MULTI–VIEW AUTOSTEREOSCOPIC 3D DISPLAY

IBC '99 (International Broadcasting Convention)
10-14 Sep 1999, Amsterdam, pp.497-502
ISBN 0-9533673-1-2
[invited paper]

N. A. Dodgson[1], J. R. Moore[2], S. R. Lang[3]

[1]University of Cambrige Computer Laboratory, UK; [2]JMEC Ltd, UK; [3]ASD Systems Ltd, UK

ABSTRACT

Autostereoscopic displays provide 3D perception without the need for special glasses or other head gear. Three basic technologies exist to make such displays: spatial multiplex, multi-projector and time-sequential. These can be used to make two types of useful device: two-view, head-tracked displays; and multi-view displays. The former tend to be single-viewer systems while the latter can support multiple viewers. However, the latter tend to require more processing power because they have more views than the former. Both types can be expected to find uses in their own niches.

The Cambridge autostereo display is a CRT-based, time-sequential, multi-view device. Recent work has combined multi-projector technology with the basic system to produce both 25", 28 view and 50", 15 view autostereoscopic 3D displays. These are currently undergoing evaluation for entertainment and visualisation applications.

INTRODUCTION

An autostereoscopic display provides the viewer with a three-dimensional image without the need for special glasses. This paper briefly looks at conventional “3D with glasses” systems before introducing the concept of an autostereo display. It then discusses the types of autostereo display and the mechanisms by which an autostereo display can be implemented. It finally considers the Cambridge display: a multi–view autostereoscopic device.

3D WITH GLASSES

3D displays which require the viewer to wear special glasses are reasonably well known (12). These displays present two different images in the same plane. The glasses select which of the two images is visible to each of the viewer’s eyes. Technologies for this include a standard colour display combined with coloured glasses (anaglyph method); two standard displays made coplanar by an half-silvered mirror, combined with polarised glasses; and a double frame rate display combined with shuttered glasses (8).

Such displays have not gained wide acceptance, partly owing to the need to wear glasses. Autostereo displays provide 3D perception without glasses and could, therefore, prove more commercially viable.

AUTOSTEREO DISPLAYS

Multi-view and head-tracked autostereoscopic displays offer the viewer three dimensional realism lacking in conventional two-dimensional or stereoscopic displays. In real life we gain three dimensional information from a variety of cues. Two important cues are *stereo parallax*: seeing a different image with each eye, and *movement parallax*: seeing different images when we move our heads. Autostereo displays combine the effects of both stereo parallax and movement parallax producing a perceived effect *similar* to that of a white light hologram.

Figure 1 illustrates the principle of multi-view autostereo displays. Figure 1(a) shows an observer looking at a scene. He sees a different image of the scene with each eye and different images again whenever he moves his head. He is able to view a potentially infinite number of different images of the scene.

Figure 1(b) shows the same viewing space divided into a finite number of horizontal *windows*. In each window only one image, or *view*, of the scene is visible. However the viewer’s two eyes each see a different image, and the images change when the viewer moves his head — albeit with jumps as the viewer moves from window to window. Thus both stereo and horizontal movement parallax cues can be provided with a small number of views. There is no fundamental restriction to horizontal movement parallax: vertical movement parallax can also be provided, but this squares the number of views.

