Reviewing Single and Multiple Viewer Stereo with DLP Projectors

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Abstract

DLP (Digital Light Processing) is in the process of dramatically changing the performance expectations with respect to stereo applications, one of the last bastions of CRT projection technology. This paper discusses stereo and the application of DLP projectors. In addition to currently available high brightness DLP projectors, we present new results with using small economical single chip DLP projectors. 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 first 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.

Walls, Caves, Benches and other similar large scale immersive systems have generally been illuminated by analog CRT projectors, especially if stereo applications are employed. Stereo images are generated by a computer and sent to CRT projectors at a high vertical scan rates. Viewers wear special glasses which sequentially permit images to be seen by each eye. CRT projectors are generally of limited brightness and require extensive ongoing maintenance to keep the analog CRT images well converged and crisp. Despite these shortcomings, CRT projectors create very deep blacks and very smooth color transitions.

In addition to newly available projection technology, the nature of stereo is also changing. In the past, stereo implied delivering a static pair of images to viewers so that they could "see" 3D – 3D movies and handheld viewers for example. Currently however, there is significant interest in interactive computer based stereo. These interactive simulations typically employ head tracking which 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 objects "as if they were real" and gain insight into a particular process or environment being displayed.

Two user CRT based interactive bench display at Stanford University (M. Agrawala & B. Fröhlich)

Prototype stereo capable single chip DLP projector 10” x 10” x 3” and 4.8lbs

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 initial 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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Stereo Cues

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. Visual cues include parallax (as 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 occur naturally in computer graphics scenes. Head tracking and real-time updates from the computer provide parallax and dynamic occlusion cues. Generally, the other spatial cues are ignored at present due to implementation issues rather than their being unimportant.

Single Person 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.

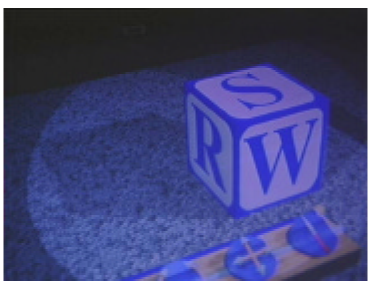


Image seen by a head tracked user standing to the left of a cube located on the surface of the bench display.

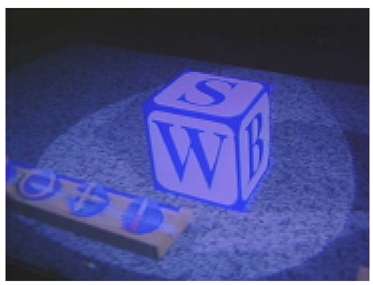


Image seen by a head tracked user standing to the right of a cube located on the surface of the bench display.

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 switched 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 who is kneeling down on the right hand side of this Cave.

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 which are orthogonally polarized to a polarization retaining display surface. In most passive stereo projection systems a pair of projectors are used and are connected to independent 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 orthogonal polarizers (either linearly or circularly polarized). The viewers of such a system wear glasses which have two orthogonally polarized lenses. Thus, only images which are polarized one way reach each eye. As a result, the two eyes receive independent images from the two projectors.

An adjustable VersaBench with 2 polarized 3 chip DLP projectors

There are many variations on this theme. For example, sometimes an LCD element is placed in front of a single projector and switched so that orthogonally polarized images are delivered over time. Another approach is to use slightly different colors to separate the images as developed by TAN in Germany for example.

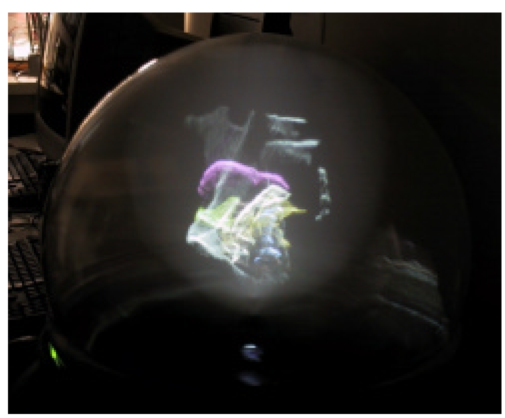
Passive stereo is generally most effective for large groups of people because the glasses can be made very cheaply from paper and two orthogonally polarized plastic film lenses.

