An Overview of Autostereoscopy as Used in Augmented and Virtual Reality Systems

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ABSTRACT

Displaying images in 3-dimensional form can prove useful for performing certain tasks, and also for entertainment purposes. In this paper we discuss 3-dimensional imaging without the use of external hardware for the user. This type of 3-dimensional imaging is becoming more and more popular as related technologies continue to develop. We also look at how 3-dimensional imaging can be used with augmented and virtual realities. Topics of commercial and professional use are discussed, along with some knowledge of how these uses work for some 3-dimensional displays.

Categories and Subject Descriptors

I.3.1 [**Computer Graphics**]: Hardware architecture—*Three-dimensional displays*; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism

General Terms

Design, Human Factors

Keywords

Stereoscopy, Autostereoscopy, 3-Dimensional Imaging, Parallax Barrier, Lenticular Lenses, Augmented Reality, Virtual Reality

1. INTRODUCTION

Technology for displaying images in 3-dimensional (3D) form is becoming more widely used. Although movie theatres have been showing 3D movies for many years, the progression of technology for displaying 3D images has grown rapidly throughout recent years. There is a trend to want to display 3D images without the use of external utilities worn by the user. There are multiple ways of achieving this type of 3D imaging, some of which are described in this paper.

Beyond entertainment, there are many practical uses for displaying 3D images without the use of external hardware. The technology of today has allowed companies to prototype virtual models through 3D displays, thus saving time and money on physically building them. Electronic communication is widely used throughout the world, and 3D imaging can help provide a more realistic feel to human interactions over a distance.

We describe how autostereoscopy can be used for several practical purposes. Background on stereoscopy and autostereoscopy are given, as well as an example of a failed attempt at creating a stereoscopic video game console. We also describe how autostereoscopy can be used for virtual prototyping and live display. How autostereoscopy can be used in augmented and virtual realities is also discussed.

2. BACKGROUND

2.1 Stereoscopy

Stereoscopy creates an illusion of three-dimensional depth from images on a two-dimensional plane. It works by presenting a slightly different image to each eye. It was first invented by Sir Charles Wheatstone in 1838 [8]. Many 3D displays use this method to display images.

Stereoscopy is used in many places today. It can be used to view images rendered from large multi-dimensional data sets such as ones produced by experimental data. Stereoscopy is used in photogrammetry, the practice of determining the geometric properties of objects from photographic images. Stereoscopy is often used for entertainment purposes, such as through stereograms. A stereogram is an optical illusion of depth created from flat, two-dimensional image or images. Stereograms were originally two stereo images that were able to be viewed through a stereoscope. A user would look through the stereoscope and view one image through the left eye and one image through the right eye, thus creating the 3D effect. Today there are several other ways to display stereograms that are not described in this paper, such as rapidly switching between images to achieve a similar effect.

2.2 Failed Stereoscopic System: Virtual Boy

The Nintendo Virtual Boy was first introduced in July of 1995. It was the first dedicated stereoscopic video game console released to the public. It is considered the most famous market failure by Nintendo, a large video gaming company. The Virtual Boy console did not last a year on the market before it was pulled. Its number of unique videogames was limited to 22, with 14 games released in North America and 19 released in Japan.

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Figure 1: The Virtual Boy console [9].

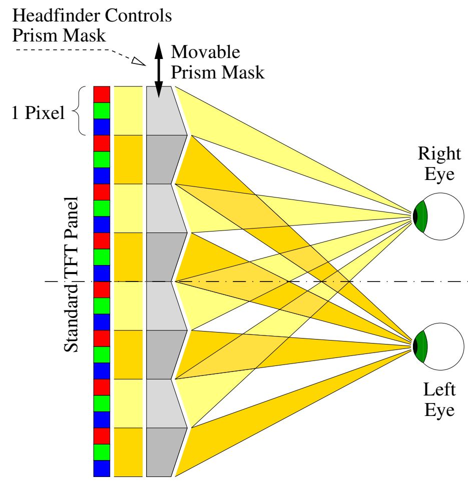

Figure 2: Principle of an autostereoscopic display [5].

Virtual Boy worked based on oscillating mirrors that displayed a linear array of lines, powered by light emitting diodes (LEDs), one for each eye [9]. The user placed their face against the eyepiece, which blocked out external light, and allowed them to focus on the two internal electronic displays. The controller for Virtual Boy held 6 AA batteries required to power the console, and was connected to the underside of the unit.