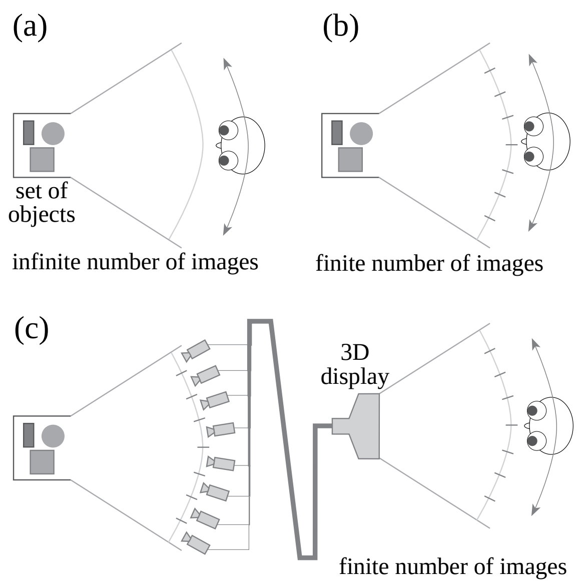

Figure 1: (a) When viewing a scene in real life, an observer sees a different image with each eye: stereo parallax. When he moves his head he sees different images: movement parallax. There are an infinite number of different images of the scene that he could see. (b) The number of different images is made finite, each visible in its own window. Each eye still sees a different image: stereo parallax, and different images are seen when the head is moved: movement parallax. (c) An autostereoscopic 3D display provides a different image to each window, producing both stereo and movement parallax with a small number of views.

The finite number of views required in Figure 1(b) allows the replacement of the scene by a three-dimensional display that outputs a different image to each window (Figure 1(c)).

Head-tracked displays, by contrast, work by displaying only two views and by tracking the viewer's head so that each eye always sees the correct view. If the image generation process takes the head position into account then movement parallax effects can be simulated. Otherwise a head-tracked display only provides stereo parallax.

TYPES OF AUTOSTEREO DISPLAY

Three types of autostereo display can be identified, albeit rather arbitrarily:

- two-view displays
- head-tracked displays, normally two-view
- multi-view displays, with three or more views

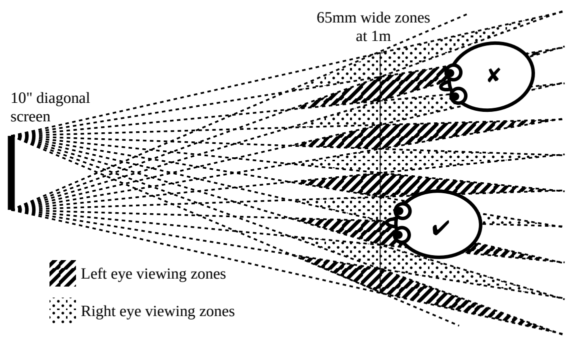

Figure 2: a two-view display produces multiple viewing zones, an eye in one of these zones will see either the left or the right image. An eye outside the shown zones will see an image made up of parts of both left and right images. Even at the ideal viewing distance there is a 50% chance that the viewer will see an incorrect, pseudoscopic image.

Two-view displays

It has long been known how to make a two-view autostereo display using either parallax barrier (5) or lenticular sheet (12) technology. These divide, into two sets, the horizontal resolution of the underlying, typically liquid crystal, display device. One of the two visible images consists of every second column of pixels; the second image consists of the other columns. The two images are captured or generated so that one is appropriate for the viewer's left eye and one appropriate for the right. The two displayed images are visible in multiple zones in space (Figure 2). If the viewer stands at the ideal distance and in the correct position he or she will perceive a stereoscopic image. The downside of this is that there is a 50% chance of the viewer being in the wrong position and seeing an incorrect, pseudoscopic image. Moving much forward of or back from the ideal distance increases further the chance of seeing an incorrect image.

These serious limitations necessitate the use of another autostereo solution. This is either to increase the number of views or to introduce head-tracking.

Head-tracked displays

Two-view technology is, as described above, well understood. If it were possible to know the position of the viewer's head then the appropriate images, left and right, could be displayed to the appropriate zones, thus preventing any pseudoscopic viewing (Figure 3). Alternatively, entirely different technology could be used which displays only two

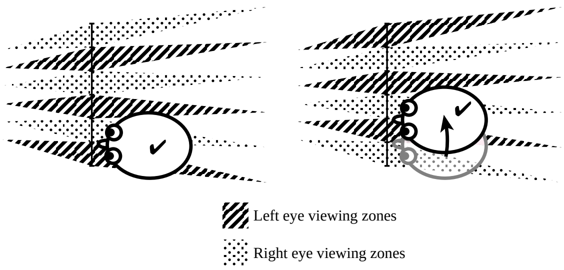

Figure 3: with head-tracking the zones can be swapped over as the viewer moves his or her head. This obviously only works for a single viewer at any one time.

