

Autostereo displays: 3D without glasses

N. A. Dodgson

Computer Laboratory, University of Cambridge,
Pembroke Street, Cambridge, UK, CB2 3QG

Abstract

3D displays which use glasses have not gained wide acceptance. Autostereo displays provide 3D perception without the need for special glasses or other head gear. Three basic technologies exist to make autostereo 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. The latter tend to require more processing power because they have more views than the former. Both types will find uses in their own niches.

Keywords: autostereoscopic, 3D, stereo

1. 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.

2. 3D with glasses

3D displays which require the viewer to wear special glasses are reasonably well known¹⁴. 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 a half-silvered mirror, combined with polarised glasses; and a double frame rate display combined with shuttered glasses⁹.

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

3. Autostereo displays

Multi-view and head-tracked autostereoscopic displays offer the viewer three dimensional realism lacking in conventional two-dimensional or stereoscopic displays. They combine the effects of both stereo parallax and movement parallax producing a perceived effect *similar* to that of a white light hologram.

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. 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.

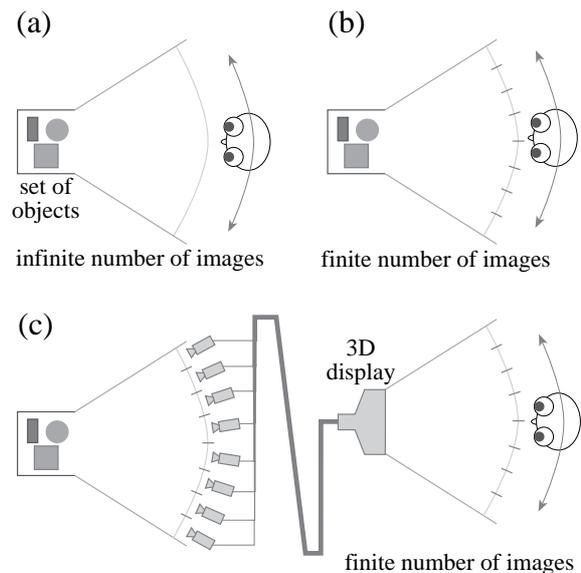


Figure 1: (a) When viewing a scene in real life, an observer sees a different image with each eye: stereo parallax. When he moves his head he sees different images: movement parallax. There are an infinite number of different images of the scene that he could see. (b) The number of different images is 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.

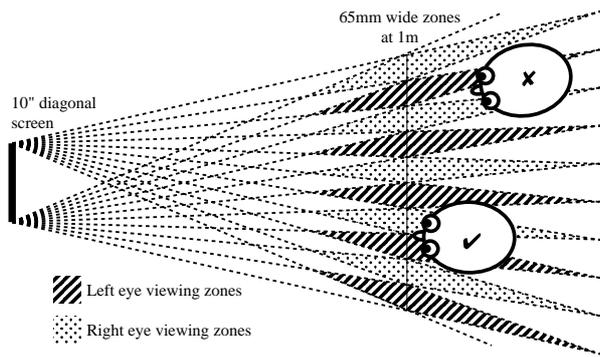


Figure 2: a two-view display produces multiple viewing zones, an eye in one of these zones will see either the left or the right image. An eye outside the shown zones will see an image made up of parts of both left and right images. Even at the ideal viewing distance there is a 50% chance that the viewer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

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)). This is the principle of multi-view autostereoscopic displays.

Head-tracked displays, on the other hand, 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.

4. 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

4.1. Two-view displays

It has long been known how to make a two-view autostereo display using either parallax barrier⁶ or lenticular sheet¹⁴ 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

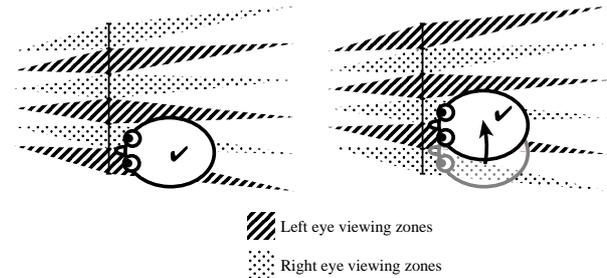


Figure 3: with head-tracking the zones can be swapped over as the viewer moves his or her head. This obviously only works for a single viewer at any one time.

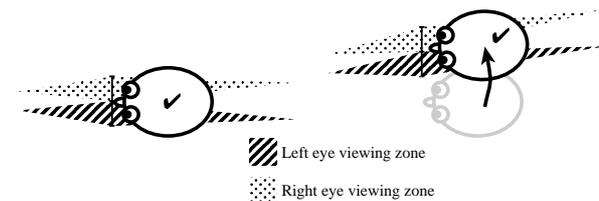


Figure 4: an alternative mechanism for head-tracking: only two zones are produced, but the image display mechanism can control where those two views are in space.

