

Stereoscopic Techniques in Computer Graphics

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Abstract

This paper describes the most important techniques to create stereoscopy. At the beginning a brief summary of the history of stereoscopic viewing is outlined. The classical stereoscopy methods such as anaglyph or polarized images and the more modern techniques such as head mounted displays or three-dimensional LCD's are described and compared. Advantages and disadvantages of each method are stated. At the end volumetric and holographic displays are described, although they don't belong to the stereoscopy techniques.

Keywords: stereoscopy, autostereoscopy, anaglyph, shutter glasses, HMD, Chromatech, volumetric display

1 Introduction

Stereoscopy is called any technique which is capable of creating the illusion of a three-dimensional image. In photographs or movies the illusion of depth is created by presenting a different image to each eye.

The human eyes are close to each other (approximately 5cm). Thus every viewed object has a slightly different viewing angle in each eye. If two artificial created images have the same angle-difference called the *deviation*, and each eye sees only the corresponding image, a spacial effect is created.

Usually a stereo-camera is used to record the two images. It has two lenses which are distant approximately 60 - 70 mm from each other. If the scene to be recorded is still, then a single camera can be used to take the two photos. However, the result is less

accurate.

There exist two types of stereoscopy:

- The stereoscopic display: The observer needs some kind of utility to see the meant spatial effect; usually some type of glasses.
- The autostereoscopic display: The observer doesn't need such a headgear. The display can be viewed freely.

2 History

The Greeks recognized that binocular single vision was a problem. By the simple trick of pressing a finger against one of the eyes, single vision could be interrupted. Therefore binocular vision was not self-evident and needed an explanation. The Greek medic Galenus (129-179) thought that the images of both eyes were united, provided the eyes were in the straight position. Galenus, and none of the ancient scientists, associated perception of depth with binocular vision. That seems strange, the more so because Galenus did notice that a near object during binocular vision was projected to two different places of the background. Evidently the Greeks never noticed that it was difficult to pass a thread through the eye of a needle with one eye closed. The Greeks never did the experiment to suppress depth perception by closing one eye. It should be noted that without such an experiment the superiority of binocular vision for depth perception is not all obvious.

In 1838 Charles Wheatstone presented the first research results regarding stereoscopic vision. He calculated and drew two stereoscopic images and developed a device for viewing them as one three-dimensional image, called the stereoscope.

In 1849 Sir David Brewster, an English physician, developed the first *stereo camera* with two objectives. This was the first possibility to create stereoscopic photographs.

3 Stereoscopic Techniques

3.1 Anaglyph Technique

An Anaglyph image contains two differently colored images (the term “anaglyph” doesn’t necessarily require this, but it’s commonly used), one for each eye. If the anaglyph image is viewed through a pair of anaglyph glasses that contain corresponding color filters, a stereoscopic image can be seen.

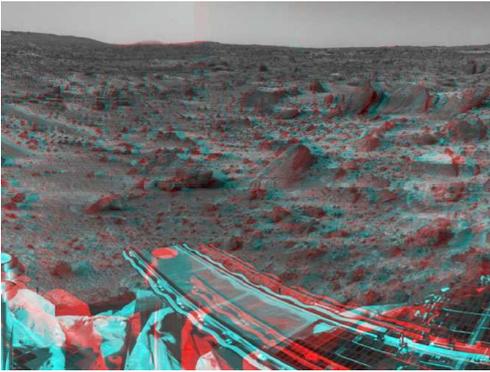


Figure 1: Example of a anaglyph image taken from the Mars Pathfinder

This method was introduced by D’Almeida in 1858, however the most significant demonstrations of the technique were by Lumiere in the 1920s. Lumiere produced the first effective stereoscopic cinema films [Valyus 1966].

Usually the image for one eye is red and the image for the other eye is a contrasting color such as blue, cyan or green (see Fig. 1). If viewed through appropriately colored glasses (see Fig. 2) each eye sees a slightly different picture. If used red/blue anaglyph, for instance, the eye which is covered by the red lens is reached only by the red part of the image whilst the eye covered by the blue lens sees only the blue part. The red part of the anaglyph image will appear dark through the cyan filter and the cyan part appears dark through the red filter.

