Observer Tracking Autostereoscopic 3D Display Systems

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Abstract

This paper presents a range of new autostereoscopic 3D display systems based on Liquid Crystal Display (LCD) technology in which observer tracking has been used to allow comfortable viewing freedom. For high image quality the Twin-LCD display has been used while other work has been in progress with flat panel displays using a new arrangement of LCD pixels. For each system the observer tracking system is described. In the flat panel display, a novel means to track such a display with no moving parts has been developed.

Introduction

A successful consumer autostereoscopic display product must have low cost combined with high image quality and ease of use. Thin film transistor (TFT) LCDs offer key advantages for these systems including flatness, thinness, regular pixel arrays, high resolution, high image contrast, high image fidelity and low cost.

The 'Twin-LCD' system [1) 2)] is an approach to display design in which each eye of the observer sees the full resolution of one LCD panel, maximising the image quality and providing a simple 3D image signal interface. Single panel embodiments generally make use of lenticular screens[3) 4)], parallax barriers [5) 6)], or holographic optical elements [7) 8) 9)]. Here, the 3D image has reduced resolution compared with the full panel 2D image so image quality is reduced. A third possibility is to use time multiplexing of images [10)].

Viewing freedom in any of these displays can be enhanced in two ways.

- Present a large number of views so that as the observer moves, a different pair of the views is seen for each new position.
- Track the position of the observer and update the display optics so that the observer is maintained in the autostereoscopic condition.

The authors feel that the maximised resolution and straightforward interface of observer tracking systems means that they are the most promising candidate for commercial autostereoscopic 3D displays with wide viewing freedom. Such an observer tracking autostereoscopic display system must have an observer position sensor, a processor and a dynamic optical system to update the autostereoscopic illumination profile at the observer. Tracking systems can therefore result in increased system complexity and cost which must be considered when designing display systems.

1. Window Design in Observer Tracking Autostereoscopic Displays

In general autostereoscopic displays produce an optical output such that at a plane in space at least two pupils or windows are created as shown in **Fig. 1.** If an observer places the right eye in one window, and the left eye in another, each eye sees a different image on the display. If the images constitute a stereo pair then a 3D image is seen, without the need to wear glasses.

We choose to characterise window structure by intensity measurements across the optimum viewing plane using a 1mm pinhole and a photometrically filtered detector. The visual intensity fluctuations can be determined approximately by convolving these structures with the observer's pupil.

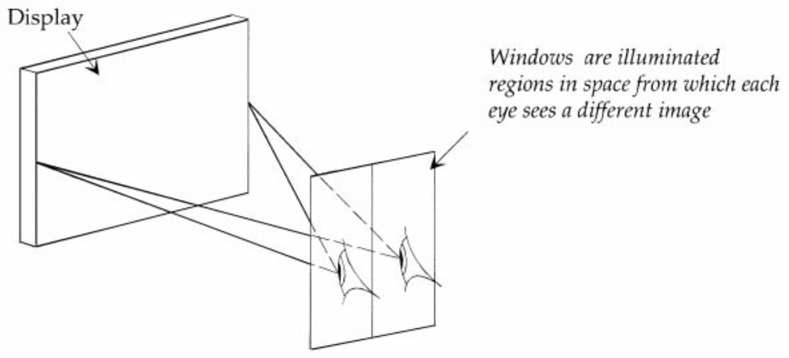

Fig. 1 Generation of windows in utostereoscopic displays.

In real display systems, the illumination profiles of the windows have artefacts as shown in **Fig. 2.** Degradation in the window profile can come from a combination of mechanisms including aberrations of the optical system, scatter, defocus, diffraction and geometric errors in the optical elements of the display.

