The development of stereoscopic display technology

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***Abstract*—The stereoscopic display technology has become a main research issue in recent years because of its unique human-computer interaction. This paper analyzed the principle of stereoscopic display with physiological and psychological factors and then briefly introduced the development of various stereoscopic display technologies, meanwhile especially talked about the principles, applications, advantages and disadvantages of new sorts of stereoscopic display technologies. Finally, it prospected the developing trend of stereoscopic display technology as well as its impact on our life.**

Keywords-stereoscopic display technology; autostereoscopic; multi-view and super multi-view; depth-fused display; integral photography; volumetric display; holographic

I. INTRODUCTION

Undoubtedly, eyes are the most important in human sense, from which about 80% of information is received [1]. Such regret has existed for a long time that what we saw in the real world are three-dimensional while almost all of artificial images (painting, computer simulation) are flat, which is not able to reflect things we saw exactly. Not until the late 19th century [2] did human began to study stereoscopic display technology, creating stereoscopic images and tools to view them. Thanks to the high simulation of the real world, stereoscopic display attracted us a lot. As the result, the technology developed rapidly with the increasing attention people paid. James • Cameron early predicted that the year of 2009 was the first outbreak era of 3D films [3]. The advent of large 3D films like Avatar indicated that stereoscopic display technology was close to maturity.

II. THE PRINCIPLE OF STEREOSCOPIC DISPLAY

Stereoscopic images as well as films seem to be magical, however in fact the basic principle is not complicated. This section will begin with the principle and introduce the relevant human factors.

A. Physiological factors

To produce stereoscopic vision, the following physiological factors are important [4]:

- Convergence: Binocular sights that are parallel in usual condition will converge into a single point when watching a near object. This process is called convergence.
- Accommodation: When watching objects in different distances, ciliary muscle will change accordingly so as to change the thickness of crystalline lens, making the images located on the retina clearly. This phenomenon is called accommodation.
- Binocular disparity: Since the spatial positions of eyes are different, there are subtle differences between the left and right images projected on the retina. This kind of difference is called binocular disparity.
- Motion parallax: The movement of images in the screen or that of viewers themselves which leads to image changes will bring about parallax called motion parallax.

When we are watching an object in the space, object image is focused on the retina by accommodation and convergence integrates the left and right images into one image. Then the brain deals with the disparity through calculation, generating one single three-dimensional image that will let us "see" the stereoscopic image.

B. Psychological factors

In addition to these physiological phenomena above, we often get three-dimensional "feelings" based on psychological factors. Two-dimensional images, by the means of perspective, occlusion, shadow, depth, shading, illusion and so on [5], allow us to form stereoscopic perception. In fact, the images are flat, however our experience tells us that they are three-dimensional. The most typical example is the principle that everything looks small in the distance and big on the contrary in painting as well as the dotted line in perspective.

III. STEREOSCOPIC DISPLAY TECHNOLOGY

To achieve three-dimensional display in two-dimensional platform (paper, screen), we need not only human physiological factors, but also certain technologies and support facilities. So far, the traditional stereoscopic display technology has been highly commercialized [6], while the emerging is continuously perfected. This section describes the common-used stereoscopic display technology.

A. Traditional technology

According to the principle of stereoscopic vision, human will automatically generate stereoscopic image by accommodation and convergence as long as the left and right images are separated, i.e., the left eye only look at the left image and so dose the right one. The traditional technologies take up the main parts of commercial applications because the principle and equipment are simple, which makes it easy to implement. Most 3D films and televisions, 3D displays and games are of this kind of approach.

