3D Display：From Autostereoscopic to True 3D

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Abstract

Developing from stereoscopic to autostereoscopic, researchers on display technology are trying to provide more depth cues to viewer, leading to the advent of true 3D display. Volumetric 3D displays seem to be practical technology at present. Ultimate display will function like human vision system, with characteristics of providing all depth cues and free interaction.

1. Introduction

World is three dimensional (3D). With two separate eyes, human being can perceive depth to recognize a three-dimensional object and the spatial relationship of objects. There has always been a desire to completely display what people see in a real world. However, until now, most of display systems are 2 dimensional. Such incompatibility between the current display systems and the real 3D world leads the industry and researchers to develop technologies and device for 3D display.

If we come to a popular encyclopedia website, a 3D display is interpreted to any display device capable of conveying three-dimensional images to the viewer [1]. In [2], 3D display is to display a two-dimensional representation of a three-dimensional scene on a conventional display device with some monocular depth cues like perspective, hidden contours or shades to give the observer an illusion of depth in the image. The conventional display device usually refers to flat display, which could be static or rotating.

The development of 3D display technology is quite in accordance with human cognitive patterns. After finding out how human being perceives the depth, researchers try every possible ways to replicate the process. At the start, some kinds of devices are exploited, which is the first phase called stereoscopic display. Then devices are removed to enter the phase of autostereoscopic display. True 3D display is the next generation of 3D display technology.

The paper is organized as following: physiological background of human depth perception is introduced in section 2. Research works on autostereoscopic display from Hefei University of Technology (HFUT) are presented in section 3. Volumetric 3D display is discussed in details in section 4 and some prospects about ultimate display and conclusions are drawn at the end of this paper.

2. 3D perception of human vision system

As early as the age of Aristotle and Euclidean, people noticed that a human doesn't see a ghost image although having two separate eyes. After numerous animal and human tests, people began to understand that human vision system uses many depth cues to determine the position relationship of objects in a 3D scene. These cues could be divided into two categories [3, 4]: physiological and psychological. Physiological depth cues include accommodation, convergence, binocular disparity, motion parallax. Psychological depth cues refer to linear perspective, shading and shadowing, aerial perspective, interposition, Retinal image size, texture gradient, and color. Today's 3D display technologies are unable to provide all the depth cues as human vision systems.

Three-dimensional vision is based by parallax effect, which had been proved by Wheatstone [5]. As shown in Fig. 1, parallax means binocular parallax and motion parallax [4]. The images with slightly differences caused by binocular/motion parallax effects are fused by brain, enabling a human to perceive spatial depth.

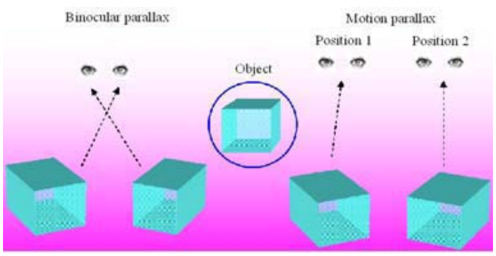

Fig. 1. Schematic diagram of parallax effects

3. Autostereoscopic 3D display

At the start, researchers resorted to some special devices to present the slightly different images to each eye for 3D perception. Such technology has some disadvantages: (1) extra weight; (2) headache after long time viewing; (3) single user; (4) isolation from real world. Naturally, researchers began to find ways to remove the devices and lead to the advent of autostereoscopic 3D display.

Autostereoscopic 3D displays show different images to each eye without the need for any special glasses or head gear [6]. On the current market, most of 3D display are autostereoscopic that mainly exploit parallax barrier or lenticular to achieve 3D effect.