Multi Person Stereo

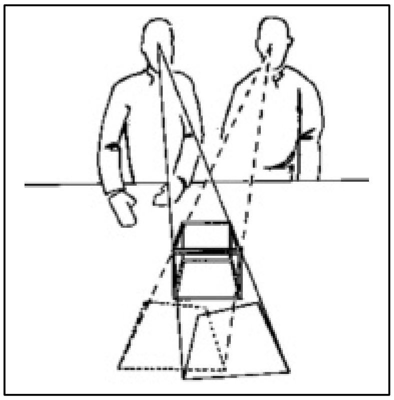
Interactive computer based systems such as Benches and Caves are great for a single user but are often perceived as being good for collaboration between people. This misunderstanding leads to various means to try to compensate. Other participants are encouraged to stand "near" the person with the head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

Volumetric Displays

Volumetric stereo displays based on DLP technology also provide multi viewer “stereo” capabilities. Systems such as those developed by Actuality Systems (as shown on the right) employ DLP chips to cast images onto a quickly rotating helical display surface enclosed in a transparent plastic bubble. Images may be seen by multiple viewers and from any angle. The images do not provide each viewer with occlusion cues however as there is no hidden surface removal.



Duo – Extended Sequential Stereo with Fast Shutter Glasses



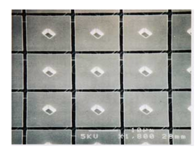
To overcome the single viewer stereo issue and to enable these systems to support multiple users, we developed, with the help of the SBIR program, a means for supporting two simultaneous users. This system uses an extension to the sequential stereo approach and delivers a pair of stereo images to two 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 along with several compelling examples developed by the researchers at Stanford University.

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 was a research tool however and images were both flickery and rather dim.

DLP Projector Technology

Chip Level DLP

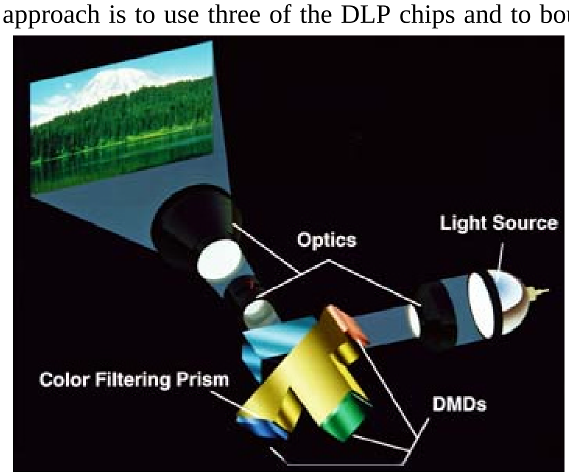
DLP projectors are all based on a unique silicon chip based movable mirror technology. The DLP chip is an array of tiny mirrors (each on the order of 10-20 microns). Each mirror may be oriented individually. In current systems, the mirrors are rotated ±12° so light is either reflected to eventually hit the viewing screen or is discarded or re-circulated. The mirrors may be switched on or off in microseconds. To generate gray scale images, mirrors are pulse width modulated over the frame time and to reduce artifacts, the pattern of the pulse width modulation and the pixels modulated at any particular instant is very carefully controlled.



DLP mirrors
(~17um across)

Big, Expensive, Very High Brightness Stereo DLP Projection Today

The DLP technology inherently produces monochromatic 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 each of the DLP chips. The three primary color images are then delivered through an optical system to a single projection lens and ultimately delivered to the screen.



Until recently, these projectors were not used in stereo 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 predictable time slot. DLP projectors digitize the incoming video stream and store a couple of images in a frame buffer. The DLP chip is running at its own rate and using data from the internal frame buffer to produce the image. Images delivered to the DLP chip were derived from several frames of incoming video to correct for various artifacts of the DLP switching and pulse width modulation. Also, rate conversion occurs - thus, if the incoming video rate is 72Hz and the DLP chip is running at 60Hz, then, at a minimum, 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 generally proved unacceptable for a high quality sequential stereo system. These projectors have been used in passive stereo systems where the images from the projectors are generally orthogonally polarized.

The 3 Chip Stereo Capable Projectors

Recently, improvements in the speed of the TI DLP interfaces has enabled projector makers to support stereo. Both Christie Digital and Barco have introduced 3 Chip DLP projectors based on this technology. These products are high brightness, high cost, large venue projectors.

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.

Note that because of the 1 frame delay, looking at a stereo image on a CRT monitor and one of these projectors at the same time is a problem – one of the images will have the left and right eyes reversed!

