An Introduction to 3D Computer Graphics, Stereoscopic Image, and Animation in OpenGL and C/C++

Fore June

Chapter 15   Stereoscopic Displays

In chapters 8 through 10, we have discussed the principles and programming of stereoscopic graphics. We have concentrated on discussing the creation of anaglyphs and the use of color-coded glasses to view anaglyphs. Nowadays, there are a lot of new 3D display systems that can provide new advantages to end users. Some new systems are able to support an auto-stereoscopic, no-glasses, 3D display that provides enhanced image quality over older generation systems. In recent years, auto-stereoscopic displays have seeked their way into desktop computing as the cost of micro-optics, LCD displays, image processing and 3D graphics technologies have been dropping rapidly. Low cost high-resolution stereoscopic displays and associated equipment are readily available, which help drive the development of applications, ranging from science and engineering to entertainment and education, using stereoscopic imaging and graphics technologies to create higher quality products or provide better services. For example, stereoscopic commercial 3D DVDs and PC games are popular and widely available to the public; NASA mounted four stereoscopic cameras on the 2004 Mars rovers (Spirit and Opportunity) as shown in Figure 15-1 below.

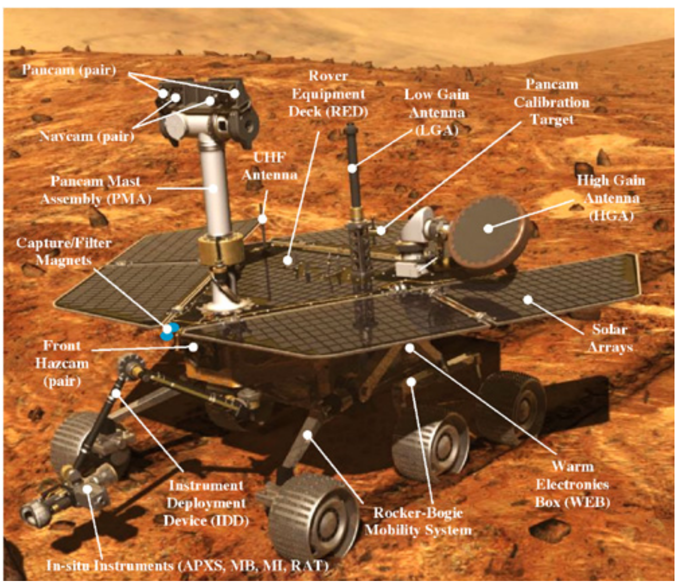


Figure 15-1   NASA Mars Rover with Stereoscopic Cameras
(Image from *http://marsrover.nasa.gov/mission/spacecraft_surface_rover.html)*

The wider availability of stereoscopic applications in turn brings down the cost of stereoscopic displays. Today, there are many vendors of 3D display systems, including Barco, Christie Digital, Dimension Technologies Inc. (DTI), Opticality, Sharp, StereoGraphics, SeeReal, and VREX. The traditional display device, Cathode Ray Tube (CRT) has given way to a new generation of displays such as Liquid Crystal Displays (LCD), Plasma Displays, and Digital Light Processing (DLP) Displays.

Whatever method a stereoscopic display device uses, it always relies on some undelying method to present to each of our eyes a different perspective image. In the following sections, we discuss some commonly used display technologies.

15.1 Anaglyph

We have discussed anaglyphs in detail in Chapters 9 and 10. In short, this method uses different colors to render left and right eye images. In general we display the left perspective image with red color and the right perspective image with blue and/or green colors. A viewer wears a pair of glasses which has a red left lens and a cyan right lens. It is possible to use other combinations of color primaries such as a combination of red and green. Anaglyphs are easy to produce and the glasses are cheap, which have made this method cost-effective. Moreover, the color composite of an anaglyph is compatible with all full color displays. In other words, we do not need to purchase any special display device to display an anaglyph. All we need is a pair of color-coded glasses. However, compared to other stereoscopic methods, the anaglyph technique produces relatively poor quality of images and cannot create truly full-color stereoscopic images. Research has revealed that anaglyph image quality depends on the spectral color purity of the display and the glasses. A study on anaglyph ranks display devices for anaglyph images in following order, from best to worst: 3-chip LCD projector, 1-chip DLP projector, CRT display, LCD display.