Although Virtual Boy used sophisticated technology for its time, it was limited to using only a single color for the display: red [9]. This limitation likely made the videogame console unattractive to buyers. Other popular gaming consoles at the time used many more colors.

The system was criticized for being uncomfortable to play. It required the player to hunch over, and also reportedly caused physiological effects such as motion sickness and eyestrain after extended periods of use. Some of these problems are alleviated through an autostereoscopic approach.

2.3 Autostereoscopy

Autostereoscopy is defined as any method of displaying stereoscopic images without the use of special headgear or glasses on the part of the viewer [7]. This technology can include motion parallax and wide viewing angles. Motion parallax uses eye-tracking, while wider viewing angles do not need to track where the viewer's eyes are located. Some examples of autostereoscopic displays include parallax barrier, lenticular, volumetric, electro-holographic, and light field displays. Several of these display types will be described later in this paper.

Most 3D flat-panel displays today use lenticular lenses or parallax barriers that redirect incoming imagery to several viewing regions at a lower resolution. When the viewer's head is in a certain position, a different image is seen with each eye. This gives the illusion of a 3D image.

Eye tracking can be used to limit the number of displayed views to just two. One disadvantage of eye tracking is that it limits the display to a single viewer. It tracks only one viewer's eyes, and therefore can not be used in larger viewing environments.

Many systems for autostereoscopic impression use a prism system or thin blades to bend or block pixel columns of a standard thin-film transistor (TFT) display. This works in a way that alternating columns can be seen either with the left or with the right eye. One approach is to use a prism mask to bend the rays and also use a dual-camera system to track the position of the viewer's eyes [5]. An embedded processor interprets the eye position and controls the position of the prism mask (see Figure 2). A pair of stereographic images has to be rendered vertically interlaced into the frame buffer for this type of display to work. Alternative techniques are described in subsequent sections of this paper.

3. MOTIVATION AND PRACTICAL USES FOR AUTOSTEREOSCOPY

Autostereoscopic displays can serve many practical purposes. Companies are able to save economically by creating virtual prototypes instead of physically building real ones. Wearing glasses to see 3D movies or images can be intrusive and uncomfortable if the user is also wearing corrective eyeglasses, while autostereo displays solve this issue. Live long-distance autostereoscopic chat could provide a more realistic experience for users on both ends of the display. There are other interesting uses for autostereo displays as well. Here, we describe two practical uses of autostereoscopy in more detail.

3.1 Virtual Prototyping

Virtual prototyping is increasingly physical real mock-ups and experiments in industrial product development [5]. Part of the process is simulation of structural and functional properties. Many aspects of this methodology are based on finite element analysis. Finite element analysis is a technique for finding approximate solutions of partial differential equations as well as integral equations.

One example is from the automotive industry. A simulation model for a safety improvement resulting from an automotive crash can consist of up to one million finite elements. Stereographic projection can support engineers who are working on complex finite element models. Engineers are able to be immersed in a 3D illusion without the need for external equipment through autostereoscopic displays (see Figure 3).

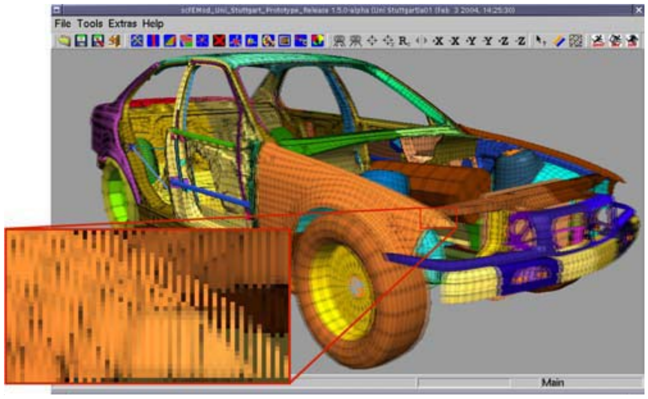

Figure 3: Finite element model of a car rendered for display on an autostereoscopic monitor (data courtesy of BMW AG) [5].

3.2 Live Autostereoscopic Display

The ability to record 3D video and display it back in 3D is becoming a somewhat more realistic possibility. Advances in multi-image capture and multi-projector display allow this to be possible. Hewlett-Packard (HP) Laboratories have created a low-cost wide-VGA-quality low-latency autostereoscopic display of live video on a single PC [1]. Multiple users are able to observe and interact with a life-sized display surface responsive to their positions.

