Single and Multiple Viewer Stereo with DLP Projectors

Ian McDowall*　Mark Bolas*　Dan Corr*　Terry Schmidt**
*** Fakespace Labs　** Christie Digital Systems**

Abstract

DLP (Digital Light Processing) is about to invade stereo applications, one of the last bastions of CRT projection technology. This paper presents various methods for achieving stereo and their application to DLP projectors. The newly developed sequential stereo capable projectors are also introduced and their performance characteristics discussed along with artifacts. Also presented are ways to employ these projectors to realize multiple simultaneous viewers.

Introduction

This paper introduces the new sequential stereo capable DLP Projectors and outlines the current state of development of stereo using DLP projection technology. DLP stands for Digital Light Processing, a Texas Instruments technology commercialized in the 1990's. This projection technology employs a solid state digital light engine and a high brightness light source to produce bright vibrant color imagery.

Stereo, and particularly stereo from computers, has generally been accomplished using analog CRT projectors. Images are generated by the computer and fed to the CRT projector at a high vertical scan rate. The viewer wears special glasses which enable different images to be seen by each eye. These systems are generally of limited brightness, and require extensive day to day maintenance to keep the images from the CRT projectors well converged and crisp.

The nature of stereo is also changing. In the past, stereo generally meant delivering a static pair of images to a viewer so that they could "see" 3D. The classic example of this is the XXX type viewers of the late 1890's. Currently however, the most benefit is derived from computer based stereo when the user is also head tracked. Head tracking enables the user to move their head or body through the computer generated scene. The scene is continually updated to reflect the user's current eye positions. Thus, the viewer may examine object "as if they were real" and gain insight into a particular process or environment being displayed. The various products in the marketplace which reflect this trend include the CAVE, RAVE, and the various Bench type products.

A stereo viewer from the 1890's

Two user bench type head tracked display

This paper presents several ways to get stereo from DLP projectors. A new class of stereo DLP projectors will be discussed and the performance characteristics outlined along with some artifacts we have noticed. In addition, ways to deliver stereo views to more viewers of the same scene from differing real time perspectives are also presented.

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* Fakespace Labs, 241 Polaris Ave., Mountain View, CA 94043 USA
http://www.fakespacelabs.com

** Christie Digital Systems, 809 Wellington St. North, Kitchener, Ontario, Canada N2G 4Y7
http://www.christiedigital.com

Stereo Techniques

The general motivation for wishing to display stereo images is to present computer generated modes in a way that is more "natural" than looking at a single 2D image of a 3D model of some mechanism or simulated process. There are actually a number of cues the body uses to determine the spatial nature of the visual environment. Amongst other things, these cues include parallax (when you move, closer objects "move" more than distant ones), occlusion (distant objects are partially obscured by closer ones), perspective (the classic rail way tracks which appear to get closer together further away), binocular disparity (each eye sees a slightly different view of the world and the brain can determine distance based on the differences), accommodation (the distance at which the eye is focused), and convergence (the eyes rotate about the body's vertical axis to point the eyes at close objects). Of these cues, the word "stereo" is generally referring to the binocular disparity cue. Other cues such as perspective and occlusion occur naturally in computer graphics scenes. Head tracking and live updates from the computer provide the parallax cues. Generally, the other spatial cues are ignored at present due to implementation issues rather than their being unimportant.

Single Viewer Stereo

Almost all head tracked stereo systems deliver a left-right pair of images to one or more screens. These images are generated by a computer system and are based on both the current state of the simulation, and the viewer's head or eye positions. There are several techniques for delivering the left eye image and the right eye image to the appropriate eye of the viewer. Note that if there are additional viewers, they can also see the stereo pair but it will not look correct because their viewpoint is not used in calculating the perspective projection of the scene onto the screen or screens. This is why when people are in a system like the CAVE, it is highly desirable to be the single person with the head tracker.

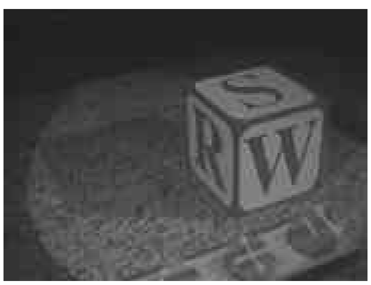


Image seen by a head tracked user standing to the left of a cube located on the surface of the bench display.

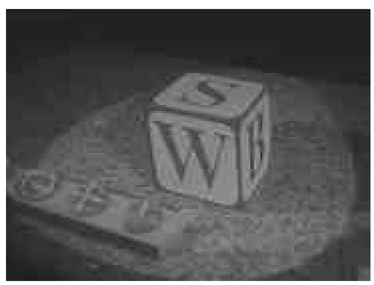


Image seen by a head tracked user standing to the right of a cube located on the surface of the bench display.