15.2 Time-Sequential

Time-sequential is also referred to as field-sequential or frame-sequential because the stereo display presents a sequence of fields or frames alternately to the left and right eyes of the viewer. The viewer wears a pair of shutter glasses whose left and right shutter 'opens' and 'closes' in synchronization with the left and right perspective images shown on the display device so that the left eye sees only the 'left' perspective images and the right eye sees only the 'right' perspective images. The shutter glasses and corresponding projectors could be mechanical or based on liquid crystal (LC). A mechanical shutter projector uses a spinning disc, half transparent and half opaque to present two sequences of images alternately. Liquid crystal shutters are widely used for shutter glasses. (See Figure 9-1 of Chapter 9 for an LCD shutter glasses.)

The image quality of time-sequential stereoscopic stereo display depends on the persistence and refresh rate of the display device and the quality of the particular LC shutter glasses used. In general, shorter persistence pixels and faster refresh rates produce better stereoscopic image quality.

15.3 Spatially Multiplexed Polarized

The VREX company has introduced a series of stereoscopic display designs that are based on polarizing micro-optics. Left and right image elements are spatially-multiplexed as shown in Figure 15-2 below. A single display is divided into two differently polarized views. A viewer wears a pair of polarized 3D glasses to view the image composed of the polarized views. The two different resolution views may be achieved using a checkerboard pattern of image multiplexing and polarization. In Figure 15-2, left (L) and right (R) image pixels are spatially-multiplexed together and the resulted image is placed behind a patterned micro-polarizer element. When viewed with polarized glasses, our left eye sees only the P_1 polarized pixels, and our right eye only sees the P_2 polarized pixels.

When the micro-polarizer is mounted over the LCD, a gap (g in Figure 15-2) forms between the substrates. This gap could induce undesired parallax, which is particularly pronounced for direct view LCD based displays. If the head is not at the right position, the adjacent normally invisible pixels may become visible as a result of crosstalk. A simple way to reduce the effect is to interlace the images in alternate rows so that the lateral head movement is not affected by parallax. This problem may be fully solved if the LCD manufacturers make the micro-polarizer element within the LCD pixel cells, which can reduce the parallax between polarizer and pixel.

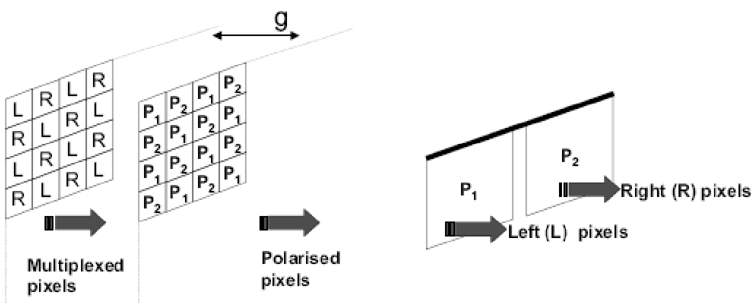


Figure 15-2 VREX Spatially Multiplexed Image (SMI)