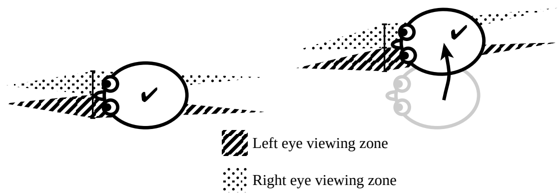

Figure 4: an alternative mechanism for head-tracking: only two zones are produced, but the image display mechanism can control where those two views are in space.

zones, and allows these zones to be physically moved (6,7) (Figure 4).

The main difficulty with this method is the head-tracking itself. Some mechanism must be used which does not require the user to wear anything special: it would be pointless to replace the wearing of special glasses with the wearing of a special head-tracker

The other limitation of most head-tracked systems is that they are single-viewer. This is acceptable in some applications but not in others. In those other applications the multi-view alternative needs to be considered.

Multi-view displays

These display multiple different images to multiple zones in space as illustrated in Figures 5 and 6. This has the advantages that: the viewer is free to place his or her head anywhere within the viewing lobe, while still perceiving a 3D image; the viewer can ‘look around’ objects in the scene simply by moving his or her head; multiple viewers can be supported, each seeing 3D from his or her own point of view (Figure 6); and head-tracking, with all its associated complexity, is not required.

The disadvantages of multi-view displays are: the difficulty of building a display with many views; and the problem of generating all the views simultaneously (3), because each view is being displayed all

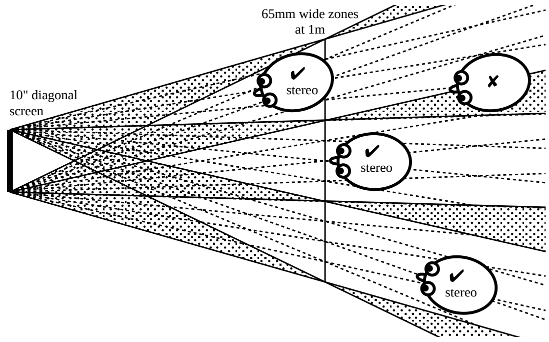

Figure 5: a four view autostereo display with three lobes. Each of the lobes contains the same set of four views. So long as a viewer’s head is within one of the lobes, a 3D image will be perceived.

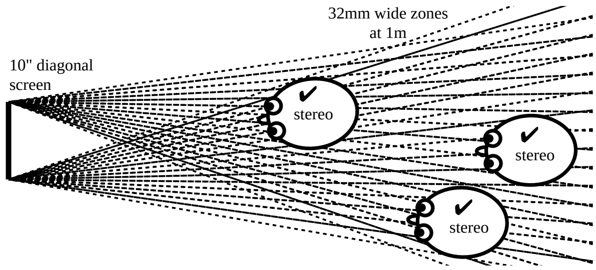

Figure 6: a sixteen view autostereo display with a single lobe. Any viewer with both eyes in the lobe will see a 3D image. A full analysis of the viewing zone can be found in (4).

of the time, whether anyone can see that particular view or not.

TECHNOLOGIES FOR MULTI-VIEW DISPLAYS

Three broad classes of technology are used to make multi-view autostereo displays:

- *spatial multiplex*: the resolution of a display device is split between the multiple views;
- *multi-projector*: a single projection display is used for each view;
- *time-sequential*: a single very fast display device is used for all views.

Spatial multiplex

Parallax barriers (5) and lenticular sheets (11) have both been used to divide the resolution of a display device between multiple views. The display is almost always a liquid crystal device, because this allows relatively simple alignment of the barrier or lenticules with the pixel structure.

The constraints on pixel size and resolution in liquid crystal displays limits traditional horizontal multiplexing to four views. This is barely sufficient for a multi-view display.

van Berkel and Clarke have demonstrated a seven-view display using a liquid crystal panel and a lenticular sheet (1). This uses both horizontal and vertical multiplexing to give a 3D display with reasonable resolution in both dimensions

Multi-projector

Such devices use a single projector for each view (10), projecting their images onto a special transmissive or reflective screen, such as a double lenticular sheet. They suffer from the problems of expense: one projector per view becomes exorbitant for even a reasonable number of views; and of alignment: the projected images must be aligned precisely with one another.