1) Goggles & helmets

Non-interfered images with disparity are provided to the left and right eye respectively using auxiliary image-separation tools based on different principles. Helmet-mounted displays (HMD) offer left and right images directly to the corresponding eye with two screens [7]. Goggles supply eyes with disparity tips through special optical characteristics of optical glasses, which can be divided into the following types [8]:

- Red-blue glasses: Image source is displayed with complementary colors of red and blue which are almost overlapped. According to the rule that glass with specific color filtrates images with the same color, the red-blue glasses observers wear make blue images shown only through the red glass meanwhile the red shown only through the blue glass so as to separate left and right images.
- Polarized glasses: When light shines on a polarized filter, only the polarized light with specific polarization direction can pass through. Add orthogonal linear polarized light to the image source and project it in an overlapping way, with observers wearing polarized glasses with a filter that is orthogonal polarized, and left and right images are separated.
- LCD shutter glasses: Image source shows the left and right images alternatively with synchronous glasses opening or closing so as to block or show the corresponding image, i.e., the left glass keeps open and the right glass maintains closed while showing the left image, and next time the right glass is open but the left is closed while showing the right image. As a result, the left and right images are separated by the time disparity. The switching frequency is so fast that people will not perceive flicker [9].

2) Autostereoscopic display

Here the so-called "auto" means not wearing any auxiliary tools like goggles or helmets [10] and viewing stereoscopic images through naked eyes only. The basic imaging principle does not change, while the “glasses” are just set in front of screens by a variety of techniques [11] to separate the left and right images. Currently there are three main approaches [12]:

- Parallax barrier: The left and right images are arrayed vertically in the screen with interval. Parallax barrier with vertical slits are placed in front of the screen in order to block or show images. So left and right eye can only see the corresponding left and right images and the separation is accomplished. See figure 1.

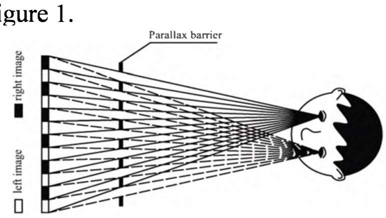

Figure 1. Parallax barrier

- Lenticular lens: The left and right images are arrayed vertically in the screen with interval. Lenticular lens consisted of a series of semi-cylindrical lens with just the same size and optical characteristics are placed before the screen. As a result, the left eye sees the left image and right eye sees the right image by refraction. See figure 2.

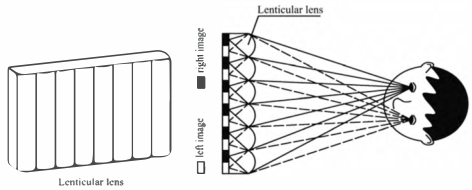

Figure 2. Lenticular lens

- Microretarder-encoded barrier screen [13]: Add a 45° linear polarized light to the image when it is projected, and the microretarder-encoded barrier screen separates it into crossed light strips with the polarization direction of 45° and 135°. Then make up crossed left and right images by a polarizer and build up the visual area by a slit barrier. See figure 3.

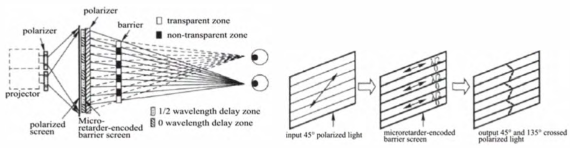

Figure 3. Microretarder-encoded barrier screen (taken from [13])

B. *Multi-view [14] & Super Multi-view*

The autostereoscopic display above are all sorts of two-view and bi-image, i.e., simultaneously offer the left and right eye with only one image with parallax respectively, which limits the number of observers and the size of viewing scope. See figure 4. To solve this problem, an eye-tracking method [15] and a variable depth moire pattern [16] are proposed but yet not fundamentally effective.

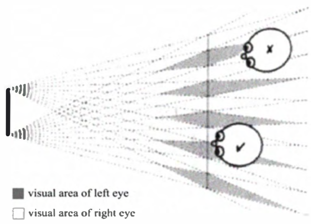

Figure 4. Limitation to visual area (taken from [17])

Multi-view uses multiple cameras to shoot the object in different perspective, and then provides multiple images and groups them in space. Then it controls the viewing directions through multiple layers of optical lens and observers in different positions will see different images. Therefore, it increases the number of observers and improves the viewing scope greatly. See figure 5.