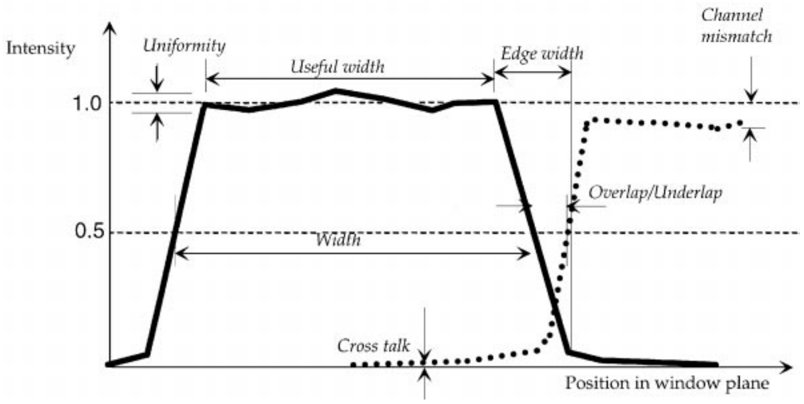

Fig. 2 Degradation of window quality.

In practice the observer tracking sensor, control and actuator systems have limitations in resolution, accuracy, and latency. A commercial infra red tracking sensor has a quoted accuracy of 2mm, 60Hz update rate with a latency of 16ms [11]. A similar latency for the remainder of the system due to processing speeds and actuator response times is typical so that an observer moving at a typically high speed of 300mms^{-1} can have moved more than 10mm in the time it takes for the system to respond. Therefore the useful width of the window must be at least this value for all tracked positions. An intensity fluctuation of less than 5% can be perceived by a moving observer [12] which defines the required intensity uniformity and therefore the useful window width. In a dynamically tracked display, an observer who falls out of the useful width at any time will see an intensity flicker artefact. Additionally, cross talk levels will fluctuate as the observer approaches the window boundary, which is often also perceived as a flicker artefact, and may result in further degradation of the useful window width.

Window design in autostereoscopic displays should therefore be optimised to maximise the freedom of location and reduce the tolerancing of the remainder of the components in the tracking system.

2. Observer Tracking in Twin-LCD displays

To overcome the bandwidth limitations of existing display components while maintaining image quality over an acceptable viewing region and enabling image look-around, various approaches were investigated which led to the 'Twin-LCD' display concept.

2•1 Macro-Optic Twin-LCD display

The Twin-LCD display principle of operation has been previously described [1]. A successful observer tracking system has been implemented in this display. However, this system uses bulky optics and is therefore not well suited to an easily portable display.

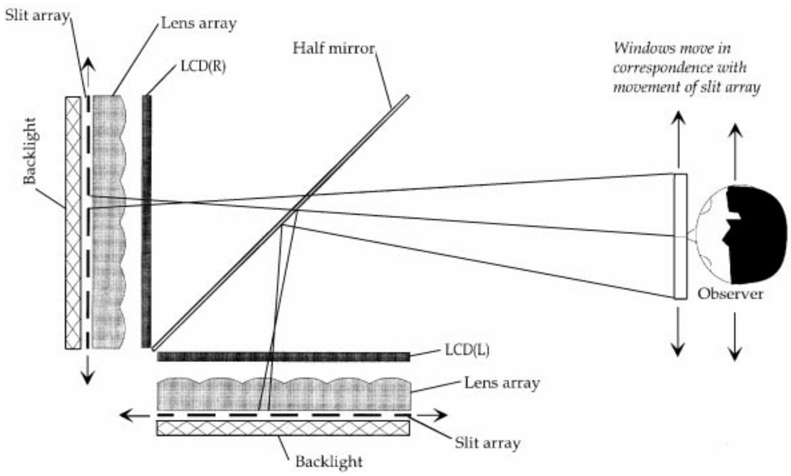

Fig. 3 The Micro-Optic Twin-LCD display.

2•2 Micro-Optic Twin-LCD display

A substantially more compact optical system for the Twin-LCD display has been developed at SLE using micro-optic components, as shown in **Fig. 3.** The display contains two orthogonal LCD panels whose images are combined by means of a half mirror. Behind each panel a sandwich of an array of slits, each aligned with a lens of a lenticular screen produces an array of windows when illuminated by a Lambertian backlight. The measured on-axis window profile for this illuminator is shown in **Fig. 4.**