One problem with anaglyph glasses is that simple red/blue filters do not compensate the 250nm difference in the wave lengths of the red/blue filters. Thus the red-filter-image can be blurry since the retinal focus differs from the one through the blue filter. Improved anaglyph glasses have different diopter power to equalize the focus between the eyes.



Figure 2: Anaglyph glasses with red/blue filter

The advantage of the anaglyph system is, that it is simple to create anaglyph images and the glasses are inexpensive. Also it is one of the few methods to make stereoscopic hard copies. The disadvantage is, that colored images are very difficult to display. In colored images as cause of the color-separation and the filters, the colors are falsified.

3.2 Polarized Glasses

Similar to anaglyph method polarized glasses create the illusion of three-dimensional images by restricting the light that reaches each eye. To achieve this, two images with different capture-angles are projected onto the same screen through two different orthogonal polarizing filter. To view the entire three-dimensional image, inexpensive glasses with a pair of orthogonal polarizing filters are needed. Only the correctly polarized light passes through the polarized filter achieving that only the intended image is seen.

A problem to be considered is that light projected to typical motion picture screens tend to lose a bit of its polarization resulting in blurry images. To prevent this a silver or Aluminized screen is used which maintains the desired polarization. This method suffers from loss of light intensity due to the polarization filters. Ghosting can occur if the viewer’s head position is wrong and the vertical resolution is halved using this approach.

3.3 Shutter Glasses

Shutter glasses are using a similar effect to create the three-dimensional image than polarized and anaglyph glasses. While with polarized and anaglyph images the two different pictures are projected or showed simultaneously, with shutter glasses every image is shown for a short period of time and after that the

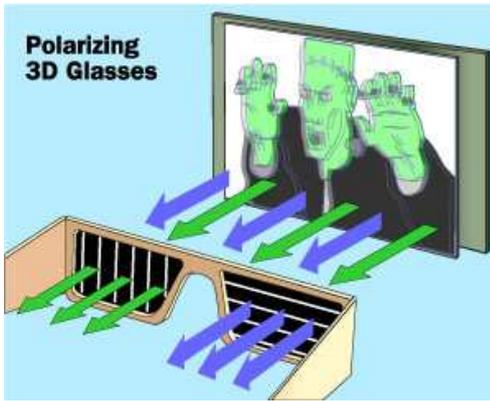


Figure 3: Polarized stereoscopic movie



Figure 4: Wireless shutter glasses

image for the other eye is shown. To achieve that only the predisposed eye sees an image, the shutter glasses consists of two Liquid Crystal Displays; one for each eye. Such a display can be transparent and thus the eye sees through, or black which impedes to see something. This glasses are connected between the graphical output and the screen. Alternately one eye is “darkened” over by the video card, or more generally by the video output, and then the other, in synchronization with the refresh rate of the monitor, while the monitor alternately displays different perspectives for each eye. A high monitor refresh rate is required because each eye sees only half of the images as a consequence of the dark liquid crystal display each two frames.

Shutter glasses at the moment are almost exclusively usable on CRT monitors by the reason that modern TFT are not capable of high enough refresh rates (100Hz and more).

As a consequence that the displays of the shutter glasses are not completely dark and some light passes through these displays, the image may be blurry or some user may experience “ghost” images from the alternate channel.

The problems associated with shutter glasses are that they cost more than anaglyph or polarized glasses (typically up to 100\$) and a flickering may be noticeable if the refresh rate is not high enough.

The synchronisation with the graphic card can be wired or done with a infrared sender station which sends signals to the glasses.

3.4 Chromadepth

The Chromadepth method is based on the chromatic aberration of the human eye. The index of refraction

of the human eye is slightly different for red and blue light. It can vary up to 2 dioptres. A source of light with only blue and red components is seen as showed in Figure 5.