The image a user standing on the left would see if generated from the position of the viewer on the right (the un tracked user view).

Frame Sequential

The most commonly used approach is to deliver stereo in sequential frames. In this approach, a sequence of left / right image pairs are delivered at a rate of between 48 and 60Hz. The viewer wears special glasses which contain a liquid crystal lens. This lens is switch on and off in sequence with the images. Thus, when the left image is displayed, the left eye can see the image and the right eye is darkened. At the next instant, the liquid crystal material changes state in each lens and the right eye sees the right image and the left is darkened. In a typical Cave as shown on the left, sequential stereo is typically used. The left user is seeing a highly distorted view relative the head tracked user.

This frame sequential stereo technique is attractive because it uses only one projector to generate the pair of images, the images are inherently relatively well aligned with one another, and can be used with CRT displays as well as projected environments. Deficiencies of this method include low brightness, "bleed" between left and right images, and the maintenance of the CRT projectors.

Passive

Passive stereo systems are based on delivering simultaneous images to a display surface with slightly different characteristics. In passive stereo projection systems, generally, a pair of projectors are used. The projectors are connected to left and right image sources. These image sources, and the projectors, are ideally genlocked so that there are no temporal differences in left - right image pairs being delivered to the screen (this is a particularly important issue for scenes with moving objects). The projectors are also equipped with polarizers such that the projected light from one projector is orthogonally polarized relative to the other (either linearly or circularly polarized). The light from the projectors is cast onto a screen material which does not disturb the polarization of the light from the projectors. The viewers of such a system also wear glasses which have two orthogonally polarized lenses. Thus, images which are polarized one way only reach one eye. As a result, the two eyes receive independent images from the two projectors.

An adjustable VersaBench with passive DLP stereo

There are a number of variations on this theme. For example, sometimes LCD elements are placed in front of a CRT projector and are switched so that orthogonally polarized images are delivered over time and the viewer can wear passive glasses. Another approach is to use different colors to separate the images - this is the classic comic book red - green glasses (this general idea has been extended by TAN in Germany to deliver full color projected images).

Passive stereo is generally most effective for large groups of people because the glasses can be made very cheaply from paper and two orthogonally polarized plastic film lenses. Passive stereo also tends to feel better because the images are generally perceived to be less flickery. Problems include "bleed" between the eyes, special image generators, and the initial physical and color balance setup is challenging.

Spatial

Stereo images may also be delivered by simply delivering to the left and right eyes different images. This may be accomplished by spatially separating the left and right eye views. Because the viewer's eyes are separated by 64mm or so, vertical "slats" of light from an image may be made to fall into bands. The two eyes of a viewer looking at the image will see light from different "slats". The light for the different slats can come from different image sources, and a stereo pair may therefore be presented. An example of this type of approach is a lenticular type 3D picture which one sometimes see used in post cars and the like.

These techniques are generally used for small displays and principally for viewers who are not moving around significantly.

Multi Person Stereo

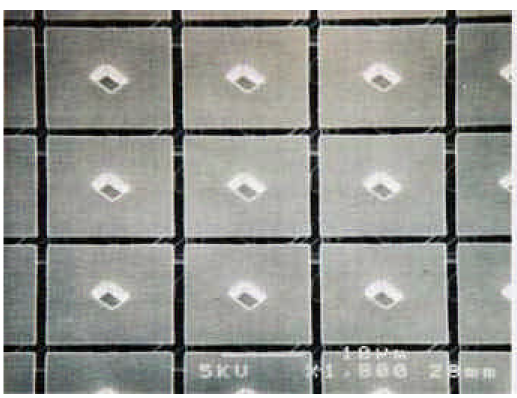
Interactive computer based systems such as Benches and Caves are great for a single user but are often perceived as being good for collaboration between people. This misunderstanding leads to various means to try to compensate. Other participants are encouraged to stand "near" the person with the head tracker for example.

To overcome these deficiencies and to enable these systems to support multiple users, we developed, with the help of the SBIR program, a means for supporting two simultaneous users. This system uses an extension to the sequential stereo approach and delivers a pair of stereo images to two viewers. These two viewers have completely independent views on the scene. Users wear special stereo glasses which, like those used for sequential stereo, can make one lens dark and the other transparent. These particular glasses can also be turned completely dark for both eyes. Thus, in time, when an image is on the screen, only one of the four lenses will be open. This unique system is more completely described in Siggraph 1997 Proceedings.