Time-sequential

Time-sequential displays use a single display device running at a high frame rate. A secondary optical component is required to direct the images to the appropriate zones in space. The display developed at Cambridge (14–19) is of this type.

Hybrid systems

Combining two of the above mechanisms can produce a system with a higher number of views, at the expense of more complex technology. Combining spatial multiplexing and multi-projector has led to prototype 40-view (13) and 72-view (11) displays. A simpler 7, 13, or 21-view hybrid system has been designed by HinesLab (9). The combination of time-sequential and multi-projector methods has led to the latest development of the Cambridge display.

THE CAMBRIDGE DISPLAY

Ideal design

The basic design of an ideal Cambridge display (Figure 7(a)) consists of a high speed liquid crystal display, a fresnel lens, and a series of abutting bar shaped light sources (17). The light sources are placed just beyond the focal plane of the fresnel lens so that an image of the light bars is projected into the user's view space (this image of the light bars is termed the *eye box*). Each light bar is illuminated in turn and, in synchronisation with this, successive laterally adjacent views of an object are displayed on the liquid crystal display. The effect of the lens is that each view is visible in a different window in front of the display. Provided that the views are repeatedly illuminated sufficiently rapidly,

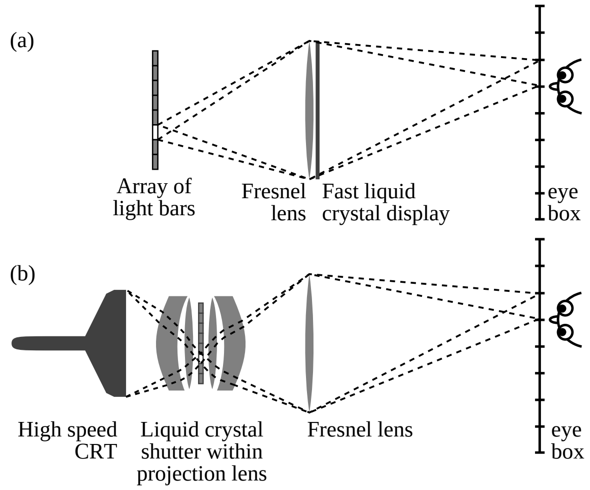

Figure 7: (a) an ideal Cambridge display; (b) a practicable version.

the user will perceive a three-dimensional image with both stereo and horizontal movement parallax. While the best position from which to view autostereo images is at the eye box, a good 3D effect is obtained over a large range of distances (4).

Eight views displayed at a 60Hz refresh rate require a liquid crystal display with a field rate of 8 · 60Hz = 480Hz. A more desirable 32 views would require almost 2kHz. Neither speed is presently feasible with nematic liquid crystals, but may be attainable with ferroelectric (smectic) liquid crystals if the problem of transferring image data sufficiently quickly to the liquid crystal array can be overcome (18).

Practical design

A practicable monochrome sixteen view version of a Cambridge display, developed in the early '90s (15,16,19), utilised a high speed CRT, a projection lens, and a ferroelectric liquid crystal shutter element to emulate the light sources and transparent display screen of the ideal version (Figure 7(b)). It was capable of 16 views at 320·240 resolution or 8 views at 640·480.

This CRT-based display essentially consists of two superimposed optical systems. The first, a compound projection lens, which projects an image of the CRT into the location of the liquid crystal display in the ideal version; the second, a large fresnel lens, which projects an image of the shutter into space

The device works by displaying each view in turn on the CRT. One of the liquid crystal shutters is made transparent in synchronisation with the image display. This directs the light from the CRT to a specific window in the eye box. The CRT