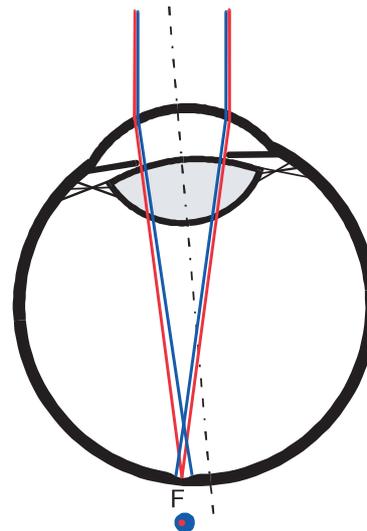


Figure 5: Different refraction index of red and blue light

Either a red dot with blue background or a blue dot with red background is viewed. The point on the retina at which the light is focused is slightly shifted away from the center. If two eyes are used, this effect is interpreted by the brain as a spatial effect. The blue dot seems to be farther away than the red dot, as shown in Figure 6. A interesting fact about it is, that also color-blind people can see the effect, because it doesn't base on the colors itself, but on the different refraction index, which also color-blind persons can experience.

3.5 HMD

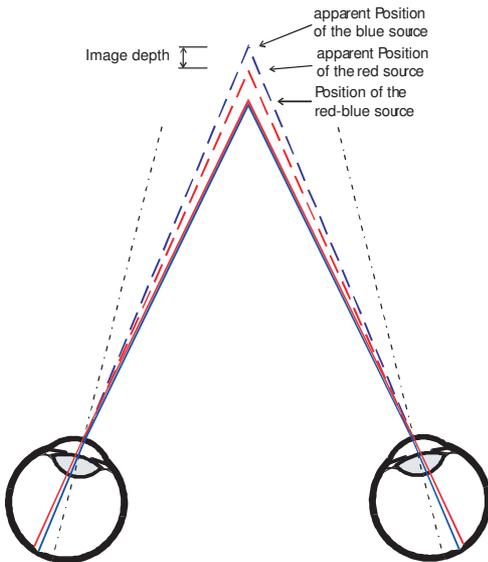


Figure 6: Effect of red and blue light source

Simple prisms or lenses can be used to intensify the depth-effect, but this method has the disadvantage that also the eye's optical axes are moved and thus it is possible that two separate images are seen, rather than one three-dimensional. Also vertigo and headache can appear. Special prisms can be used to reduce these effects, but these prisms are complex, expensive and also quite big to use for glasses.

A better method is the use of special foil with tiny prisms in a grid structure. This foil has all the required properties and are used in ChromaDepth glasses, which are patented. With them it's possible to create a spatial effect of images with specific color-properties, as seen in Figure 7. However the colors are only limitedly selectable, since they contain the depth information of the picture. If one changes the color of an object, then its observed distance will also be changed.



Figure 7: Example of a ChromaDepth image



Figure 8: Picture of a modern HMD using LCD's

The head-mounted display is made of two canonical displays, and usually consists of two liquid crystal, cathode-ray tube or OLED display screens that are either mounted on a helmet or glasses-frame structure. There are several attributes that affect the usability of the head-mounted displays. Head-mounted displays can be either binocular, showing the same image to both eyes, or stereoscopic in nature, showing different images to each eye. The choice between binocular or stereoscopic depends on whether three-dimensional interaction or presentation is required. Whilst head-mounted displays use a range of display resolutions, it is important to note, however, that a tradeoff exists between the resolution used and the field of view, which in turn impacts the perceived level of experienced immersion. A low field of view decreases the experienced level of user immersion, yet a higher field of view involves spreading the available pixels, which can cause distortion on the picture. Finally, ergonomic and usability factors vary considerably between different devices. Issues such as display size, weight and adjustability of physical and visual settings all affect the usability of a particular head-mounted display for any specific task.

Although there is now a wide range of headmounted displays, there are several drawbacks that prevent their everyday popularity. Thus, the current high cost of the head-mounted displays that display both high resolution and wide field of view is a major factor. The large and encumbering size is also an important factor for users, especially those of cathoderay tube based displays.