Capturing, transmitting, and reconstructing enough of the local lightfield is a challenge for establishing 3D video communication. Five major challenges for this work come from multi-viewpoint capture, multi-viewpoint display, mathematics and analysis for calibration across them, efficient compression to permit reasonable transmission, and smart processing of the signals to provide an interactive experience [1]. Researchers at Hewlett-Packard Laboratories discuss the first three.

Their system works with 9 cameras and 9 projectors offering 7 discrete binocular view zones at the plane of the projectors. Video bandwidth approaches a gigabit per second. Hewlett-Packard Laboratories states that their camera system can support 8 times this number (72 imagers) [1].

4. AUTOSTEREOSCOPY IN AUGMENTED AND VIRTUAL REALITY SYSTEMS

Augmented reality (AR) refers to a live direct or an indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input, such as sound or graphics [6]. The technology functions by enhancing one's perception of reality. Advanced AR technology allows the information about the surrounding real world of the user to become interactive and digitally manipulable. Virtual reality (VR) works in a similar way except that it replaces the real world with a simulated one. In this section, we describe three AR or VR systems and how they use autostereoscopic techniques to achieve 3D imagery.

4.1 ASTOR

ASTOR is an Autostereoscopic Optical See-through Augmented Reality System. See-through augmented reality displays can be either video or optical see-through. Head-mounted displays usually use video see-through technology. This is much more common than optical see-through displays, because of compatibility and availability issues. Optical see-through displays are typically the preferred choice in many applications in which a "direct" view of the world is desirable.

ASTOR uses an optical see-through display where a holographic optical element is used for autostereoscopy. It is a "walk-up-and-use" 3D augmented reality system where the user does not need to wear any external equipment. Different images are seen depending on the user's position. The holographic optical element in ASTOR produces a holographic image of a light-diffusing screen. When the holographic optical element is illuminated, the light reflects to create a real image of the diffusing screen floating in front of the holographic optical element plate (see Figure 4).

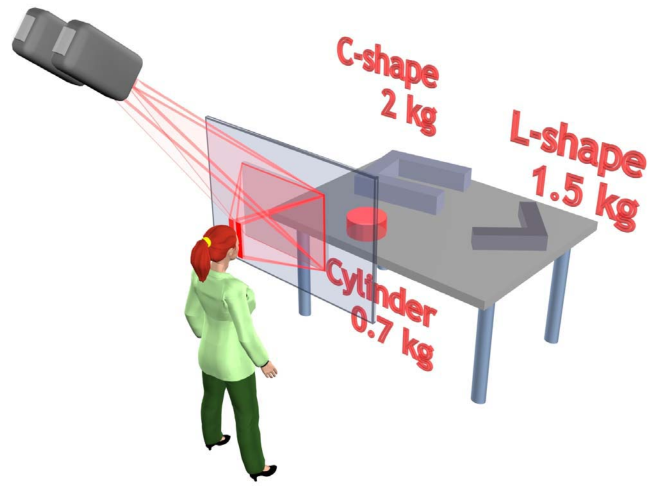

Figure 4: An autostereoscopic optical see-through augmented reality system [3].

The diffusing screen can be extended in the vertical direction and narrowed in the horizontal direction to form a vertical slit. The holographic optical element will produce one slit image for each light source. Light from the left projector in Figure 2 will pass through the right slit. The opposite applies to light from the right projector. The slits can be lined up side by side by adjusting the projector positions. Adding more projectors will increase the number of perspective views and enlarge the viewing zone.

The technology used for the display are consumer-grade projectors. Each projector is driven by a separate computer (2.5 GHz CPU, 256 MB RAM, NVIDIA GeForce4 MX 440-SE) [3]. Java3D is used for rendering and Java Remote Method Invocation is used for communication in a client/server architecture over TCP/IP. The display is suitable for augmented reality applications since it provides good see-through capabilities, it has more than sufficient brightness, it does not physically interfere with the real scene seen through it, and it is economic to produce [3].

There are some limitations to the ASTOR project. The number of views is limited to the number of projectors used, and are also constrained to lie along the horizontal axis. This means that the display suffers from image distortions that are common to all horizontal-parallax-only displays. When the viewer gets closer or farther from the display, the depth position of an image point will change. The prototype is also limited in that it can currently only display monochrome red images. It is believed that developing a color version will be non-trivial after a color-capable holographic optical element has been manufactured [3]. The human viewer has to focus on both the display and the objects behind it at the same time which makes the display more suitable for small work spaces.