In 2002, HFUT developed the first parallax barrier based 3D display in mainland China, as shown in Fig.2. The barrier is placed between LCD and backlight， called rear barrier. The performance specifications are shown in Table 1:

Fig. 2. HFUT 3D display

TABLE 1: Performance specifications of HFUT display

Size	15"
Resolution	1024*768
Color	16.7M
Viewing angle	Horizontal: +75°/-75° Vertical:+70°/-70°
Contrast ratio	400:1
Brightness	250cd/m^2
2D–3D switch	Yes

No matter parallax barrier or lenticular, stereo-pair is required, which has fundamental problem of inherent unnatural depth perception. When watching a natural scene, accommodation and convergence are necessary. However, during the above autostereoscopic display technologies, there is no accommodation because of the fixed distance between observer eyes and display. Such unnatural perception may lead to visual fatigue, headache or uncomfortable feeling at the observers. True 3D display in principle solves this problem.

4. True 3D display

With images displaying in a physical volume with depth, true 3D display provides both psychological and biological depth field. True 3D display mainly includes volumetric display and holography. Some issues related to holography are still in study and far away from practical applications. For example, for a hologram of 300mm by 300mm, it contains data more than 10T. It is almost impossible to calculate such massive data or update a spatial light modulator (SLM) system with this many pixels at interactive rates. What's more, holography display systems are currently too expensive for many applications.

Some products based on volumetric display technology have been available on market. Volumetric displays use some physical mechanism to display points of light within a volume. Such displays use voxels (volumetric pixel) instead of pixels. Volumetric displays include multiplanar displays and rotating panel displays. Multiplanar displays have multiple display planes to stack up to form a volume while a rotating panel displays has a rotating panel to sweep out a volume. Two typical applications of above volumetric 3D display technologies are Depthcube [7] from LightSpace Company and Perspecta [8] from Actuality System Company, respectively.

As the fact that flat display is today's mainstream display technology, multiplanar display is considered to be more compatible than rotating panel display with flat display. With no mechanical motion, multiplanar display can put on desk in front of viewer and easier to work with legacy system.

For multiplanar 3D displays, some problems must be solved, including rapid-response LC shutters, high-speed projection engine with high luminance output, and high-efficient imaging processing algorithms. Another important factor that has to be considered is cost. If looking back history, we will find the cost is always a main obstacle for a technology for wider applications.

To reduce cost, HFUT begins to develop a single digital micro-mirror device (DMD) based solid-state 3D display. Compared with Depthcube that uses 3 DMDs to module each primary color light, HFUT volumetric display is expected to be much cheaper. Fig. 3 is the schematic diagram of single DMD system. Lights from lamp are separated by rotating color wheel into primary color of red (R), green (G), and blue (B). Primary RGB lights are reflected by DMD on sequence and projected by lens on screen. Human vision system fuses these lights in brain. The high-speed video projector projects a sequence of slices of the 3D images into a set of LC shutters where each slice is halted at the proper depth.

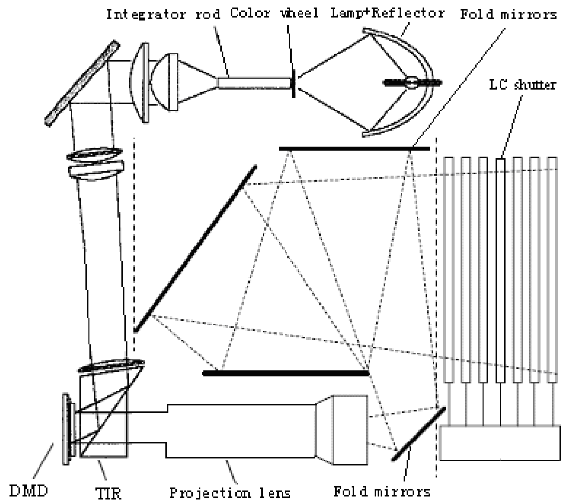

Fig.3. Schematic diagram of single DMD system

The LC shutters have 2 states: clear state with high transmission and scattering state with low transmission rate. When a shutter is in scattering rate, the image can display on it. With the use of time multiplex and visual persistence, switching time between 2 states has to be shorter than 2ms, which is a challenge for today's LC materials.