Moreover, the visual limitation within the real world and reduced interactions with colleagues are also possible reasons that prevent head-mounted displays from regular everyday popularity. Lastly, other factors, such as hygiene and weight, also have possible unknown long-term medical implications on the supporting muscles and, indeed, even on the eyes.

A number of research studies thus exist looking at the symptoms related to head-mounted display usage, such as nausea [EC 1995], dizziness [Cobb S 1995], headaches [Kennedy RS 1995] and eyestrain [EM 1995]. From a different perspective, Geelhoed et al. [Geelhoed E 2000] investigated the comfort level of various tasks, such as text reading and video watching, on two different head-mounted displays, identifying that tasks requiring more long-term attention, such as watching video, causes a greater level of discomfort to the user. Despite the computational costs and usability drawbacks of the head-mounted displays, they are used widely in active research, ranging from virtual environments to wearable Internet applications.

4 Autostereoscopic Techniques

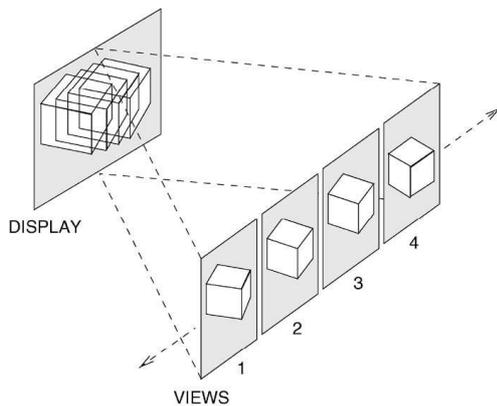


Figure 9: A four-view multiview display: Adjacent views (1 and 2, 2 and 3, 3 and 4) form stereoscopic pairs.

As already mentioned before, autostereoscopic display does not need special glasses. Various optical elements are used to direct each view into space in front of the display. When the users eyes are in the regions known as viewing windows, then each eye receives a different image. For all these displays, the user should face the display at a specific distance in order to avoid the views merging. Autostereoscopic displays can be classified into the following three types.

- *Fixed viewing windows:* The display is designed to produce two windows at fixed positions in front of the display. The user must be located correctly laterally in order for each eye to see the correct image and therefore it is only practical for a single user to use.

- *With viewer tracking:* The display uses adjustable optics with a video camera. The users head is tracked using the video image so that they always see the correct 3-D image. Generally, only one user can view the display at one time but they are not constrained by location.
- *Multiple views:* The display produces a number of views, usually in fixed positions, as shown in Figure 9. Adjacent views form stereo pairs; several users can view stereo simultaneously from different pairs of views. If the user moves, then it is quite easy for them to reposition themselves so that each eye is in a different pair on views.

4.1 Swan's cube

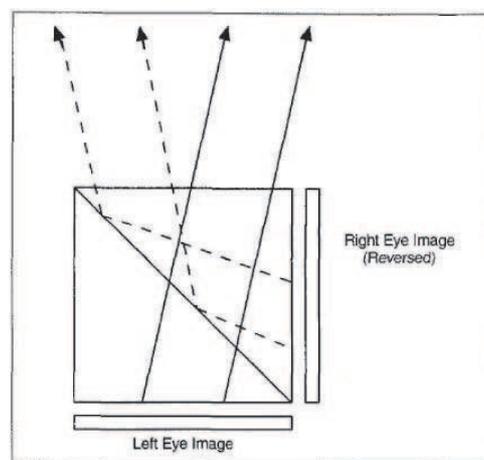


Figure 10: Example of a Chromadepth image

In 1862 the first known autostereoscopic device was demonstrated by H. Swan, in form of a cube. The cube consists of two separated images and two prisms, as shown in Figure 10. While the light of the left eye image is seen directly through one prism, the light from the other image is total reflected by the other prism and is directed to the other eye. Originally the images produced with this method were extremely small, but later the technique was improved so that large images were possible.