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.

4.2. 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 zones, and allows these zones to be physically moved^{7,8} (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. Such mechanisms have been developed and have recently reached the commercially useful stage.

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.

4.3. 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

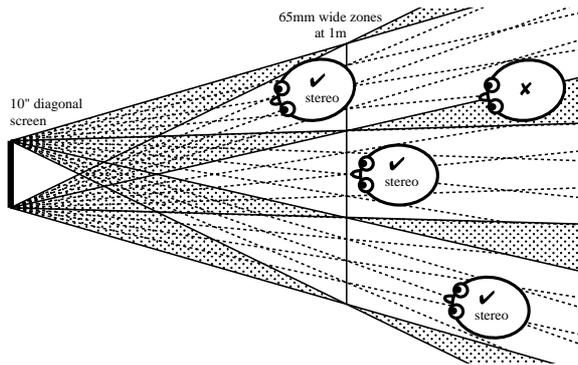


Figure 5: a four view autostereo display with three lobes. Each of the lobes contains the same set of four views. So long as a viewer's head is within one of the lobes, a 3D image will be perceived.

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 simultaneously⁴, because each view is being displayed all of the time, whether anyone can see that particular view or not.

5. 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.

5.1. Spatial multiplex

Parallax barriers⁶, lenticular sheets¹¹, and holographic optical elements²⁵ have all 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.

Philips have recently demonstrated a seven-view display using a liquid crystal panel and a lenticular sheet¹. This uses both horizontal and vertical multiplexing to give a 3D display with reasonable resolution in both dimensions

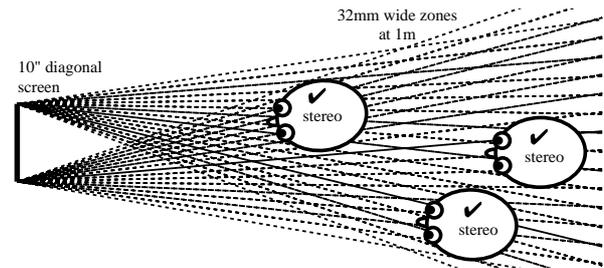


Figure 6: a sixteen view autostereo display with a single lobe. Any viewer with both eyes in the lobe will see a 3D image. A full analysis of the viewing zone can be found in reference 5.

5.2. Multi-projector

Such devices use a single projector for each view¹², 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.

5.3. 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^{16,20-24} is currently capable of 21 views at a resolution of 512×384 pixels. This requires a field rate of 1200 Hz. The system is based around a small CRT with a fast phosphor, a set of lenses, and a ferroelectric liquid crystal shutter.

5.4. 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-view¹⁵ and 72-view¹³ displays. A simpler 7, 13, or 21-view hybrid system has been designed by HinesLab¹⁰.

6. 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 are commercially viable. Both will find uses in particular market niches. Whether 3D displays will go beyond these niches is an open question.

7. Further reading

An annual conference is held by the SPIE on "Stereoscopic displays and applications". The first of

these was held in 1990. Since 1994 the conference has been held in conjunction with another on virtual reality, giving it the overall title of “Stereoscopic displays and virtual reality systems”. The proceedings of all of these conferences are published in the *Proc. SPIE* series, volume numbers 1256, 1457, 1669, 1915, 2177, 2409, 2653, and 3012. Books on stereoscopic displays have been published by both Okoshi¹⁷ and McAllister¹⁴. Starks has written an annotated bibliography^{18,19}, including a considerable quantity of patent information, on a wide variety of 3D display technologies.

8. UK research

The author is aware of work on autostereo displays in a variety of UK-based organisations. Philips Research Labs at Redhill, Surrey are working on lenticular/LCD multi-view displays^{1,2}. Autostereo Systems at Cambridge are commercialising the time-multiplexed, multi-view Cambridge display¹⁰. Sharp Laboratories in Oxford have worked on a two-view head-tracked system⁷. Richmond Holographic Studios in London are working on a variety of autostereo display concepts using LCDs and holographic optical elements, currently concentrating on two-view systems^{25,26}. De Montfort University in Leicester have (at least) two groups working in 3D displays, one of which is developing a display based on integral imaging³.

This list is not exhaustive and, in addition, there are a significant number of organisations outside the UK, principally in the USA and Japan, which are investigating this technology.

9. About the author

Dr Neil Dodgson is with the Computer Laboratory at the University of Cambridge. He acts as a consultant to Autostereo Systems Ltd, who are commercialising the Cambridge autostereo display. He has worked on the Cambridge display since 1991 and has published eight papers on the subject^{5,16,24}. He can be contacted by e-mail at nad@c1.cam.ac.uk.

