TIME-MANIPULATED THREE-DIMENSIONAL VIDEO

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Abstract

A true 3D image is synthesised from many 2D views of the original. The views are presented in rapid succession on a CRT whose field of view is restricted to a different zone for each view. This restriction is achieved by using optical fourier transforms which result in a 3D image that is especially sharp and clear. The display is bulky but inherently robust and flexible. It is therefore well adapted for the design of novel 3D systems.

Introduction

A variety of technologies are being developed which aim to display a three dimensional image in a compact and light device. It remains unclear which will succeed, but in the meantime a display is needed that system designers can use to develop 3D applications. It need not matter if this model is big, heavy or expensive as long as it is stable, robust and excels in the quality of its three dimensional image. This paper explains how a display has been made in Cambridge University for this purpose, and why it was designed the way it is.

True three dimensional images - such as are encapsulated in a hologram - can be pixellated by making multiple two dimensional perspective views of the image. In principle the number of views required is approximately the field of view (in radians) times the depth of field (in pixels)[1]. However in practice one view per degree seems to satisfy the human eye. Nevertheless the extra dimension requires that a three dimensional image has an order of magnitude more pixels than a two dimensional one.

Three dimensional images can be projected by lenticular[2,3,4,5] displays and holograms[6,7]. Both provide extra pixellation by having high resolution, the former with sub-pixels beneath each microlens, the latter with pixellation fine enough to form diffraction gratings. Lenticular displays require that each lenslet and its sub-pixels are precisely aligned. Such precision is difficult with scanning displays such as cathode ray tubes (CRT's) because the alignment cannot be fixed. Matrix displays can be glued to the rear of the lenslet array, but the yield of matrix displays falls with increasing resolution which makes them prohibitively expensive. Furthermore the pixellation of a matrix display is fixed so one cannot experiment with different pixellations as is possible with a CRT.

Precise alignment is not needed to display holograms so scanning displays can be used. But the resolution needed to create a diffraction grating is particularly great and a super-computer is needed to drive such displays.

Lenticular displays and holograms provide the extra pixellation of a three dimensional image by having more resolution than a two dimensional display. An alternative is to have a higher frame rate[8].

A two dimensional display is made visible to a single direction at a time, and one view is made visible to each direction. If this process is repeated sufficiently quickly the whole seems continuous to the human eye.

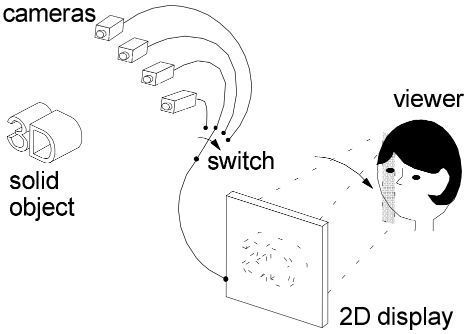

Figure 1. A 2D display synthesises a 3D image by presenting successive views of the original, each to a different zone.

The advantage of this approach is that it can be easier to increase frame rate than resolution. This is because the chance of failure rises with the number of components. So the manufacturing yield of conventional matrix displays is lower than that of CRT's, and the manufacturing yield of high resolution matrix displays is lower than of conventional matrix displays. But if a high frame rate display is to be used, then some way of making the display visible from a single direction is needed.

With liquid crystal displays this is simple. One merely needs to shine parallel rays of light through the display[9]. There exist liquid crystals which switch at the frame rates that would be needed[10]. But these require a narrower cell gap than is provided in conventional production lines. It has been hard enough to get useful yields even on conventional production lines: commissioning a new line for a device without a demonstrable market is out of the question.

One solution to this is to track the head movement of the viewer so that only two views are needed (or with several viewers, two views each)[11,12]. The frame rate need now only double (or be multiplied by twice the number of viewers). But one is now hostage to the vagaries of human inconsistency. Moderately reliable head-tracking devices have been demonstrated: a fail-safe head-tracking device presents a substantial challenge.