4.2 3D - LCDs

In this section, we describe the main types of 3D LCDs. Any type of matrix display can be used as the basis of the 3D display; it is not yet clear which display technology will dominate the market. The recent fall in cost of LCDs has made some older stereoscopic display methods viable for mass production of

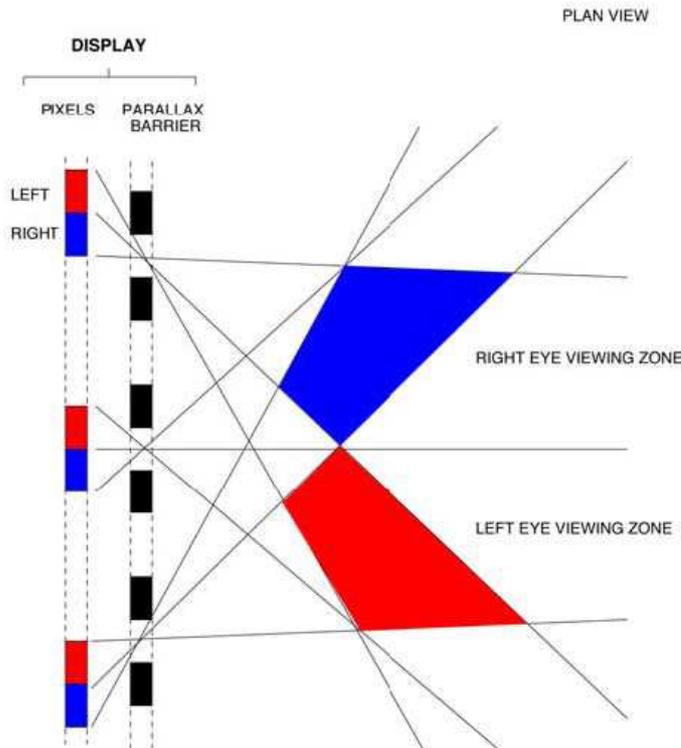


Figure 11: The parallax barrier display

3D displays. In general, the display is a standard mass produced LCD component, but some additional optical elements have been attached:

- *Parallax barrier* type displays use a simple series of opaque vertical lines to block light from selected subpixels from reaching the users eyes; see Figure 11. By careful selection of the barrier geometry, it is possible to adjust the viewing window position and angles. The main disadvantage to parallax barriers is that the barrier reduces the brightness of the display.
- *Lenticular- or integral-type* displays use tiny lenslets attached to the display with high accuracy; see Fig. 7. Lenticulars are often slanted to improve the transition between viewing zones for a multiview display. Also the resolution loss is shared between horizontal and vertical (rather than unaffected vertical resolution and very low horizontal resolution). The main advantage of lenticulars is, that they transmit full brightness. The disadvantages are, that it is harder to switch the function off to achieve perfect 2D. Also as the method involves the magnification of the pixel into the viewing window plane, any nonuniform features in the pixel (including the black mask between pixels) are also

magnified and becomes part of the intensity profile in the viewing window. Note that both parallax barriers and lenticulars must be attached with a high degree of accuracy to avoid crosstalk.

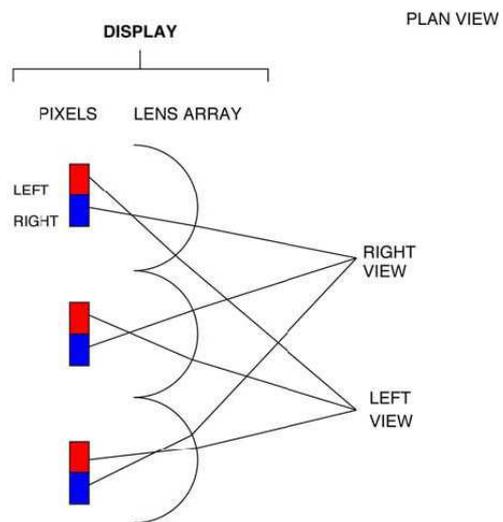


Figure 12: A Lenticular display.