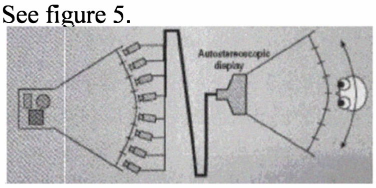

Figure 5. Multi-view (taken from [18])

Super multi-view is an extension of multi-view which still offers only one image to each eye. However, super multi-view sends multiple images into monocular pupil and allows accommodation along with images observed. As is shown in figure 6, the distance between viewpoints that express the image is shorter than that of the pupil diameter, which allows more than two viewpoints getting into monocular pupil, i.e., more than two beams of light which pass through the exact point in space will get into monocular pupil at the same time. It is possible for eyes to accommodate just on the imaging point. The accommodation of super multi-view is not in the screen but may be in the stereoscopic image, which relieves the visual fatigue caused by the inconsistence of accommodation and convergence [19]. As a result of the improvement on viewpoint limits, multi-view and super multi-view are extensively used in large 3D movies.

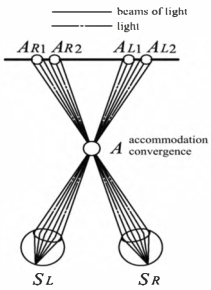

Figure 6. Super multi-view

C. Depth-fused display

Depth-fused display (DFD) represents three-dimensional feelings by illusion: two transparent images with overlapping edges will be automatically perceived as stereoscopic image instead of two different images when one is shown in front of the other [20]. The depth feeling of the "stereoscopic image" changes as the brightness contrast of the two images changes. As is shown in figure 7, images with different brightness and the same size are projected on two transparent screens and the observer will automatically generate stereoscopic image with depth. The observer's depth perception changes regularly with the illumination of the former and the latter screens [21]. See figure 8.

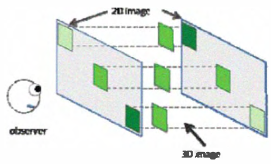

Figure 7. DFD (taken from [20])

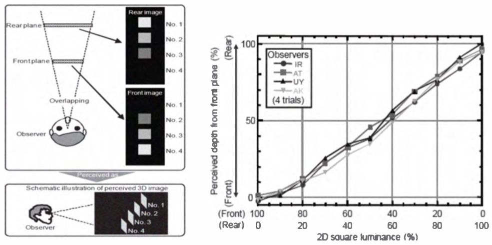

Figure 8. Depth feeling changes with brightness contrast(taken from [21])

This technology not only does not require additional optical devices, but will not induce visual fatigue when viewers watch for a long time. Although the operation is simple and the amount of data is low, however the drawback is the limitation to the angle and distance of observation, which means a slight angle-increase will result in separation of the former and the latter images. Currently DFD is still studied in labs.

D. Integral photography

Integral photography (IP) or integral imaging [22] comes from the integral photography technology proposed by MG Lippmann in 1908 [23]. As illustrated in figure 9, the basic process includes two steps named pickup and reproduction [24]. First, the three-dimensional object, through the matrix of lens, generates elemental images whose number is the same as the number of lens. Next, the elemental images are projected in the screen and produce transparent photos that are inverted. At last, these transparent as well as inverted photos are placed before the screen and transmitted to observers through the same path as that of pickup process by reverse illumination, which brings about stereoscopic image. Recently a technique named computer-generated integral photography (CGIP) [25] which takes the place of traditional pickup process to generate elemental images by computer is also developed.

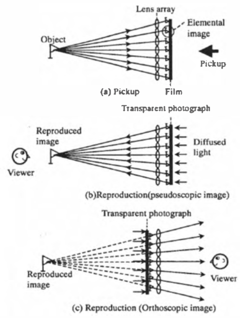

Figure 9. IP (taken from [23])

Special glasses are not required in integral photography and neither does laser, which means ordinary natural light will fit. Besides, IP provides continuous viewpoints. So it is considered to be an ideal method of stereoscopic display [23]. The problem IP needs to solve immediately is the limitation to the depth of field and the resolution of images. Like DFD, there are no commercial applications of integral photography either.