One of the few display technologies that is cheap and has high frame rate is the CRT. It is less obvious how to make a CRT visible from a single direction because CRT's are emissive and optically incoherent[13]. The technique used at Cambridge[14] is to spatially filter the optical fourier transform of the CRT image.

Optical fourier transforms

In its most popular form a fourier transform converts time to frequency and vice versa. An optical fourier transform converts position to spatial frequency[15]. It transpires that the complex amplitude of light in one focal plane of a lens is the optical fourier transform of the complex amplitude of light in the other focal plane. This is demonstrated by the way a lens treats light coming from a single position in its focal plane.

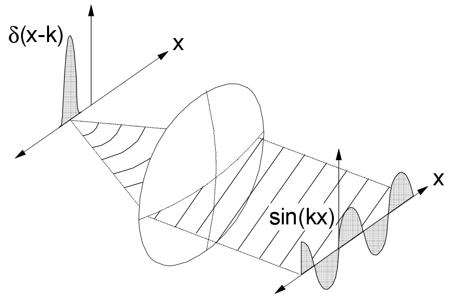

Figure 2. A lens does an optical fourier transform by converting the position of light in one focal plane to spatial frequency in the other.

A spot source of light in the focal plane of a lens is collimated into parallel wavefronts. If the instantaneous amplitude of these wavefronts is plotted as they intersect the other focal plane of the lens one records a sinusoid of amplitude. The more acute the angle at which the wavefronts cross the latter focal plane, the higher the spatial frequency of the intersection. The lens therefore converts the position of light in one focal plane to the spatial frequency of light in the other focal plane.

It is a property of fourier transforms that if one takes the fourier transform of a function twice in succession, the negative of the original function results.

The same holds true with optical fourier transforms. If one passes an image through two lenses in succession one has taken its optical fourier transform twice over. The image therefore reappears in the latter focal plane of the second lens but up-side-down.

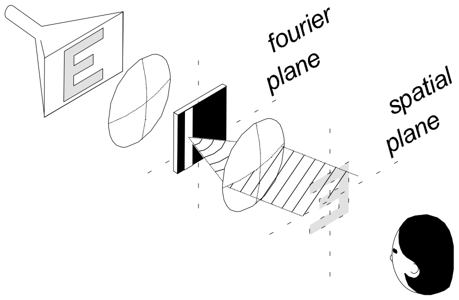

Figure 3. Two lenses execute two optical fourier transforms which produce an image of the CRT. A slit in the fourier plane now restricts the image's field of view.

The advantage of this operation is that it is now possible to filter the fourier transform of the image.

The fourier transform of the image lies in the focal plane shared by the two lenses. If a slit is placed in the fourier plane rays of light still get through to reconstitute the image in the spatial plane. But because position in the fourier plane transforms to direction in the focal plane, the rays all leave the system travelling in the same direction. It follows that the image in the final focal plane can be seen from only one direction.

The optical system

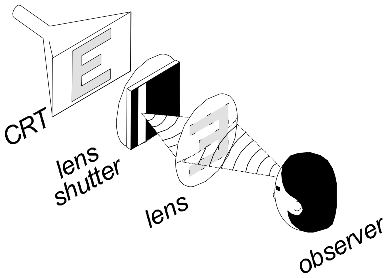

Figure 4. The 3D display comprises a CRT, a pair of lenses and a liquid crystal shutter.

The three dimensional display comprises a pair of lenses, a CRT and a liquid crystal shutter. It proves to be both unnecessary and inconveniently bulky to have a conventional optical fourier system layout. Instead it is modified in two ways.

Firstly the CRT is moved backwards by a distance equal to one focal length. The advantage of this is that the image of the CRT is now adjacent with the second lens so that it need be no bigger than the CRT image.

Secondly the liquid crystal shutter is moved backwards, also by a distance of one focal length. An image of the liquid crystal shutter is now formed where a third lens would go if we were to have a third optical fourier transform. In fact it is the viewer's head which goes here.