- *Time-sequential displays* employ a directional light source behind the display whose direction can be altered. In a first time frame, the light

is directed to the left eye while the left image is displayed. In a second time frame, the light is directed to the right eye while the right image is displayed. All this gives full resolution to both views; it has the disadvantage that the refresh rate of the display must be doubled. This would preferably be 120 Hz for video rate images, a speed which is at the limits of achievement for current LCDs.

4.2.1 Problems with 3D LCD's

Almost every method to create a three dimensional effect with a LCD has its disadvantages and problems. Following the most common are described:

- **Interlacing:** All 3D displays require modified input in order to drive the correct view with the corresponding image. For implementation reasons, the images are often mixed at the subpixel level; this mixing is called interlacing although it has nothing to do with conventional interlacing as used with CRT displays. Figure 13 demonstrates one example of subpixel interlacing that might be used for a 3D parallax barrier LCD. It is often assumed that the interlacing for a parallax barrier will simply be left pixel right pixel left pixel, and so on, but as can be seen from the diagram interlacing is required at subpixel level when the subpixels are arranged as R-G-B. Interlacing should be performed at the last stage before display. If the interlaced images are subject to lossy compression before display, then the images will become mixed, leading to image crosstalk.

Parallax barrier and lenticular-type autostereoscopic LCDs usually require high driving accuracy in order to achieve subpixel accuracy. In particular, there should be minimal jitter between pixels or other electrical noise; otherwise, this will result in image crosstalk. In this case, only digital video interface (DVI) connections between source and display or similar that can achieve subpixel addressing are practical. Conventional analog driving signals can be used if the tolerances are very low.

- **2D/3D Switching Methods:** The ability to switch between 2D and 3D gives a significant advantage to those users who need both types of display. Most users would prefer to have the ability to switch between 2D and 3D modes, as they do not want to have two displays on their desks. If a 3D autostereoscopic display is used to show 2D information, a distorted effect is of-

ten seen, particularly for text. This is because each eye is still only viewing a subset of the pixels even if the data is no longer providing a stereo image pair. To widen the appeal of a 3D display, it is desirable to be able to "turn off" the 3D function so that the display may also be used as a 2D device. A number of techniques are known for achieving this. The opaque stripes of the parallax barrier may constitute any component that will block light and therefore gives some freedom in how 2D/3D switching may be achieved for example, an additional simple LCD device whose electrodes form the shape of the parallax barrier. With power off, the whole area is transmitting and the device has no function (2D mode); with power on, the barrier is realized (3D mode).

Turning off the lenticular function is generally more difficult, as the effect of a physical lens must be negated. This can be done by controlling the orientation of a liquid crystal in contact with a lens such that in one state there is no refractive index contrast and hence no lens function. In other methods polarization sensitive lenses or liquid crystal switchable gradient index lenses can be used.

- **Brightness:** Optical elements such as parallax barriers block light. This reduces the amount of light reaching the more noticeable when the display is switchable between 3D and much brighter 2D mode. The ideal situation is that 2D mode brightness is equal to 3D brightness. Good contrast is also important in order to show a good quality image.
- **Resolution:** Stereo displays require two images and multiview displays even more. The resolution of the underlying display is fixed therefore the pixels must be divided by the number of views. A two-view autostereoscopic LCD displays two images simultaneously ($n=2$); the user sees both images (half resolution in each eye). All the resolution of the display is used, although each eye does not see a full resolution image. Multiview displays driven with n images often show only $1/n$ of the horizontal resolution per view. At any one position the user can only see $2/n$ of the total display resolution. On-screen text is less readable and details in the images are lost. Images designed for a specific resolution or number of views may need anti alias filtering in order to be suitable for another display, an unwelcome extra stage of processing. In the future 3D displays should be expected to show full horizontal resolution.