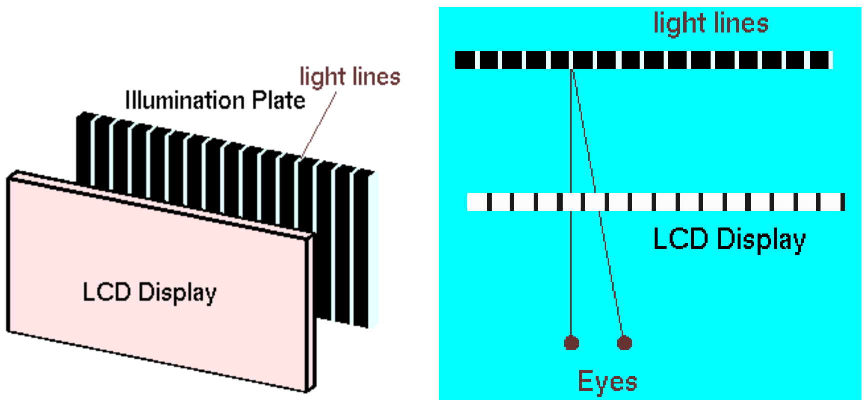
15.4 Polarized Projection

In this method, we optically overlay two images for display and use polarization to code images. Two images are projected onto the same screen or display through different filters. A viewer wears polarized 3D glasses that contains a pair of different polarizing filters to view the overlayed images. As each filter passes only the light that is similarly polarized and blocks the light polarized in the opposite direction, each eye sees a different image. Figure 15-3 shows a pair of glasses containing polarized filters.

Figure 15-3 A Pair of Polarized Glasses

15.4 Lenticular, Parallax Barrier and Parallax Illumination

These methods are some of the **autostereoscopic** display techniques, in which a viewer can view stereo pairs without wearing a pair of glasses. The methods are similar in the way that they need to work with a fixed-pixel display; the display device consists of spatially-grouped pixels that are aligned with an optical element. The views of the two eyes of a viewer fall into two zones, each of which is only visible to one eye. As a consequence, this creates a 3D sensation without the use of 3D glasses. Figure 15-4 below illustrates this principle. In the figure, the white light lines are the optical element. The LCD pixels are illuminated by the light lines and form viewing zones where particular groups of pixels are only visible from a particular direction as shown in (b).



(a) (b)

Figure 15-4 Illumination Zones

In lenticular display, the optical element consists of a series of vertical lenslets (lenticules) fitted over the display surface. Lenticules are tiny lenses on a special film. The lenses direct the light from the stereoscopic images to our eyes with each image visible to only one eye. To sense the 3D effect, our eyes must be in a sweet spot so that each eye sees light from one zone. (See also the discussion on integral method below.) If we were to move to the left or right from one of the sweet spots, the image on the screen would appear blur. Future televisions may include a camera that tracks our position. The television may be able to adjust the image so that our eyes are always in a sweet spot.

In parallax barrier display, the optical element consists of a series of opaque vertical strips placed over the display surface, similar to the black strips of Figure 15-4(b) of the LCD display.

In parallax illumination display, vertical strips of light are fitted behind the display similar to the one shown in Figure 15-4. As illustrated in the figure, such a system displays left and right images of stereo pairs on alternate columns of pixels on the LCD. The left image may appear on the odd numbered columns and the right image may appear on the even numbered columns. If the LCD has 1024 columns and 768 rows of pixels, then each complete stereoscopic image has 512 columns and 768 rows. Both halves of a stereo pair are displayed simultaneously; a special illumination plate located behind the LCD directs them to corresponding eyes. The illumination plate, consisting of compact intense light sources, generates a lattice of very thin and bright, and uniformly spaced vertical light lines, in this case 512 of them, which are precisely spaced with respect to the pixel columns of the LCD so that the left eye sees all of the lines through the odd columns of the LCD, while the right eye sees the even column pixels as shown in Figure 15-4(b). This technology may allow several people to view the stereo on the same screen at the same time.

15.5 Dual-View Twin-LCD Systems

Using two LCD elements has been a successful approach to building high quality autostereoscopic displays. In this method, one LCD directs an image of a stereo pair to the left eye while the other LCD directs the other image to the right eye. Figure 15-5 below shows one of the Sharp designs of dual-view system, which produces high quality 3D stereoscopic video over a wide horizontal range. The display has two viewing windows with a single illuminator.

