Stereopsis to Support Discovery-Based learning

Stephanie A. Smullen
Clinton W. Smullen III
The University of Tennessee at Chattanooga
Stephanie-Smullen@utc.edu
Clinton-Smullen@utc.edu

Abstract: Stereopsis is an important part of scientific visualization in some areas, such as the geosciences, physics, mathematics, medicine and chemistry. Its use is increasing in many others such as architecture, land management, and homeland security and in workforce training programs. It is important that students studying these subjects be trained in the use of such visualization tools. The use of stereopsis can also benefit non-specialist students by encouraging discovery-based learning and enabling a student to manipulate the data presentation to uncover relationships and to build insight. This paper discusses the technologies used to display stereoscopic 3D images. Affordable hardware solutions are discussed for a variety of viewing techniques: GeoWall, shutter glasses, and anaglyphs. Special software is needed for stereoscopic viewing. Two viewing programs, Stereoviewer and StereoFunctions, are presented with applications.

Introduction

The widespread use of computers in education has developed only over the last twenty-five years. Early computers presented information using a one-dimensional line-based interface. In the last fifteen years two-dimensional presentations, such as the graphical user interface using windows, icons, menus and mice, have become standard. On the web, pages largely use the two-dimensional document model. In the last decade three-dimensional technology has advanced, driven by improvements in computing and display power. Sophisticated graphical displays are rapidly becoming the norm in several professional fields. The current student generation has grown up with TV, multimedia computer games and sophisticated animated movies. Leading edge graphics technology can be used to engage their interest and deepen their learning experience.

Background

The term three-dimensional (3D) display can be used in two different ways. Monoscopic 3D is a representation of objects in a 3D space by length, width and height coordinates on a 2D surface such as a computer monitor. The perception of depth is simulated by visual clues such as lighting, shadows and perspective. Stereoscopic 3D (stereopsis) simulates depth perception by using two images, a stereo pair consisting of a left eye perspective and a right eye perspective. The left eye sees only the left view and the right eye sees only the right view. This mimics the real-life behavior of the human eyes. Stereopsis dates from 1838, when Charles Wheatstone published his discovery of stereopsis in a paper to the Royal Society (Wheatstone, 1838).

Monoscopic 3D requires no special viewing hardware. Many inexpensive, general-purpose computer packages are available that can generate such images with modest effort. Some of these software packages allow the user to move the viewpoint to explore the image. While these images can provide useful tools for showing the dimensional relationships, they fail to fully exploit human perception and the long practiced human ability to understand three-dimensional space. Humans naturally learn about their world by manipulating the objects within it. This manipulation can also help to develop an understanding of spatial relationships and mathematical concepts. The manipulation of 3D objects needs stereopsis to provide a three-dimensional view, a view that changes as the object moves relative to the user.

While both monoscopic and stereoscopic representations offer the perception of depth, only stereopsis allows users to take advantage of their stereoscopic vision. This can be a benefit in understanding complex structures, where a 2D or monoscopic representation does not provide sufficient visual cues to allow a viewer to fully understand the structure. Stereopsis also helps the viewer to judge relative sizes of objects and distances between objects. In stereopsis, the user can move the view as needed to understand the structure, to recognize an object that sits in an unusual orientation, or to see parts of the object that were otherwise hidden from view. Stereopsis today requires special viewing hardware. It is the low cost and high performance of modern computer systems that makes stereopsis practical for educational use with a variety of audiences.

Stereopsis is an important part of scientific visualization in some areas, such as the geosciences (for terrain and volume visualization), physics (for astronomy, design of optical devices, and the study of physical properties), mathematics (for experimental mathematics), medicine (for 3D imaging, x-ray displays and surgery planning) and chemistry (to study the 3D structure of molecules), and its use is increasing in many others (such as collaborative design, architecture, land management, and homeland security) and in workforce training programs. The use of stereopsis in computer gaming is driving the development of 3D displays for the consumer market.

Stereopsis has become a basic scientific tool for practicing scientists in several fields. It is important that students studying these subjects be trained in the use of such visualization tools. However, the use of stereopsis can also benefit non-specialist students. It encourages discovery-based learning by enabling a student to manipulate the data presentation to uncover relationships and to build insight. When used with real data, it allows users to interact in an intuitive manner with the data presentation. There is evidence that the use of 3D visualization as a teaching method assists in improving information retention (Hubona, Shirah and Fout 1997). It certainly provides a dynamic and active learner-centered experience. The utility of stereopsis has been publicly demonstrated by the Mars Rover missions. Both Rovers include panoramic cameras that provide both panoramas and stereo views of the terrain. The availability of these images has generated a large amount of public interest in stereopsis. The images also demonstrate the usefulness of stereopsis. The variations of surface of Mars can be easily seen in the stereoscopic images, but are very difficult to discern in the single (monoscopic) images.