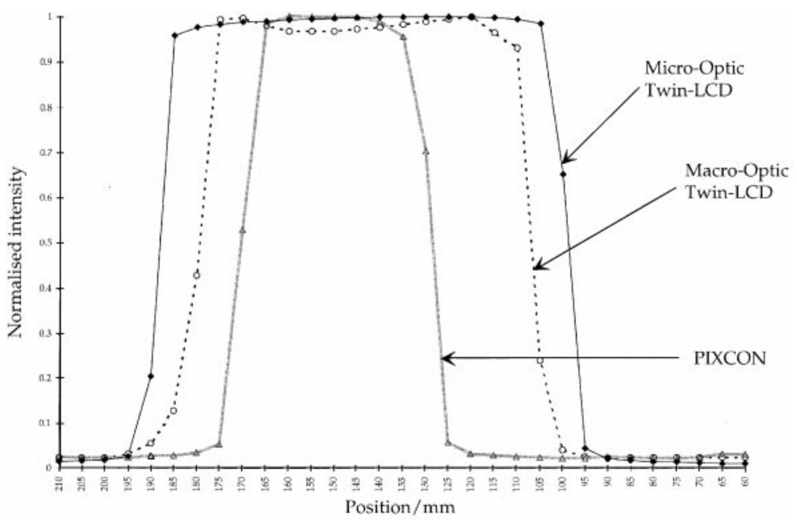

Fig. 4 Window profiles for the illuminators used in Macro-Optic Twin-LCD Micro-Optic Twin-LCD and PIXCON displays.

The observer can be tracked by

translating the slit array with respect to the lenticular screen. Both windows are required to move simultaneously so the two parallax barriers can be attached to the same mechanical stage.

The introduction of a micro-optic backlight has led to important display enhancements with respect to the Macro-Optic Twin-LCD display:

- Cross talk performance is optimised by window structure design, thus maintaining image quality.
- Illuminator thickness is reduced from 600mm to 6mm.
- The micro-optic Twin-LCD display is now a similar size to a 2D CRT monitor of equivalent screen size.
- The display is easily upgradeable to larger panel sizes.
- The optical design of the sandwich has lead to enhanced window quality. The lateral viewing freedom has increased from 230mm to 480mm in the window plane.
- The side lobes of the display are now of sufficient aberrational quality that a number of observers can see the display simultaneously if the observer is not tracked.

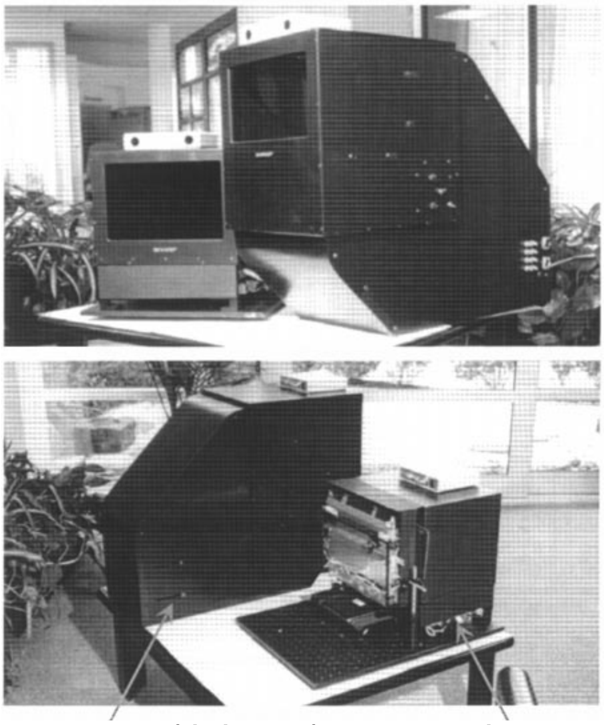

Fig. 5 Comparison of display sizes for Macro-Optic and Micro-Optic Twin-LCD displays

Fig. 5 shows a comparison of the sizes of the Micro-Optic and Macro-Optic Twin-LCD displays.

The Twin-LCD display is a high quality, full resolution display system, which is expected to make a contribution in a wide range of applications.

3. Flat Panel Observer Tracked Autostereoscopic Displays

In the Twin-LCD approach, the quality of the windows is dominated by the performance of the rear illumination system, the LCD largely being an independent component. In flat panel displays based on parallax optics such as lenticular screens and parallax barriers, the LCD pixel structure plays an important role in the imaging of the windows.