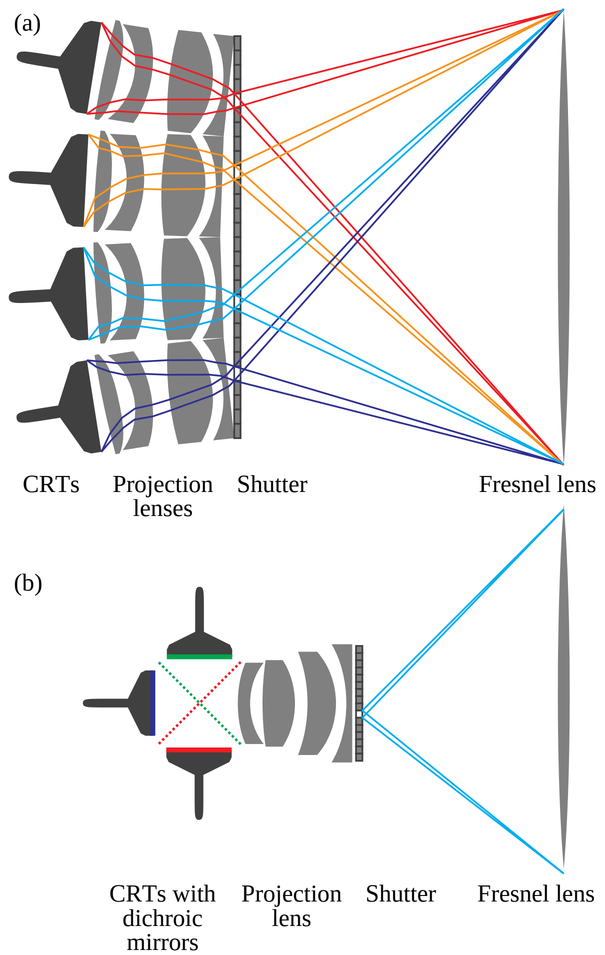

Figure 8: (a) the 28 view, multi-projector, time sequential display. Multiple CRTs and their associated projection lenses are placed behind a single shutter. The front elements of the lenses abut. (b) the 15 view parallel-colour system with one CRT for each primary colour combined by dichroic mirrors. Note that the compound lenses and dichroic elements in these figures are indicative only; they are not exact representations.

based version is thus functionally identical to the simpler ideal version.

Colour and other advances

The original Cambridge display was monochrome (15,16). Colour was achieved in late 1995 using a colour sequential solution. A Tektronix liquid crystal colour shutter was used to dynamically filter the light from a monochrome CRT (14).

Advances in the driving electronics improved the speed of the Cambridge display so that it is now capable of 21 views at a resolution of 512·384 pixels (2), requiring a field rate of 1200Hz. This provides seven views in a colour sequential system. Dropping from 21 to 15 views allows resolution to be increased to 640·480 although this reduces the number of colour views to just five. This small number of views led to investigations into how multiple CRTs could be combined in a single display device.

MULTIPLE CRT SOLUTIONS

It is obvious that multiple CRTs and projection lens systems can be placed behind a single fresnel lens. A projection lens was designed with a planar final face against which a shutter could be placed. The lens is designed such that rays from each pixel will pass through every point on the final face (and hence on the shutter) on their way to forming the image of that pixel. This allows the use of multiple CRTs: abutting multiple projection lenses behind a single large shutter (Figure 8(a)).

In parallel with this development, an alternative, multi-CRT, solution has been designed which replaces the colour sequential system with three tubes, one for each colour (Figure 8(b)). Both systems are described below.

Multi-projector system

The fundamental requirement of an autostereo display is that an eye box is formed in space. The eye box contains many windows, from each of which a different image is visible. These images must all appear to be formed in the same place on the same plane. The multi-projector display thus has a single large fresnel lens imaging a single shutter to a single large eye box. Immediately behind the shutter are a multiplicity of projection lenses, each casting an image of a CRT onto the large lens (Figure 8(a)).

A four projector system has been built. The CRTs in this system have a 4" diagonal and a fast, high brightness, wide band phosphor. Each provides 21 monochrome views at 512·384 resolution. The 21 views are used in the colour sequential system to deliver seven full colour views from each CRT. The driving electronics have sufficient flexibility that the images from all of the CRTs can be precisely aligned on the fresnel lens. The user thus sees a 25" diagonal, full colour 3D image with a total of 28 views.

Parallel colour system

Dedicating one CRT to each colour appears to be a reasonable idea. The images on the three CRTs can be precisely aligned by adjusting their controlling electronics, as in the multi-projector case. The difficulty here is that the three colours must be combined in such a way that their light appears to pass through the shutter in exactly the same way. The original projection lens designs did not have sufficient space in the optical path in which to do this.