This was the first time that two viewers could see completely independent head tracked views of a computer generated scene on the same display surface which allows for real collaboration between them. The system is more of a research tool however and images are flickery and rather dim.

DLP Projector Technology

Chip Level DLP

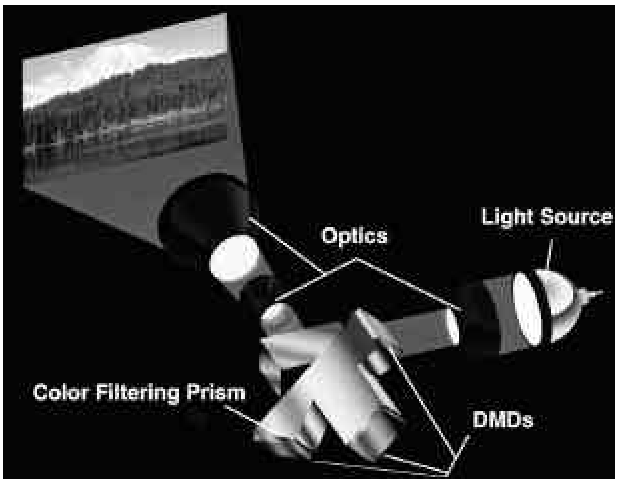


DLP mirrors (~17um across)

DLP projectors are all based on a unique silicon chip movable mirror technology. The DLP chip is an array of tiny mirrors (each on the order of 10-20 microns). Each mirror may be oriented individually. In current systems, the mirrors are either "on" or "off" and light is either reflected to eventually hit the viewing screen or is directed such that it does not pass through the projection lens but hits an absorber of some kind. The mirrors may be switched quite quickly, on the order of microseconds. To generate gray scale images, the mirrors are pulse width modulated over the frame time. In order to reduce artifacts, the pattern of the pulse width modulation and the pixels modulated at any particular instant is carefully controlled by the drive electronics for the part.

Three Chip DLP Projection

The DLP technology inherently produces monochrome images. In order to generate a color image, one approach is to use three of the DLP chips and to bounce red, green, and blue light off of the DLP chips. The three primary color images are then delivered through an optical system to projection lens and ultimately delivered to the screen.

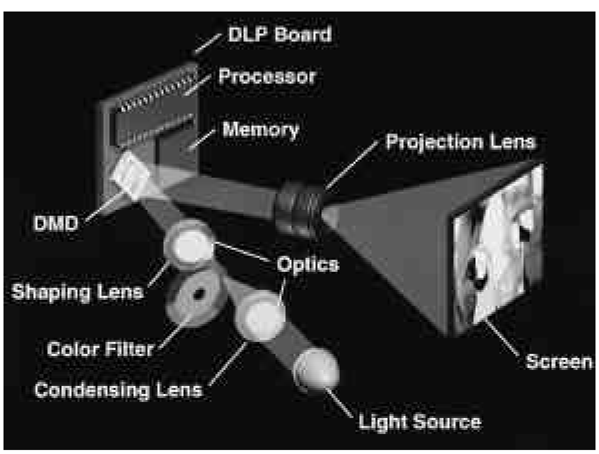


3 Chip Projector Design

These projectors have generally not been used in stereo applications. This is because they are designed primarily for monoscopic applications. Sequential stereo requires that a particular frame be treated as a left or right image throughout the system and delivered in its entirety to the screen in one time slot. A DLP projector digitizes the incoming video stream and stores the images in a frame buffer. The DLP chip is running at its own rate and using data from the frame buffer to produce the image. Thus, if the incoming video rate is 72Hz and the DLP chip is running at 60Hz, then every 5^{th} incoming frame must be dropped or averaged into the frame buffer some how. This decoupled relationship between incoming images and outgoing images is, of course, unacceptable for a high quality sequential stereo system.

These projectors have been used in passive stereo systems. The images from the projectors are generally orthogonally polarized.

Single Chip DLP Projection



Single Chip Projector Design

Multi DLP chip projection is expensive and the optics required to merge the three color images together are bulky. Thus, for portable applications, there is a field sequential color solution which employs a color wheel and a single DLP chip. Light is delivered to the DLP which changes from red to green to blue and the images delivered to the DLP chip are synchronized with the changing colors. As a result, a color image is perceived by the viewer.

DLP Stereo

Active Stereo - New DLP Stereo Enabled Projectors

The new DLP stereo enabled projectors which have been developed provide high brightness, low setup, and low maintenance systems suitable for a wide range of computer visualization tasks. A prototype of these new projectors were first shown by Christie Digital Systems in conjunction with Fakespace Systems in Dallas at the fall Supercomputing Show of 2000.