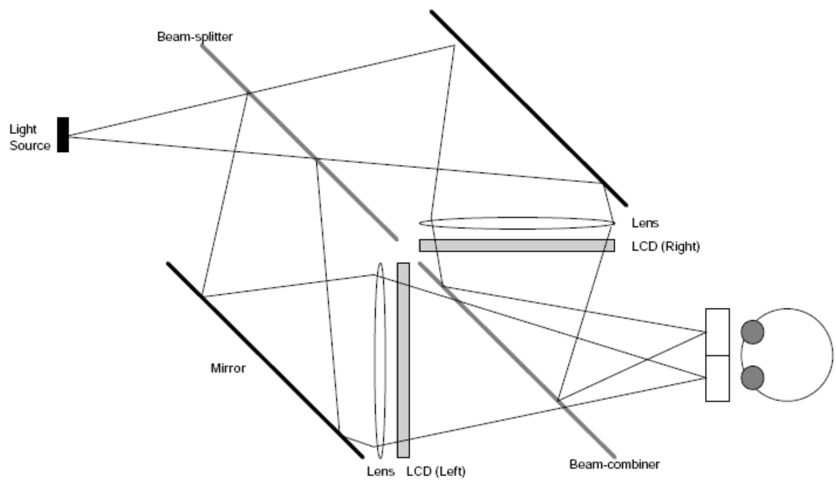


Figure 15-5 The Sharp Twin-LCD Display

As shown in the figure, horizontally offset images are generated from the optical elements. An eye can only see one image passing through the viewing window. Therefore, if we place a stereo pair images on the left LCD and the right LCD, we will see a stereoscopic 3D image. This optical arrangement can be used in a low cost desktop PC system.

The viewing windows play an important role in determining the quality of autostereoscopic displays. Undesirable visual effects such as image flickering, reduced viewing freedom and increased inter-channel cross-talk could result from degradation of the windows due to unresolved issues in the optical design. When designing the windows, designers have to carefully take into consideration the windows' shape and size, and the lateral and longitudinal viewing freedom.

15.6 Other Methods

There are many other methods of displaying stereoscopic 3D images. We breifly discuss a few here.

Autostereogram

Autostereogram refers to the single-image form of stereograms that can give a visual illusion of a 3D scene from a 2D image without using any special visual aid. For us to perceive 3D in an autostereogram, we have to overcome the coordination between vergence and focusing that normally occurs automatically in our brain.

To create an autostereogram, we modulate a repeated horizontal pattern to create an image that can be viewed with an abnormal convergence (or divergence) angle; the image would give an illusion of 3D within the space of the pattern. Figure 15-6 shows such an image, which is a structured pattern autostereogram of a heart on a ground of roses; the image is downloaded from Magic Eye (*http://www.magiceye.com/*). If we view the image with normal convergence, we will see it as a flat repeating pattern. However, a hidden 3D scene would appear if we view it with the correct vergence. Recall that we perceive depth via binocular disparity, in which our left eye and right eye see the same object from slightly different angles, leading to two slightly different perspective images. With autostereogram, when we look at the repeated pattern at a distance that our eyes either diverge or converge, our brain is not able to match the images from the eyes correctly and the small differences between adjacent pattern cycles could provide binocular disparity. Consequently, we see a 3D scene.

In creating an autostereogram, we may construct the disparity structure to correspond to the depth map of the desired 3D scene. We will obtain the 3D sensation when our eyes are at the appropriate convergence angle while looking at the image. However, to perceive the 3D scene, the viewer must overcome the nominal tendency of the eyes that focus at the convergence distance; the viewer has to refocus at the plane of the image. (For Figure 15-6, it is easier to see the 3D scene if you print the image on a piece of paper, not necessarily colorful. You first hold the paper near your eyes and focus on the whole image which appears blur. Then you move the image slowly away; at a certain distance, you will see a heart structure pops out.)

We can also create 3D animation by showing a series of autostereograms one after another, in the same way we normally render animated graphics.

Figure 15-6 Magic Eye Image (from *http://www.magiceye.com/*)

Volumetric Display

Volumetric displays are true 3D display systems, meaning that each spatial position (x, y, z) is displayed physically in a real 3D space volume. The displays use a voxel, the

3D analog to a pixel in 2D image, to describe a displayed position. Traditional volumetric displays have multiplanar displays, giving rise to multiple display planes; they also have rotating panel displays to sweep out a volume. Newer technologies may use projection of light dots in the air above a device; by focusing an infrared laser beam at a point in space, we can generate a small bubble of plasma that emits visible light.