The benefit of the second operation is that it ensures that each of the viewer's eyes a single entire view. This is not a particularly important refinement, but without it the eye may see what is a composition of views, and slight discontinuities can arise at the borders within the composition. Otherwise the discontinuities are eliminated by providing more views which is better because the compositions are inherent to the formation of a true three dimensional image.

Advantages

The advantage of using a CRT with time sequential views is that the display is completely flexible. Both the CRT and the scanning shutter are reset by synchronisation pulses. So any number of views of any pixellation within the limits of the display can be chosen simply by altering the position of the synchronisation pulses. Television resolution has been demonstrated, and images comprising up to sixteen views have been screened.

Furthermore the interface is flexible. A conventional frame-store designed for a high resolution CRT display can be adapted for three dimensional display simply by making it emit an extra synchronisation pulse to control the shutter.

A final degree of flexibility is provided by the system optics used to control view direction. Different fields of view or screen sizes can be set up by shifting the position of the lenses in the display or by swapping the second lens for a different fresnel lens.

The combination of CRT and fourier optics is fundamentally robust. The optical system can be assembled with none of the precision required to collimate light on a pixel-by-pixel basis.

Furthermore the elements which constitute the display are robust. That this is so for CRT's and lenses is well known, but the liquid crystal shutter also has good resistance to shock. Versions of our display have been flown to a variety of destinations without mishap.

Particularly helpful is the remarkably high frame-rate available with a CRT. It is possible to display a sufficient number of views to different positions that there is no need to track the positions of viewers' heads in the room. This eliminates occasional hiccups in viewing. Of course if one specifically wants to experiment with head-tracking systems this is also possible.

The quality of the image seen in the display is particularly satisfactory. This is because it is the whole image which is processed by the lenses so there is none of the striation or clutter associated with lenticular screens or grids. Cues are absent which might remind the viewer that whatever the quality of the three dimensional image, it is presented on a two dimensional screen.

Conclusions

A video display which presents a three dimensional image has been developed at Cambridge University. The technique used to create the three dimensional image is inherently flexible and robust. Furthermore it gives a three dimensional image of particularly good quality. For those experimenting with 3D systems the display should make progress considerably more rapid.

References

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[1] A. R. L. Travis, Proc. ICAT 94, Tokyo, p. 229 (1994)

[2] R. Borner, Proc. SPIE 761 (1987)

[3] S. Ichinose, N. Tetsutani and M. Ishibashi, SID 89 Digest, p. 188 (1989)

[4] N. Tetsutani, K. Omura and F. Kishino, Opt. Eng. 33 p. 3690 (1994)

[5] H. Isono and M. Yasuda, ITEC 91, Tokyo, p. 615 (1991)

[6] P. St. Hilaire, S. A. Benton, M. Lucente, P. M. Hubel, Proc. SPIE 1667, p.73 (1992)

[7] H. Farhoosh, Y. Fainman, K. Urquhart and S. H. Lee, Proc. SPIE 1052, p.172 (1989)

[8] R. B. Collender, IEEE Trans. Consumer Electronics, CE-32, p. 56 (1986)

[9] A. R. L. Travis, App. Opt. 29, p. 4341 (1990)

[10] N. Collings, W. A. Crossland, P. J. Ayliffe, D. G. Vass and I. Underwood, App. Opt. 28 p. 4740 (1989)

[11] J. B. Eichenlaub, SID 93 Digest, p. 997 (1993)

[12] D. Ezra, G. Woodgate, B. Omar, N. Holliman, J. Harrold and L. Shapiro, Proc. SPIE 2409 (1995)

[13] H. B. Tilton, Proc. SPIE 120, p. 68 (1977)

[14] J. R. Moore, A. R. L. Travis, S. R. Lang and O. M. Castle, SID Digest 93, p. 700 (1993)

[15] E. Hecht, Optics, 2nd edn., Addison-Wesley, p. 472 (1989)