A new design of the optical system has allowed insertion of dichroic combining optics (Figure 8(b)). This system is thus capable of producing 21 views at 512·384 or 15 views at 640·480. The prototype has a 50" screen.

SUMMARY

Autostereo displays provide 3D perception without the need for special glasses or other head gear. They can thus be used in situations where 3D is required but where glasses are either undesirable or impractical.

Both head-tracked and multi-view systems have commercial potential. Both will find uses in particular market niches. Whether 3D displays will go beyond these niches is an open question.

A viable autostereoscopic display has been developed by combining Cambridge's time sequential system with multi-projector optics. This has allowed the production of displays with large screens, a big eye box, and a reasonable number of views

ACKNOWLEDGEMENT

Most of the development work on the Cambridge display has been undertaken by ASD Systems Ltd.

REFERENCES

1. C. van Berkel & J. A. Clarke, 1997, "Characterisation and optimisation of 3D-LCD module design", Proc. SPIE, 3012, 179–186

2. P. Canepa, Sep 1998, "Riding Moore to market…in 3-D", Information Display, 28–31

3. O. M. Castle, 1995, Synthetic Image Generation for a Multiple-View Autostereo Display, Tech. Rep't No. 382, University of Cambridge Computer Laboratory, Pembroke St, Cambridge, UK

4. N. A. Dodgson, 1996, "Analysis of the viewing zone of the Cambridge autostereoscopic display", Applied Optics, 35(10), 1705–1710

5. J. B. Eichenlaub, 1993, "Developments in autostereoscopic technology at Dimension Technologies Inc." Proc. SPIE, 1915,177–186

6. D. Ezra, G. J. Woodgate, B. A. Omar, N. S. Holliman, J. Harrold & L. S. Shapiro, 1995, "New autostereoscopic display system", Proc. SPIE, 2409, 31–40

7. P. Harman, 1996, "Autostereoscopic display system", Proc. SPIE, 2653, 56–64

8. W. J. A. M. Hartmann & H. M. J. Hikspoors, 1987, "Three-dimensional TV with cordless FLC spectacles", Information Display, 3(9)

9. S. P. Hines, 1997, "Autostereoscopic video display with motion parallax", Proc. SPIE, 3012, 208–219

10. G. R. Little, S. C. Gustafson & V. E. Nikolaou, 1994, "Multiperspective autostereoscopic display", Proc. SPIE, 2219, 388–394

11. K. Matsumoto & T. Honda, 1997, "Research of 3-D display using the anamorphic optics", Proc. SPIE, 3012, 208–219

12. D. F. McAllister (editor), 1993, Stereo Computer Graphics and Other True 3D Technologies, Princeton University Press

13. J. D. Montes & P. Campoy, 1995, "A new three-dimensional visualisation system based on angular image differentiation", Proc. SPIE, 2409, 125–140

14. J. R. Moore, N. A. Dodgson, A. R. L. Travis & S. R. Lang, 1996, "Time-multiplexed color auto-stereoscopic display", Proc. SPIE, 2653, 10–19

15. S. R. Lang, A. R. L. Travis, O. M. Castle & J. R. Moore, 1992, "A 2nd generation autostereoscopic 3-D display", in Seventh Eurographics Workshop on Graphics Hardware, Eurographics, Technical Report EG92 HW, 53–63

16. J. R. Moore, A. R. L. Travis, S. R. Lang, & O. M. Castle, 1992, "The implementation of a multi-view autostereoscopic display", in IEE Colloquium on Stereoscopic Television, IEE, London, UK Digest No. 1992/173, 4/1–4/16

17. A. R. L. Travis, 1990, "Autostereoscopic 3-D display", Applied Optics, 29(29), 4341–4342

18. A. R. L. Travis & S. R. Lang, 1991, "The design and evaluation of a CRT-based autostereoscopic 3-D display", Proc. SID, 32(4), 279–283

19. A. R. L. Travis, S. R. Lang, J. R. Moore & N. A. Dodgson, 1995, "Time-multiplexed three-dimensional video display", J. Soc. for Information Display, 3(4), 203–205