Informal interviews with production engineers who used ASTOR for manufacturing research gave enthusiastic responses. They were used to their current setup which forced them to divide their attention between the machine and the control computer. They liked the idea of simultaneously being able to monitor the values and the movement in the machine through an AR approach [3]. This new approach was less intrusive in that, because an operator needs to inspect values and program execution on multiple machines in-between other tasks, the operator does not need to wear head-mounted-displays or shutter glasses.

4.2 Personal Varrier

Personal Varrier is a display built by the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago. It is a single-screen version of its 35-panel tiled Varrier display. Personal Varrier is based on a static parallax barrier and the Varrier computational method. EVL states that Personal Varrier provides a quality 3D autostereo experience in an economical, compact form [4].

Varrier (variable or virtual barrier) is the name of both the system and a unique computational method [4]. This method utilizes a static parallax barrier, which is fine-pitch alternating sequence of opaque and transparent regions printed on photographic film, as shown in Figure 5. The front of the LCD display is mounted with the film, offset from it by a small distance. This distance allows the user to see one image with the left eye and one image with the right eye. The image is divided in such a way that all of the left eye regions are visible only by the left eye and the right eye images are only visible by the right eye regions. Two views are simultaneously presented to the brain, which become one 3D image.

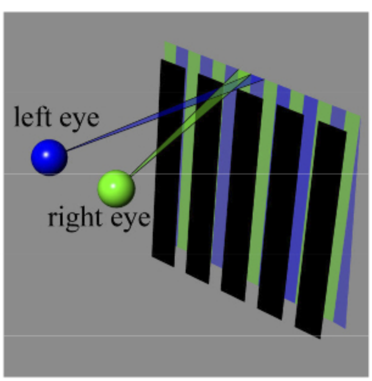

Figure 5: Varrier is based on a static parallax barrier. The left eye is represented by blue stripes and the right eye with green; these image stripes change with the viewer's motion while the black barrier remains fixed [4].

There is an alternative to the static barrier called an active barrier. It is built from a solid state micro-stripe display. Lenticular displays work equivalently to barrier strip displays, except that the barrier strip film is replaced by a sheet of cylindrical lenses.

There are two design paradigms that parallax barrier autostereo displays typically follow. One is tracked systems such as Varrier, that produces a stereo pair of views that follow the user in space, given the location of the user's head or eyes from the tracking system [4]. These systems are only capable of serving one user at a time. An untracked system shown in Figure 6 is another popular design pattern. A sequence of multiple perspective views is displayed from slightly varying vantage points. This allows a user to have a limited "look around" capability. In other words, if a user moves to a different location about the display, they will see the 3D image from a different perspective since their eyes are in a new static eye position.

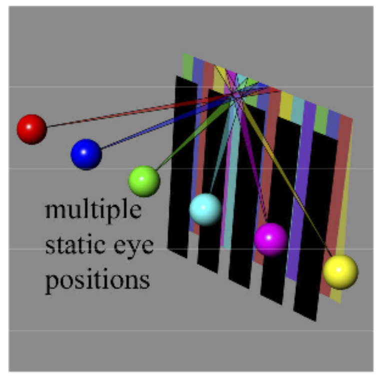

Figure 6: An alternative to Varrier's tracked 2-view method in Figure 5 is used in some other systems: the multi-view panoramagram. Multiple views represented by multi-colored stripes are rendered from static untracked eye positions [4].

The Personal Varrier LCD display device is an Apple^{TM}30" wide-screen monitor. It has a base resolution of 2560 x 1600 pixels. Construction of the Varrier screen is a simple modification to a standard LCD display [4]. Varrier users are able to freely move in an area approximately 1.5 ft. x 1.5 ft., centered about 2.5 feet from the display screen.

Their system uses a dual Opteron^{TM}64-bit 2.4GHz processors computer with 4GB RAM, and 1Gbps Ethernet. The system also uses auxiliary equipment. Two 640x480 Unibrain^{TM}cameras are used to capture stereo teleconferencing video of the user's face. A six-degrees-of-freedom tracked wand is included, tracked by a medium-range Flock of Birds^{TM}tracker. The wand includes a joystick and also three programmable buttons, for 3D navigation and interaction. The layout of the Personal Varrier including these elements is shown in Figure 7.

