approach for landing.

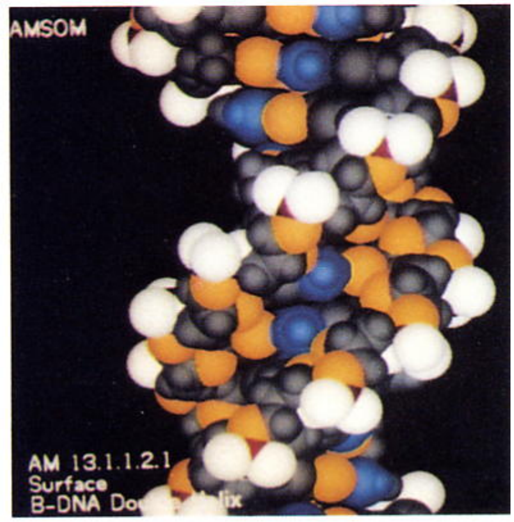

Figure 13. Double helix DNA structure model.

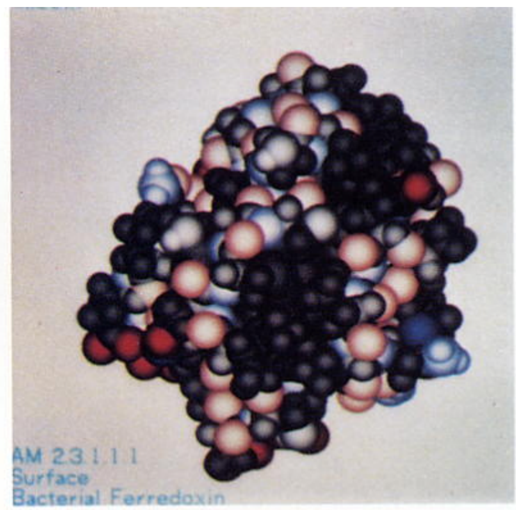

Figure 14. Bacterial ferredoxin molecule model.

CONCLUSIONS

Alternating image stereoscopic display techniques represent a class of simple yet visually effective methods for adding depth-of-field sensations to computer graphics displays. Stereoscopic techniques have been shown to be well suited for enhancing the realism of flight trainers and simulators and for providing unambiguous visualizations of complex computer generated object models.

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