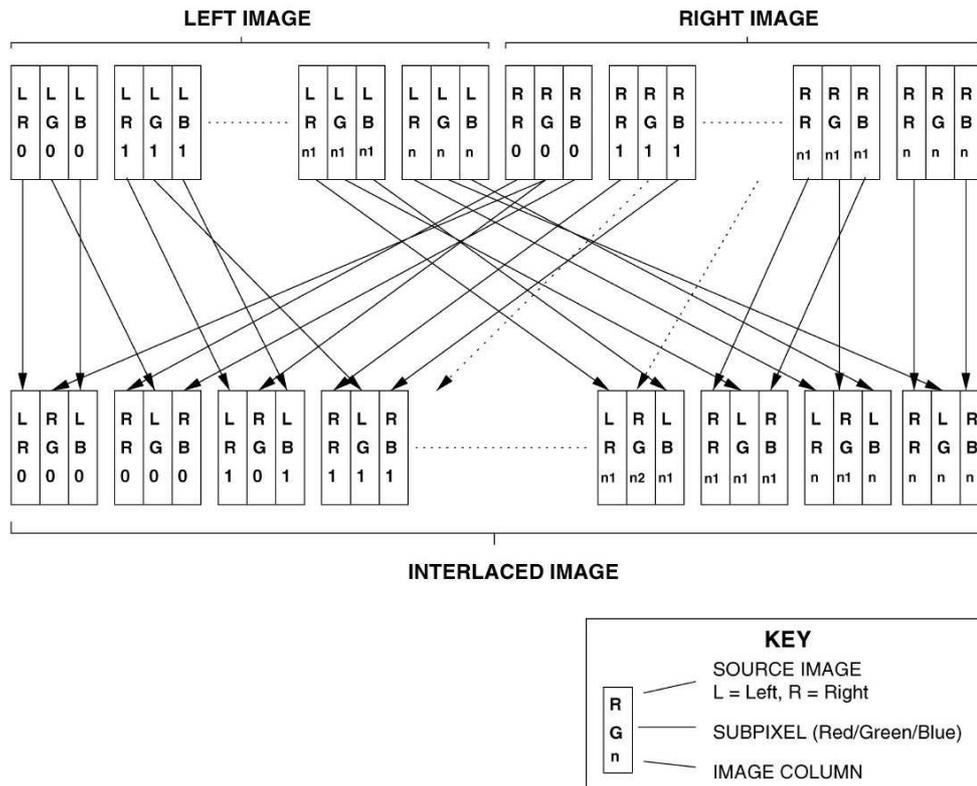


Figure 13: Subpixel interlacing pattern.

4.3 IllusionHole - Multi-User Stereoscopic Display

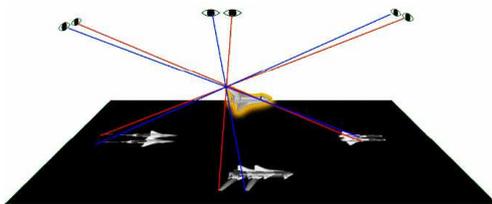


Figure 14: Generation of stereoscopic images in IllusionHole

The IllusionHole multi-user stereoscopic display consists of a display device and a display mask with a hole formed in its center. The display mask is positioned at a suitable distance from the display screen so that each user views a different region of the display according to his or her viewing position. By detecting the users viewing positions and calculating the position and size of the display region for each user based on these positions, a separate stereoscopic image for each user can be displayed in each of these regions. The users view these regions through the mask hole, which allows them to see their own dis-

play regions but not those of the other users. In this way, a single display can be used to show distortion-free stereoscopic images tailored to the viewing positions of multiple users. The position of the stereoscopic image is set close to the mask hole so that it appears to be in the same place from each users perspective as shown in Figure 14, and the users are able to reach out to and point at the stereoscopic image in a natural manner without being obstructed by the optical equipment. These characteristics make the system more efficient for use in cooperative work situations. In Figure 15 the general composition of Illusionhole is showed.