E. Volumetric display

Unlike the flat displays above, volumetric display provides pseudo-volumetric [26] images with three-dimensional coordinates by special stereoscopic displays. Someone calls it the true 3D display because the images are thought to be truly three-dimensional [27]. The basic principle is to use persistence of vision produced by high-speed rotation or optical projection in order to make people see stereoscopic illusion. It can be divided into two categories according to the principle [28]:

- Volume scanning/swept: The object is partitioned into a series of two-dimensional slices with the sphere display scanning them around the center axis at a high speed. Since each slice takes turns to be projected onto the screen at a high speed, eyes will automatically merge the afterimages into stereoscopic image. The volume swept display named Perspecta by Actuality Systems is a typical representative [29]. See figure 10.

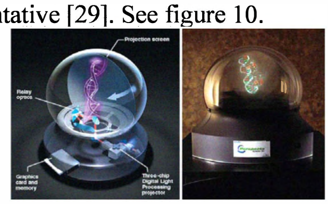

Figure 10. Perspecta (taken from [29])

- Static/Solid volume display: It stimulates voxels [30] by the absorption and reflection of light and makes high-speed switch layer by layer to generate afterimage stereoscopic. The solid volume display named DepthCube (figure 11) by Light Space Technologies [29] uses 20 LCD monitors which are controllable of light-in or light-off to pile up closely layer by layer as the optical media and switches quickly so as to represent the feeling of depth.

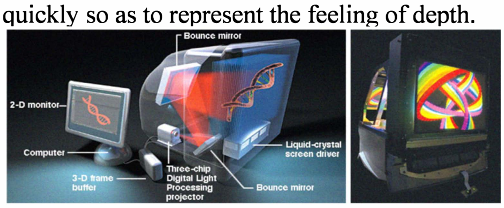

Figure 11. DepthCube (taken from [29])

Volumetric display is highly thought as the true three-dimensional display because of its viewing angle which is close to 360°. In addition, it works just like watching the real object, for which the visual fatigue induced by the inconsistence of accommodation and convergence is eliminated. Based on these two advantages, volumetric display is supposed to make more development and applications in public display and especially medical field. The biggest disadvantage is that it only provides an external view outside the monitor thus offers no immersive feeling. Besides, opaque objects can not be displayed in this way due to the transmitting problem of light.

F. Holographic

Holographic technology was invented by the Hungarian-born physicist Dennis Gabor (1900-1979) of the Imperial College London in 1947 [31]. The essential principle of holographic is to capture objects by recording the information of objects' light waves through interference and display objects images by reproducing the information of objects' light waves through diffraction [32].

Holographic technology used for stereoscopic display is usually combined with electronic technology, called electroholography [33] or digital holography [34]. The interference fringes obtained by optical method are shot by cameras and processed into holographic electronic photos for post-processing. Or directly generate interference fringes by electronic method and change them into electronic signals for store and output. The most advanced computer gengrated holograpgy (CGH) [35] requires neither laser nor real objects and produces simulation of interference fringes by computing only through virtual objects or digital models. SeeReal Company has already developed the real-time color holographic display system for large screens [36].

Since the principle of holographic is to reproduce the light waves of objects, therefore it is capable of truly reproducing the three-dimensional information of objects and providing totally complete stereoscopic images, which seems a perfect solution to the problems of full-angle viewing as well as visual fatigue. Holographic is currently used in the field of photography, exhibitions and 3D animation. Holographic will be the "ultimate goal of stereoscopic display" [37] as long as the improvement of huge amount of data and supporting devices that require a high resolution is accomplished.

IV. CONCLUSIONS

Stereoscopic display technology will be perfect with the development of society and technology. In addition to playing an important role in medical, aerospace, driving, manufacturing, entertainment and other fields, in will finally replace the traditional two-dimensional technology in every family, absolutely changing the existing situation of flat televisions, flat mobile phones and flat computers. Traditional stereoscopic display technology that causes visual burden will gradually be eliminated, with auxiliary tools like glasses or helmets showing up only in museums. Thriving modern technology, especially the holographic, is going to provide us with a perfect 3D world.

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