Cameras are needed to collect real-time knowledge of the user's 3D head position. Being an autostereo system, Personal Varrier uses no external gear worn by the user. This is achieved by using three high speed cameras and several artificial neural networks. The cameras record at 120 frames per second at a resolution of 640 x 480. Eight infrared panels and infrared band-pass filters on the camera lenses produce independence from room and display illumination. The center camera is used for face recognition and for x,y tracking. Outer cameras serve for range finding. Three computers

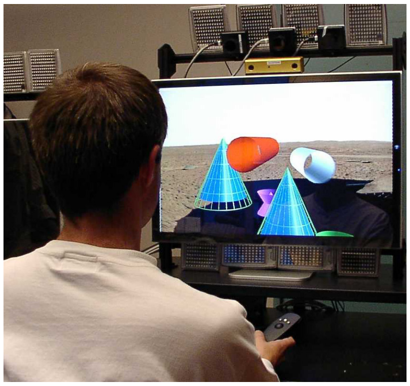

Figure 7: A user is seated at the Personal Varrier system, designed in a desktop form factor to be used comfortably for extended periods of time. Autostereo together with camera-based tracking permits the user to see 3D stereo while being completely untethered [4].

process the video data and transmit tracking coordinates.

New users need to train the artificial neural networks, which requires less than two minutes. Users slowly move their head in a sequence of normal poses while 512 frames of video are captured and used to train the artificial neural networks. There is an 80% probability that a generic training session can be applied to other users [4].

The tracking system does have certain limitations. The operating range is restricted to 1.5 ft x 1.5 ft. A new interface is being prepared that will make this unnecessary [4].

The Personal Varrier also creates the possibility of real-time 3D. At 25 Hz rendering, end-to-end latency is approximately .3s (round trip). Even with a 10% packet drop rate, real-time display appears flawlessly [4]. See Figure 8 as an example of Personal Varrier real-time autostereo chat.

Figure 8: A researcher at the Electronic Visualization Library chats autostereoscopically with a remote colleague on the Personal Varrier [4].

4.3 Multi-viewer Tiled Autostereo VR Display

The Electronic Visualization Laboratory at the University of Illinois at Chicago is also developing an autostereoscopic display that can provide a wider comfortable viewing area for larger groups of people. They are using large arrays of small lenticular displays that are capable of serving sizeable groups. A Graphics Processing Unit(GPU)-accelerated mechanism has been implemented for performing real-time rendering to lenticular displays. EVL is able to synchronize the displays and superimpose autostereo functionality on them, resulting in large arrays that behave as a single display [2].

Their installations use Alioscopy 24" and 42" 3DHD displays. They have also tested their approaches on a variety of similar lenticular and parallax barrier displays. These displays are capable of presenting eight independent image channels.

Lenticular display systems pose a challenge to rendering efficiency due to the need to render the scene from multiple different view points. Despite complexities, EVL is able to achieve real-time display using the programmable GPU. Their approach is a generalization of a GPU-based algorithm for autostereoscopic rendering that targets the Varrier parallax barrier display [2]. As a single-user system, the Varrier presents exactly two image channels using parallax barrier display. The lenticular implementation can generalize this to an arbitrary number of views that are limited only by the graphics hardware.

Normally, a lenticular display projects its channels forward, and thus two adjacent lenticular displays project their channels parallel to one another [2]. Projected channels must be brought into alignment at the plane of focus for multiple lenticular displays to appear to the user as a single continuous display. Their display can accomplish this by shifting center channels of all displays into alignment at the plane of focus.

Current research uses a camera-based tracking system not appropriate for public spaces. EVL states that future installations plan to use camera tracking without targets. This approach has been developed for the Personal Varrier [2].

5. CONCLUSION

To conclude, research and development for autostereoscopic displays are growing more rapidly. These displays can be used for many different purposes. Some examples shown have been for automobile engineers, users of video conferencing, video gaming, personal use, and commercial use.

As shown, there are currently some limitations and restrictions in these displays. Providing an economic display is one of the biggest challenges that autostereo engineers face. Depending on the implementation, multiple users may not be able to share the full experience simultaneously. Overall, as more research is completed, presumably these 3D technologies will become more economical, more usable, more useful, and therefore, more widely used.

Acknowledgments

Thank you Kristin Lamberty and Elena Machkasova for proof-reading this paper and for giving useful feedback.

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