4.4 Volumetric displays

A volumetric display device is a graphical display device that forms a visual representation of an object in three physical dimensions. One definition offered by pioneers in the field is that volumetric displays create 3-D imagery via the emission, scattering, or relaying of illumination from well-defined regions in (x,y,z) space. There exists two different types of volumetric displays implementing two different techniques:

- *Swept-surface* volumetric 3D-Display: This

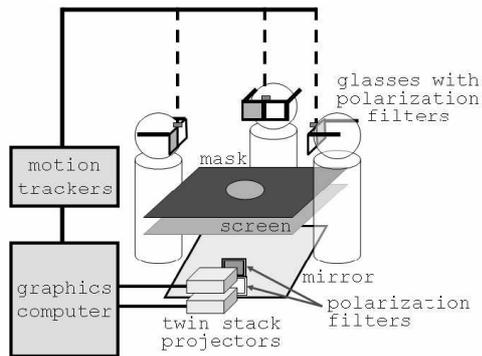


Figure 15: The composition of Illusionhole

method takes advantage of the human persistence of vision, which is the fact, that the human eye and brain retains an image for a brief moment. Generally, 24 fps (frames per second) for the human eye is a fluid animation.

The three dimensional scene is decomposed in



Figure 16: A volumetric display made of rotating leds

2D-“slices” which later are projected onto some type of display undergoing motion. For example, as seen in Figure 16 [International], these two dimensional slices can be displayed with leds which perform a rotation. Every new step made by the leds, the next slice can be displayed, forming a 3D Image. Obviously the display have

to rotate with high speed at about 900 rpm to achieve 25-30 fps.

- *static volume* volumetric 3D displays create images without any moving parts. In the simplest case, the display consists of active elements that are transparent in the off-state, but luminous in the on-state. A simple implementation is made by a cube which contains leds. A more complex method is to create light points with specialized fibre-optic illumination.

Another technique uses a focused pulsed infrared laser (about 100 pulses per second; each lasting a nanosecond) to create balls of glowing plasma at the focal point in normal air (see Figure 17). The focal point is directed by two moving mirrors and a sliding lens, allowing it to draw shapes in the air. Each pulse creates a popping sound, so the device crackles as it runs. Currently it can generate dots anywhere within a cubic meter.

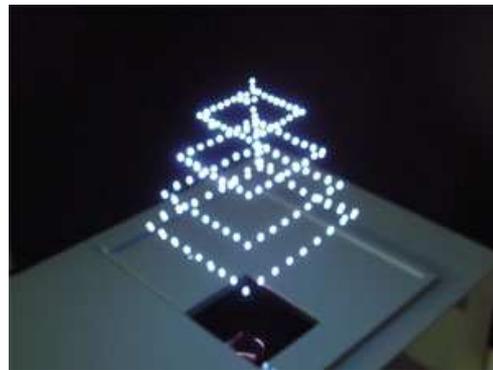


Figure 17: A volumetric display using a pulsed laser to create balls of plasma in air.

4.5 Holographic displays

Holographic displays are “true 3-D.” They record both phase and amplitude information of the light reflected from the scene. They are the ultimate way to achieve high-quality 3-D, as they do not have the accommodation vergence conflict and can be seen from multiple angles by multiple observers. The main drawback is that the bandwidth required for a real-time electronic hologram is prohibitively high. For a high-quality full color desktop monitor-sized display, the data rate is of order of 100 Tb/s. Some techniques have been developed involving tiling of separate images and parallel computing to provide a driving solution, but resolution still remains low. Due to the

nature of the laser illumination, such displays are often monochrome. Other research groups have demonstrated devices which make use of holographic optical elements to produce autostereoscopic displays. Although these contain fixed holograms, they have the same viewing position restrictions as other stereoscopic displays.

5 Conclusion

In this paper the most important techniques to create a spatial three-dimensional image were described. Every technique has its advantages and disadvantages, thus it cannot be said which one is the best. Stereoscopia with polarized glasses is a good method which is available already under \$10000 and provides a good three-dimensional effect to a big audience. 3D-LCD's are a appropriate method, if only one person has to see the image.

Holography systems and volumetric displays are in its beginnings and at the moment the results are not sufficient.

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