10. References

1. C. van Berkel and J. A. Clarke, “Characterisation and optimisation of 3D-LCD module design”, *Proc. SPIE*, **3012**, 179–186 (1997)
2. C. van Berkel, D. W. Parker and A. R. Franklin, “Multiview 3D-LCD”, *Proc. SPIE*, **2653**, 32–39 (1996)
3. M. Brewin, M. Forman and N. Davies, “Electronic capture and display of full parallax 3D images”, *Proc. SPIE* **2409**, 118–124 (1995)
4. O. M. Castle, *Synthetic Image Generation for a Multiple-View Autostereo Display*, Tech. Rep’t No. 382, University of Cambridge Computer Laboratory, Pembroke St, Cambridge, UK, CB2 3QG (1995)
5. N. A. Dodgson, “Analysis of the viewing zone of the Cambridge autostereoscopic display”, *Applied Optics*, **35**(10), 1705–1710 (1996)
6. J. B. Eichenlaub, “Developments in autostereoscopic technology at Dimension Technologies Inc.” *Proc. SPIE*, **1915**, 177–186 (1993)
7. D. Ezra, G. J. Woodgate, B. A. Omar, N. S. Holliman, J. Harrold and L. S. Shapiro, “New autostereoscopic display system”, *Proc. SPIE*, **2409**, 31–40 (1995)
8. P. Harman, “Autostereoscopic display system”, *Proc. SPIE*, **2653**, 56–64 (1996)
9. W. J. A. M. Hartmann and H. M. J. Hikspoors, “Three-dimensional TV with cordless FLC spectacles”, *Information Display*, **3**(9) (1987)
10. S. P. Hines, “Autostereoscopic video display with motion parallax”, *Proc. SPIE*, **3012**, 208–219 (1997)
11. H. Isono, M. Yasuda, D. Takemori, H. Kanayama, C. Yamada and K. Chiba, “50-inch autostereoscopic full-color 3-D TV display system”, *Proc. SPIE*, **1669**, 176–185 (1992)
12. G. R. Little, S. C. Gustafson and V. E. Nikolaou, “Multiperspective autostereoscopic display”, *Proc. SPIE*, **2219**, 388–394 (1994)
13. K. Matsumoto and T. Honda, “Research of 3-D display using the anamorphic optics”, *Proc. SPIE*, **3012**, 208–219 (1997)
14. D. F. McAllister (editor), *Stereo Computer Graphics and Other True 3D Technologies*, Princeton University Press (1993)
15. J. D. Montes and P. Campoy, “A new three-dimensional visualisation system based on angular image differentiation”, *Proc. SPIE*, **2409**, 125–140 (1995)
16. J. R. Moore, N. A. Dodgson, A. R. L. Travis and S. R. Lang, “Time-multiplexed color autostereoscopic display”, *Proc. SPIE*, **2653**, 10–19 (1996)
17. T. Okoshi, *Three-Dimensional Imaging Techniques*, Academic Press (1976)
18. M. Starks, “Stereoscopic video and the quest for virtual reality: an annotated bibliography of selected topics”, *Proc. SPIE*, **1457**, 327–342 (1991)
19. M. Starks, “Stereoscopic video and the quest for virtual reality: an annotated bibliography of selected topics — Part II”, *Proc. SPIE*, **1669**, 216–227 (1992)
20. S. R. Lang, A. R. L. Travis, O. M. Castle and J. R. Moore, “A 2nd generation autostereoscopic 3-D display”, in *Seventh Eurographics Workshop on Graphics Hardware*, 5–6 Sep, 1992, Cambridge, UK, P. F. Lister (editor), Eurographics, Technical Report EG92 HW, 53–63 (1992)
21. J. R. Moore, A. R. L. Travis, S. R. Lang, and O. M. Castle, “The implementation of a multi-view autostereoscopic display”, in *IEE Colloquium on Stereoscopic Television*, 15 Oct, 1992, IEE, London, UK Digest No. 1992/173, 4/1–4/16 (1992)
22. A. R. L. Travis, “Autostereoscopic 3-D display”, *Applied Optics*, **29**(29), 4341–4342 (1990)

23. A. R. L. Travis and S. R. Lang, "The design and evaluation of a CRT-based autostereoscopic 3-D display", *Proc. SID*, **32**(4), 279–283 (1991)
24. A. R. L. Travis, S. R. Lang, J. R. Moore and N. A. Dodgson, "Time-multiplexed three-dimensional video display", *J. Soc. for Information Display*, **3**(4), 203–205 (1995)
25. D. Trayner and E. Orr, "Autostereoscopic display using holographic optical elements", *Proc. SPIE*, **2653**, 65–74 (1996)
26. D. Trayner and E. Orr, "Developments in autostereoscopic display using holographic optical elements", *Proc. SPIE*, **3012**, 167–174 (1997)