Example specifications for 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 Vertical 24Hz to 110Hz 1 frame delay @ 1280x1024 resolution
5,000 ANSI	160:1 Minimum	1.2kW Xenon	
9,000 ANSI	150:1 Minimum	1.6kW Xenon	

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.

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. There are problems however, light spill from one screen to another (particularly at a corner) reduces the overall contrast ratio of the display and because low gain screens are generally used, this stray light is reflected off all the other screens leading to a generally increased ambient brightness. Experiments with darker screen surfaces which reduce this problem are underway.

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 or 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 over data.

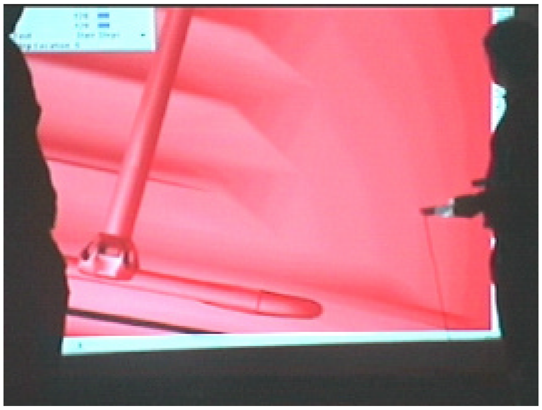
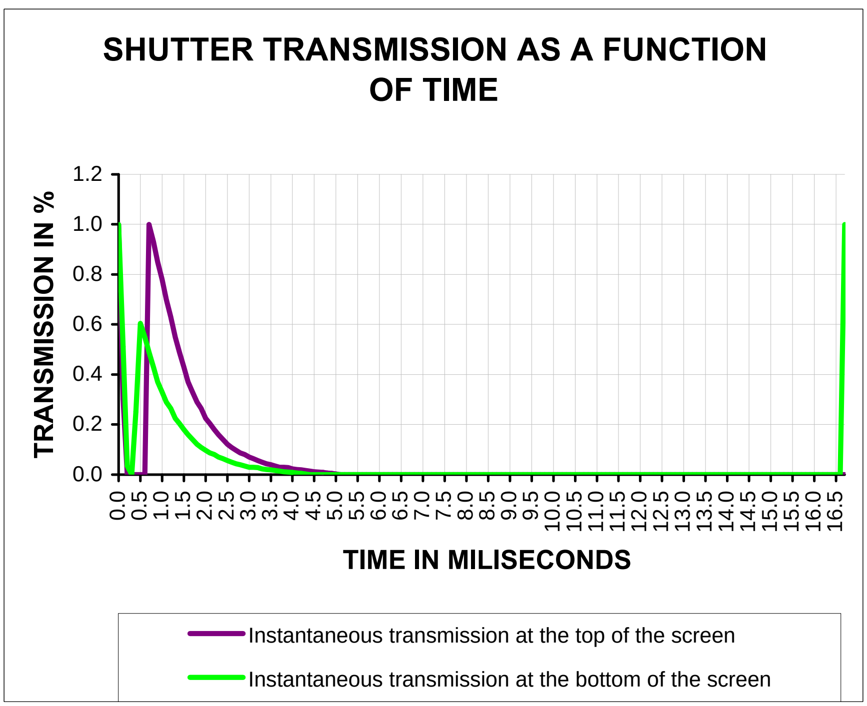
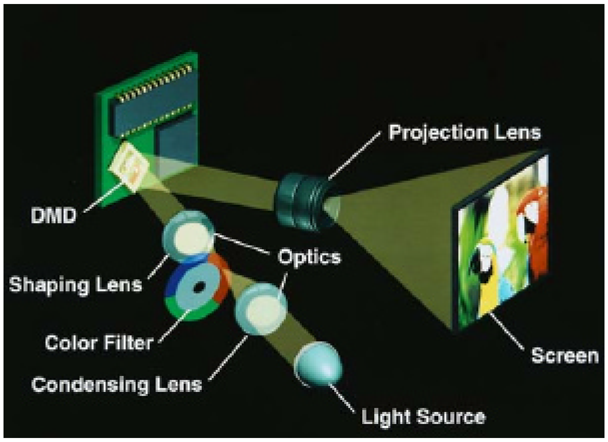


Image banding, fixed with extended inter-frame black time matched to glasses switching time

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 lead 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 worked with Christie Digital and they have since introduced the Dark Interval Adjust on their projectors which allows the interval between frames to be set to match decay time of the glasses. The change of state time of the Crystal Eyes glasses is asymmetric – the shutters change state in both directions with an exponential curve but one direction is a "relaxation" and has a much longer time constant. As both eyes are switched out of phase, one of the two eyes is always going through the slow transition.