In a single DMD system, the color wheel is used to create primary color lights of RGB. The characteristics of color wheel have significant effect on system performance. To avoid the perception of flicker, the refresh rate on one shutter should reach 24Hz, meaning projector rate as high as 480Hz. Thus, color wheel is required to create RGB color field at frequency of 480Hz, which is quite high for available color wheels. Colorimetric characters of color wheel is another concern. The colorimetric characters of color wheel and light source should match each other for better effect. [9] presents some research works about color wheel.

The other issue related to single DMD is color. As claimed by TI, DMD can reach above 8000 single-bit-depth frame per second. When refresh rate of an image is required to 480Hz, display rate for individual color will reach 1440Hz. According to [10], the bit for each color will be max 4. It is some kind of tradeoffs between performance and cost.

5. Prospects and conclusion

Although volumetric display is called true 3D display, it still can't provide all the depth cues as human vision system does. In authors' view, volumetric 3D display is intermediate technology. The ultimate display should be one that can provide an image to viewers as what they see in real world using human vision system. Except the expectations of advances on display materials, computer, image processing, and communication, achieving the ultimate display also requires the great developments in the following technologies:

- Head tracking;
- Free interaction;
- Holography.

Until now, computer-generated holography (CGH) is the only technology capable of providing all the human visual systems' depth cues [11]. With computer power and display hardware continuing to decrease in price and other required technologies rapidly advancing, CGH will become affordable to common users and have wide applications.

Like in real world, images presented to viewers should be position-depended, which requires information from head tracking devices. When a human see an object in a scene, no extra devices except hands are needed to interact with the observed object. Until now, human can only communicate with a display by keyboard and mouse. Ultimate display should have capability to interact with viewers only by hands (we call it 'free interactive'). HFUT is developing a free interactive device that can work with single DMD volumetric display.

In general, the development of 3D display followed such road: stereoscopic 3D→ autostereoscopic 3D→ true 3D. True 3D display can provide psychological and biological depth perception to a viewer that is more similar to human vision system, compared to autostereoscop display. With the development of LC materials, computer, communication, and image processing, true 3D displays will replace today's flat display. However, true 3D display is not ultimate. Ultimate display will be one that functions as human vision system.

6. References

1. http://en.wikipedia.org/wiki/3D_display
2. D. Bahr, K. Langhans, M. Gerken, C. Vogt, D. Bezecny and D. Homann, FELIX: A volumetric 3D laser display, SPIE Proc. of Projection displays II, Vol. 2650, p. 265 (1996).
3. David F. McAllister, Display technology: Stereo & 3D display technology, http://research.csc.ncsu.edu /stereographics/wiley.pdf.
4. Jian kewei, Xie hanping, Development and futuer of 3D display, http:// osdlab.eic.nctu.edu.tw /osdlab/
5. C. Wheatstone, Contributions to the physiology of vision I: On some remarkable and higher to unobserved phenomena of vision. Phil Trans R Coc (Bilo). Vol. 18(13), p371.
6. Neil A.Dodgson, Autostereoscopic 3D display, IEEE Trans. of Computer,Vol. 38(8), p.31 (2006).
7. A. Sullivan, Depthcube solid-state 3D volumetric display, SPIE Proc., Vol. 5291, p. 279 (2004).
8. Gregg E. Favalora, Volumetric 3D displays and application infrastructure, IEEE Trans. of Computer, Vol. 38(8), p.37 (2005).
9. Feng Qibin, Lv Guoqiang, Yuan Ye, Colorimetric Characters and Control of Color Wheel in Single-chip DLP, Chinese Journal of Instrument, Vol. 29(4), p. 713.
10. Roland Höfling, Enrico Ahl, ALP: universal DMD controller for metrology and testing, Proc SPIE, Vol. 5289B, p. 322 (2004).
11. Chris Slinger, Colin Cameron, Maurice Stanley, Computer-generated holography as a generic display technology, IEEE Trans. of Computer, Vol. 38(8), p.46 (2005).