Stereopsis Technology

The technology used to deliver stereoscopic 3D varies in cost by three orders of magnitude or more. The growing popularity of IMAX™ theaters illustrates the public acceptance of large-scale immersive and 3D viewing. Several recent commercial movies were released in both standard format and IMAX™ 3D. IMAX™ cameras and projectors use 70 mm film to provide large, immersive images. Two projectors, each with a polarizing filter, are used to provide the stereopsis for IMAX™ 3D. Viewers must wear polarized glasses. The polarizing filters and glasses are arranged so that a viewer's left eye sees the left image and blocks out the right image, and vice versa for the right eye. Such projectors cost from $50,000 to over $1 million. Costs for commercial 3D systems (such as those from Christie Digital Systems) using similar technology for use in a presentation room start at $20,000. Electronic News (September 6, 2004) reported that in the next five years, sales of 3D display systems in the private sector are predicted to increase by 250%.

The GeoWall (Morin, 2004) technology was developed to make 3D viewing of geographic data easily affordable and accessible. The GeoWall projection technology can be acquired pre-packaged for $10,000 to $20,000 or assembled from individual components for $6,000 to $10,000. There are currently over 400 GeoWall installations in universities, research centers and museums. The GeoWall technology provides a cost-effective system for classroom or large group use of stereoscopic images.

Autostereoscopic displays that require no special eyewear for the user are under development. High definition displays (such the HD3D TV from DeepLight) are scheduled to appear on the market in 2006 and will cost over $10,000. Lower resolution computer displays (such as the Sharp LL-151-3D) are available for about $1500, although the 3D image is viewable by only one person at a time and the current resolution is below what is needed for scientific visualization.

A computer CRT monitor may be used by a few people for 3D viewing using shutter glasses to provide active stereo. The left and right eye images are presented in rapid succession on the monitor, and the LCD shutters on the glasses go alternately transparent or opaque in perfect synchronization with the stereo pairs being presented. When the left eye image is being presented the left eye shutter of the glasses is transparent and the right eye opaque. The reverse is true when the right eye image is being projected. The synchronization signal may use a wire or it may be wireless. Both the computer display card and the software application must support this sequential presentation of the image pairs. The cost of shutter glasses is dropping, and quality shutter glasses can be bought for under $300 today. Lower resolution shutter glasses cost $75 to $100.

Anaglyphs are a simple way of presenting passive stereo pair images. Here, the glasses have two different color filters, for example red on the left eye and cyan on the right eye, but no moving or electronic parts. The left eye image is colored in shades of cyan while the right eye image is colored in shades of red. The two images are then overlapped appropriately to provide the stereographic separation, and the result makes the presentation image. Some people find that the red/blue glasses create eyestrain and hence are more difficult to use than the polarized glasses utilized in GeoWall technology. Anaglyphic glasses can be bought for $1 to $10.

Stereopsis requires a pair of images. The paired images can be generated using one computer with a graphics card that provides two outputs, or using multiple computers. Moderate cost graphics cards (such as GEForce4 and ATI Radeon, $80) provide two display outputs that can be used in a horizontal or vertical span mode to produce two full size images, one per display output. More expensive graphics cards (such as the NVidia Quadro line) have two display outputs and four display buffers. These buffers can be used to store left and right, front and back images for display purposes, improving performance.

Stereopsis Software

Special software is needed for stereoscopic viewing. Much of the software used with a GeoWall is available as open source software through the GeoWall website. Some commercial software is also becoming available, primarily for geographic information system display (Davis, 2004). The original GeoWall configurations were based on Linux systems. As a result, much of the cross-platform software is command line based. The Viewer program (Burdick, 2005) is a stereo pair aligner and viewer. It provides a variety of options for extracting and aligning stereo pairs. However the command line interface of Viewer is somewhat difficult to use.

While the GeoWall programs are open source and easily obtainable, they require some expertise to download, install and set up, and the command line interface can be difficult for some to use. The commercial software is quite expensive. Programs are needed that are openly available, small in size, easy to download and install, support the several types of stereoscopic images in use, and provide the use of a graphical user interface.