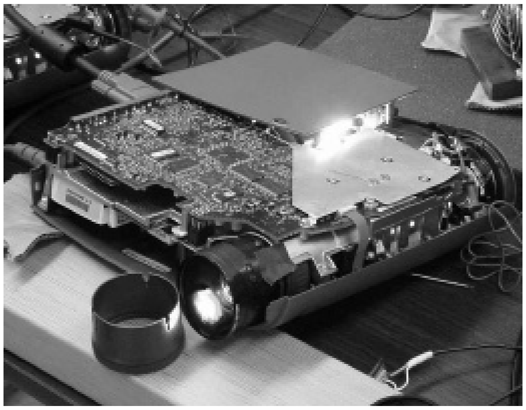


Small, Economical, High Brightness Single Chip DLP Stereo Tomorrow



Multi DLP chip projection is expensive and the optics required to merge the three color images together are bulky. Thus, for portable applications, TI developed 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 sub field images delivered to the DLP chip are synchronized with the changing colors. As a result, a color image is perceived by the viewer. These 1024x768 pixel projectors perform a significant amount of processing on the images in order to present a reasonable image.

Fakespace Labs has recently discovered how to alter these low cost projectors to produce full color sequential stereo at 120Hz per eye or 60Hz for both eyes. This is an initial result and we have not yet measured the image quality in these projectors where half the bit depth is essentially missing from each eye to see if they are really suitable for mainstream immersive applications. We are exploring this new capability and ways to make this new technology work well. One characteristic is that these projectors are slightly modified inFocus projectors and will still work correctly in normal, non-stereo, modes.



Modified single chip DLP projector

Multi Viewer DLP Stereo

Now that the stereo DLP projectors have been introduced, we are working on methods to extend their functionality to support more than a single viewer so that large scale projected environments can be used in the collaborative way one might expect by more than one user at a time.

We have been experimenting with taking three of the single chip DLP engines and integrating their high rate of refresh with the optics and light source from the three chip projectors. The single chip stereo projectors are both sequential color and stereo so they produce 6 color fields in 1/60th of a second, 3 colors per eye (and actually it is eight because the projectors also have a small white color segment in the color wheel for improved whites). This combination produces a projector which can create full color images at much higher frame rates than previously possible (over 360Hz) while preserving reasonable brightness. For these high frame rate systems, the time to switch the glasses becomes important so we are using glasses which switch more quickly than the Crystal Eyes. This is of interest as it lets us start to experiment several simultaneous viewers of the same stereo scene.

Conclusion

In conclusion, 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. Methods have also been developed to implement low cost portable systems with single chip projectors and multi-person stereo environments which will improve the utility of collaborative stereo environments.

Acknowledgements

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References

Press Release; Christie Digital Announces World's First 3D Stereoscopic DLP Projector, November 6, Christie Digital Systems, Kitchener, Ontario

Schmidt, T. and Norris, R.; Eliminating Compromize in Professional Large Screen Digital Images, Electrohome Limited, Kitchener, Ontario, 1998

Jim Durbin, J. Edward Swan II, Brad Colbert, John Crowe, Rob King, Tony King, Chris Scannell, Zachary Wartell, Terry Welsh, "Battlefield Visualization on the Responsive Workbench", Proceedings IEEE Visualization '98, October 18-23, Research Triangle Park, North Carolina: IEEE Computer Society Press, 1998, pages 463-466

Agrawala, M.; Beers, A.C.; Fröhlich B.; Hanrahan P.; McDowall, I. and Bolas, M. The Two-User Responsive Workbench: Support for Collaboration Through Individual Views of a Shared Space, Conference Proceedings, SIGGRAPH '97 (http://www-graphics.stanford.edu/papers/twoviewer/)

Texas Instuments DLP technology web site: http://www.dlp.com

Christie Digital Systems web site: http://www.christiedigital.com

Fakespace Labs web site: http://www.fakespacelabs.com

Actuality Systems web site: http://www.actuality-systems.com

TAN Projection Technology web site: http://www.tan.de