Figure 15-7 shows a volumetric device from Sony.

Figure 15-7 A Sony Volumetric 3D Display

Holographic Display

Holographic displays are another kind of true 3D display systems. They can provide a viewer various depth cues, including motion parallax, binocular disparity, accommodation and convergence and the images they display are scalable; the images can be created with one light wavelength and viewed with another. Again a viewer does not need any special glasses to view 3D objects and the viewing will not cause any visual fatigue.

The principles of the displays are based on holography, which is a technique that makes use of the coherent properties of laser beams to record the 3D structure of an object. The recorded image is referred to as a hologram, which is **not** recorded as a conventional image on a film, but as an interference pattern of light on the film. Holograms must be recorded with coherent light. Coherent light consists of light waves that are "in phase" with one another, which is typically produced by lasers. Light from the sun or light bulbs are incoherent light.

Scattering, reflection and refraction of light waves by a surface can change the phase of the waves. Different surface shapes will change the phase in different ways, leaving a distinct footprint of the surface in the light waves. When two waves interact, they interface with each other to generate an interference pattern, which may be a standing wave. If the two interacting light waves do not change, the resulted standing wave will remain unchanged. The standing wave is what is recorded onto a hologram.

In the process of creating a hologram, a coherent light beam from a laser is split into two beams, an illumination beam and a reference beam, as shown in Figure 15-8. The illumination beam shines the object and is reflected or scattered by the object. The reflected beam, referred to as object beam in the Figure, is combined with the reference light beam at the film. The recorded interference pattern allows one to reconstruct the 3D scene; a viewer sees a different appearance of the object when viewing the hologram at a different angle.

When a hologram is viewed with a coherent light source as shown in Figure 15-9, the original light waves are reconstructed, creating a 3D virtual object in space. We can view the virtual object (image) from different angles, as if it were actually there. When viewing from the front, we see the front of the object, and when viewing from the side, we see the side of the object. Even if we cut the hologram into two halves, we still can see the whole virtual object from each piece. This is because each point of a hologram contains information about light reflected from every point of the real object. This is in analogy of seeing a mountain through a window. We still can see the whole mountain through a smaller window with half the size; all we need to do is to tilt our head to change our viewing angle. This makes holograms good data storage media as they inherently have the fault tolerant property.