The viewing program Stereoviewer (Smullen and Dudley, 2005) meets these needs. It has a graphical user interface. The current version utilizes a Windows Open File dialog to allow the user to easily select files for display. The remainder of the program is operating system independent, and is easily transported to other environments. The current version runs on all Windows-based computers.

Stereoviewer uses stereopsis techniques for 3D visualization. It allows two views of a scene to be loaded, one for the left eye and one for the right, and displays the scene so that objects appear to have depth. Stereoviewer supports all of the stereoscopic technology mentioned above. The user can view the stereo scene using passive stereoscopy (with projectors, polarized filters and polarizing glasses), active stereoscopy (with shutter glasses), as an anaglyph image (with red-cyan glasses), or with an autostereoscopic display.

Stereoviewer allows the use of images stored in a variety of file formats: bmp, jpg, gif, png, ppm, and the most common of the tiff file formats. The image overlap can be adjusted to align the pair for optimal stereopsis. Adjusted images can be saved for later viewing.

Stereoviewer also supports a variety of stereo presentation techniques: dual screen with horizontal or vertical span, quad buffered stereo display, and anaglyphic single or dual image display. A variety of options and features are provided:

- Multiple File Modes: The user can open a single image file (into both views) as a stereo pair or as single image. For added flexibility, the user can load a separate image into the left eye view, and another image into the right eye view. To speed things up, the left and right eye images can be loaded in succession with one command.
- Alter Red/Cyan: The user can select the left or right image as the red image. The other image is cyan. This supports both varieties of anaglyphic glasses in common use.
- Full Screen: The image can occupy the entire scene or a smaller window size.
- Position Image: The image can be rotated 90, 180, -90 or -180 degrees. To allow for precise alignment, the image can be moved left, right, up or down.
- Multiple Display Sizes: The image can be displayed with its native proportions or be sized to fit the current window. In addition, the left and right images can be sized together or separately.
- Stereo Buffer: The display card's buffer capability is automatically detected. If the card provides quad buffering, the use of the left and right buffers can be toggled off and on.
- Trim image overlap: Images that have been moved for alignment may have a ragged border. This option allows the overlap to be trimmed from the display.
- Save Display to File: The image(s) as displayed in the window(s) can be saved to a file.

Stereoviewer uses OpenGL and the glut libraries (OpenGL, 2005) for display. The file open display routine is operating system dependent. The current Windows application file executable is only 36 KB. However, a number of dll libraries are required for the application's files and glut display: glut, jpg, png, tif and gif. The executable and dlls are about 2.3 MB. A complete installation file is available that installs all needed parts. The installation file without examples is 2.7 MB. A set of extensive example images is available separately (6.5 MB) or packaged with Stereoviewer (9.2 MB).

A variety of special purpose programs allow the display of molecules, the astronomical universe and other physical phenomena. Abstract phenomena such as mathematical functions can also be displayed. The understanding of many mathematical structures can be enhanced by displaying their graphs in 3D. The field of experimental mathematics (Bailey and Borwein, 2005) applies the scientific method to mathematical research. It uses computation to investigate mathematical structures, identify their fundamental properties, and make conjectures that can then be tested by additional experiments and theoretical work. An important component is the use of sophisticated graphical displays to assist in the investigation. Mathematics programs such as MATLAB™ and Maplesoft will generate anaglyphic images for viewing, but the resolution of these images is not generally good enough to project on a large screen or to enlarge for detailed examination.

The StereoFunctions (Smullen and Dudley, 2005) program was developed to produce 3D displays, suitable for projection, of a variety of mathematical structures. Structures that have been tested with the software are simple geometric 3D shapes (cube, sphere, grid), complex geometric shapes (pulsar, tritorus, Lorenz attractor, knots and spirals), and differential equations (heat transfer and wave function solutions). The user can rotate the display in any axis to view the result from a different point, and use a zoom feature to enlarge or shrink the display. A simple file format allows the user to define additional structures to display. This program is operating system independent. The executable is 500 KB. It does require the glut32.dll (232 KB).

Conclusions

Improvements in computing power and display capabilities, along with decreasing hardware costs, have made the use of stereoscopic visualization achievable over a wide range of cost and performance. The software described here provides a more easily usable and more affordable alternative to expensive commercial software. It supports the range of current stereoscopic display technologies in use. The small size and ease of installation make this software usable by self-learners and distance education students, as well as students in a more traditional setting.

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