This new class of 3 chip DLP projector incorporates a new projector engine able to produce sequential stereo images at rates of up to about 110Hz (for a frame rate of about 55Hz). In addition to the ability to synchronize to faster vertical refresh rates, the new system also guarantees a fixed single frame delay. This single frame delay is a significant and important change to the existing way this class of projector works. The guaranteed latency of a single frame time also makes this class of projector more appropriate for demanding real time applications such as flight simulation. In flight simulation systems, a predictable latency (ideally zero) between a generated pixel and its display is essential for synchronization of motion cues, and to avoid temporal aliasing effects.

Planned Products - New Projector Specifications & Characteristics

SXGA (1280x1024 pixels) 3 Chip DLP projectors with stereo capability.

Light Output	ANSI Contrast Ratio	Light Source	Common Specifications
1,500 ANSI	160:1 Minimum	500W Xenon	Horizontal 15kHz to 120kHz
5,000 ANSI	160:1 Minimum	1.2kW Xenon	Vertical 24Hz to 110Hz
9,000 ANSI	150:1 Minimum	1.6kW Xenon	1 frame delay @ 1280x1024 resolution

A typical CRT projector would have a brightness level of about 250 ANSI lumens and an ANSI contrast ratio of about 50:1. Clearly, relative to the CRT benchmark, these new projectors provide an order of magnitude improvement in the brightness and contrast ratios available for stereo.

These new stereo capable DLP projectors have a number of characteristics which are different from their CRT counterparts. This is because the way in which the images are created is different.

High brightness is great for environments in which people are wearing stereo glasses. By their nature, stereo glasses generally pass *less than 30% of the available light in the on or clear state* (in the "off" state, transmission is generally less than 1%). Thus, by having a brighter image source, these environments will be usable under more normal lighting conditions.

The contrast ratio for displays seen through stereo glasses is also degraded by the persistence of the phosphor of the CRT display. Even though most CRT projectors used in these projected environments use the P43 fast green phosphor, the exponential decay of the prior image means that there is a non trivial amount of bleed from one image to the next. The phosphor decay times are color dependant with red and green being much longer than blue. The latent images from the prior frame may be more evident at the top and bottom of the screen. The DLP stereo projectors on the other hand do not have the latent image problem. If the prior frame was pure white, and the next pure black, there will be no light from the prior frame. This is a dramatic improvement in image quality for stereo environments where the ghosting can be distracting on symbology superimposed on data.

Image banding, fixed with different glasses

Due to the fast switching of the DLP images, the timing of the shutter glasses is crucial. In some initial work, we have found that using standard stereo glasses leads to some subtle but important image quality problems. In the 3 chip projectors, the images fed to the DLP chip are pulse width modulated. This is done over the entire frame of the image over a number of instants during the frame time. Thus, if the glasses being used to view the image do not switch out of one state and into the other within the timing constraints of the DLP projector, image quality will be sub optimal. These problems show up in areas of smooth shading. The actual artifact is that a smooth shaded area will appear to have banding and incorrect color rendition. The image artifacts under these conditions are distracting and, for applications such as automotive styling, would be unacceptable. We have tested some alternative glasses which performed much better and continue to work on solutions to ameliorate these artifacts.

Multi Viewer DLP Stereo

Now that the stereo DLP projectors have been proven, we are working on methods to extend their functionality to support more than a single viewer so that these projected environments can be used in the collaborative way an outsider might expect.

Our initial approach has been to employ the single chip DLP projectors and to create low cost time sequential projectors. We have been experimenting with various aspects of these projectors, including faster vertical refresh rates. As well as experimenting with full color images we have, for example, removed the color wheel and created a projector which delivers monochrome images at a high rate. Two of these projectors may then be used together in an orthogonally polarized system to deliver a number of different configurations. Again, we use custom glasses for the best performance. This is of interest as it lets us start to experiment with as many as 3 simultaneous viewers of the same monochrome stereo scene. Some of the available combinations are summarized to the table below.

Modified single chip DLP projector

Simultaneous Viewers

1 full color stereo
- or -
1 full color monoscopic
3 monochrome monoscopic
- or -
3 monochrome stereo
- or -
2 monochrome monoscopic
2 monochrome stereoscopic
…

Conclusion

In conclusion, in the last year, new DLP projector engines have been designed which will support sequential stereo applications. These new projectors will greatly improve the perceived image quality of many stereo systems since the projectors are very bright, sharp, and require less tuning and support. Progress continues to reach the best quality of stereo imagery through improved stereo glasses. Methods have also been developed to implement muti person stereo environments which will improve the utility of collaborative stereo environments.

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