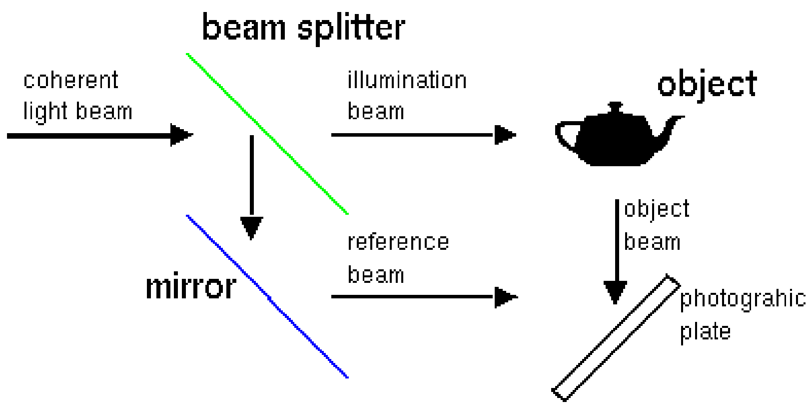


Figure 15-8 Creating a Hologram

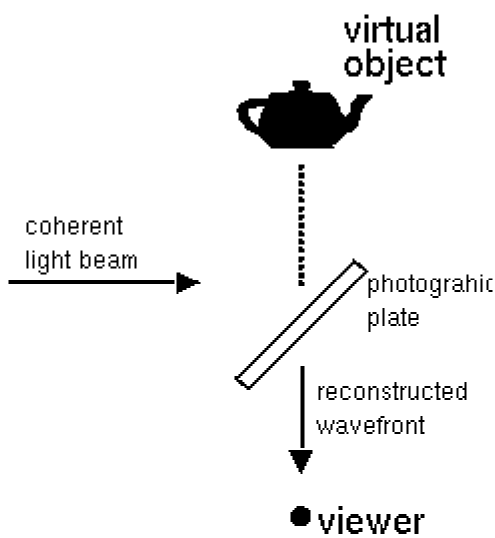


Figure 15-9 Reconstructing Scene From a Hologram

Integral Imaging

Integral imaging is also an autostereoscopic method, similar to the lenticular method. It makes use of an array of spherical convex lenses, each containing a micro-image, to create 3D viewing. The lens array is known as a fly's eye or integral lens array. Parallel incident light rays are focused on a flat surface, known as focal plane, which is on the opposing side of the array as shown in Figure 15-10. (Note that a light path is reversible meaning that it is always bidirectional.) Different sets of parallel light rays will focus onto different points. This implies that our eyes will see different focal points of a lens as our eyes look at the lens at different angles. On the focal plane, one micro-image is placed at the focal point of one lens. Consequently our left and right eyes will never see the same spot of a micro-image; the eyes always see different spots as parallel light rays along the paths from the eyes always focus on different spots. For example, if a micro-image consists of only a white dot and a black dot which are carefully placed by pre-calculations, then it is possible that the left eye can see only the black dot and the right eye can see only the white dot. Therefore, by carefully decomposing a composite image into micro-images, we can have our left eye sees one image and the right eye sees another one.

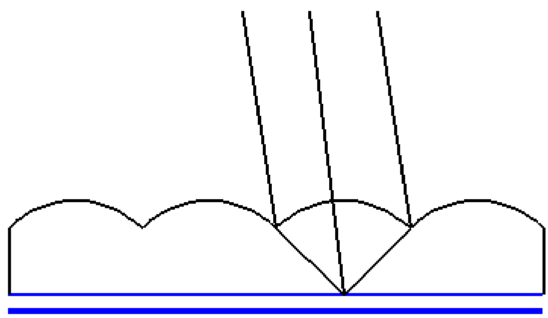


Figure 15-10 Light Rays Focus on Flat Panel of Lens Array

15.7 Stereoscopic Compatibility

When we develop a stereoscopic application, we need a display device to show the image pairs. The display must be compatible with the stereoscopic display method we intend to use otherwise a stereo pair cannot be properly displayed. Unfortunately, current display products are not always compatible with existing stereoscopic display methods. Therefore, stereo image developers need to have a knowledge about the compatibility of current display products with commonly used stereoscopic display methods.

Besides some special cases such as autostereogram and volumetric display, the compatibility between a display and a stereoscopic display method is determined by a few factors, including native polarization, image persistence (also called refresh rate or response time), color purity, and the spatial configuration of the pixels. There has been quite a lot of study on this subject in recent years.

LCD

Conventional Liquid Crystal Displays (LCD) are not well-suited to time-sequential 3D because of the scanning image update method and the hold-type operation of LCDs, and in some cases slow pixel response time. The maximum speed at which a display can render a sequence of images is determined by the display's maximum refresh rate. If the refresh rate is not high enough, the rendered images cannot be synchronized with the shutter glasses. Also, it takes a finite amount of time for to a display to switch the state of an individual pixel. It takes a long time for the brightness of a pixel of an LCD display to stabilize. The refresh rate of an LCD is effectively halved when displaying time-sequential stereo images. For time-sequential 3D viewing, the Liquid Crystal Shutter (LCS) should be closed until the changed state of the pixel has stabilized sufficiently. If the pixel response time is not fast enough, the rendered image could not be stabilized before the next image is displayed, and hence give poor visual effect for time-sequential 3D viewing. LCD's image update method also hinders its usage for time-sequential 3D because a new image is written to an LCD one line at a time from top to bottom. This is similar to the way that an image is scanned on a CRT, except that an LCD is a hold-type display whereas a CRT is an impulse-type display. This means that there is no single image shown exclusively on the whole LCD panel at a time. This implies that we cannot see exclusively a single perspective image when the shutters in the LCS glasses open. However, the improvement in the pixel response time and refresh rate could mitigate this effect, and LCD will become more compatible with time-sequential 3D in the future.

On the other hand, LCDs are compatible with anaglyphs, polarized projections and other fixed-pixel methods. The color purity of an LCD affects the quality of a rendered 3D image; this quantity varies considerably from display to display.

CRT

For many years in the last century, the Cathode Ray Tube (CRT) was the dominant display technology. However, in the past couple of decades, CRT has given way to better emerging new display technologies such as LCD, Plasma, and DLP. Pixel brightness of CRT or plasma phosphorus changes a lot faster than that of LCD. Therefore, CRT is naturally well-suited for time-sequential 3D viewing. The technology is also compatible with anaglyph, and polarized projection methods. However, a CRT is a device with a photosensor that detects a scanning electron beam; it is not compatible with fixed-pixel methods.

Plasma

Plasma is a collection of charged particles (positive and negative ions) in the form of gas-like clouds or ion-beams that respond strongly and collectively to electromagnetic fields and is often described as an *ionized gas*. Plasma display panels (PDP) consist of small plasma cells that change color with the strength of an electromagnetic field like what a fluorescent lamp does.

Plasma displays are usually bright and have a wide color gamut, and have fairly large sizes (up to 3.8 meters diagonally). They are now commonly used for both commercial information display and consumer television applications. Studies show that plasma displays are not ideal for use with time-sequential stereo. While many plasma displays do support time-sequential, they usually have a maximum display frequency of 60Hz and most have long phosphor persistence which produces a lot of stereoscopic crosstalk. The compatibility of plasma display and 3D stereos is expected to be similar to that of CRT.

DLP

Digital Light Processing (DLP) is a rear-projection technology that competes against LCD and plasma flat panel displays in the high-definition TV (HDTV) market. The image formed by a DLP projector is created by a Digital Micromirror Device (DMD) which is a semiconductor chip consisting of microscopically small mirrors laid out in a matrix form. Each of the micromirrors represents one or more pixels of the projected image. This technology is compatible with polarized and time-sequential methods. It is not usually considered for fixed-pixel methods as the technology is currently only used in projection displays. The anaglyph compatibility ranges from poor to good as the color purity of different DLP displays varies significantly.

Others

There are also many other emerging display products available or becoming available in the market. These include Light Emitting Diode (LED) , Organic Light Emitting Diode (OLED), Ferro-Electric Liquid Crystal Display (FELCD), and Liquid Crystal on Silicon (LCoS). Currently, there have not been many studies on the compatibility of the emerging display technologies and stereoscopic display methods.

Other books by the same author

Windows Fan, Linux Fan

by *Fore June*

Windws Fan, Linux Fan describes a true story about a spiritual battle between a Linux fan and a Windows fan. You can learn from the successful fan to become a successful Internet Service Provider (ISP) and create your own wealth. See *http://www.forejune.com/*

Second Edition, 2002.
ISBN: 0-595-26355-0 Price: $6.86

An Introduction to Digital Video Data Compression in Java

by *Fore June*

The book describes the the principles of digital video data compression techniques and its implementations in java. Topics covered include RBG-YCbCr conversion, macroblocks, DCT and IDCT, integer arithmetic, quantization, reorder, run-level encoding, entropy encoding, motion estimation, motion compensation and hybrid coding. See
http://www.forejune.com/
January 2011

ISBN-10: 1456570870

ISBN-13: 978-1456570873

An Introduction to Video Compression in C/C++

by *Fore June*

The book describes the the principles of digital video data compression techniques and its implementations in C/C++. Topics covered include RBG-YCbCr conversion, macroblocks, DCT and IDCT, integer arithmetic, quantization, reorder, run-level encoding, entropy encoding, motion estimation, motion compensation and hybrid coding.

January 2010
ISBN: 9781451522273