3•1 Novel LCD pixel configuration: PIXCON

TFT-LCD panels have a pixel structure which is defined by the associated driving electronics. The gaps between the pixels contain addressing electrodes, thin film transistors and storage capacitors required to control the pixel transmittance. These opaque electronic components and some interelectrode regions are obscured to the viewer by a layer called the black mask. LCD panels are designed to maximise light transmission and so the pixel shape is often quite complex.

The pixel structure is illustrated in **Fig. 6** for a typical 'stripe' type TFT-LCD (Sharp LQ10M211). In a flat panel autostereoscopic display, the black areas between pixels are imaged to black areas in the window plane and the areas of reduced vertical aperture are imaged to grey areas in the window plane, with significantly reduced intensity.

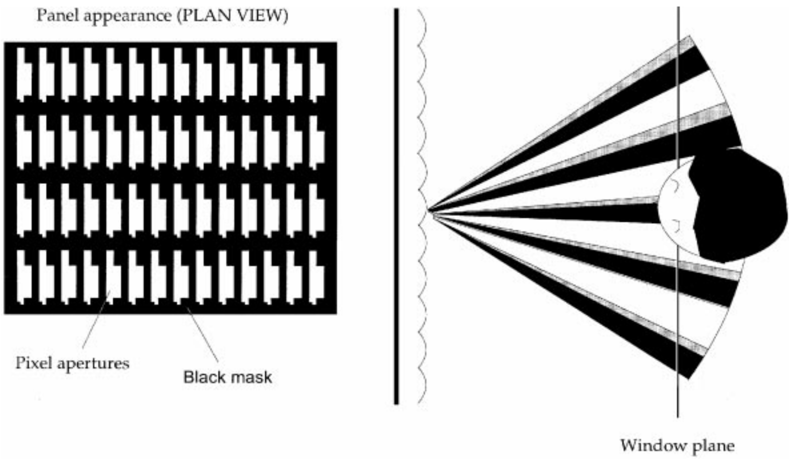

Fig. 6 Flat panel autostereoscopic display using Sharp LQ10M211.

One approach to track such a display would be to mechanically translate the parallax optic laterally with respect to the observer's position to maintain the autostereoscopic condition. As can be seen the windows are significantly degraded and it has been found that the flicker artefact cannot be adequately removed in such circumstances, even for an observer at the window plane.

It has been found possible to completely remove all of these black mask artefacts by using the novel pixel configuration referred to as PIXCON[14] shown in **Fig. 7.** The display has the same number of pixels as the conventional panel so that the electronic addressing requirements of such a display are no different from the standard panel, but their distribution and shape has been altered. The PIXCON pixels are rectangular and horizontally contiguous, so that the have the maximum lateral extent. Thus, when imaged by a parallax optic, the window shape is optimised, and has comparable optical quality to those produced in the Twin-LCD displays.

Such a novel PIXCON TFT-LCD panel has been fabricated, capable of showing full colour, moving video images. In a mechanically tracked display in which the parallax optic is translated with respect to a PIXCON panel, artefact free images were seen with dynamic performance and a lateral viewing freedom equivalent to the Micro-Optic Twin-LCD

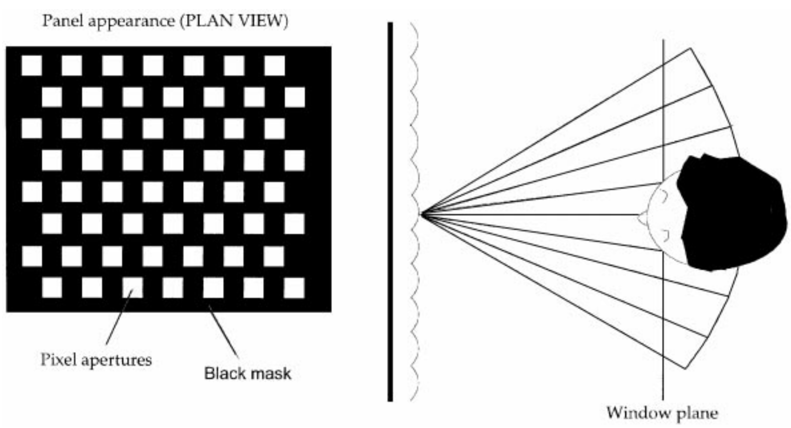

Fig. 7 Flat panel autostereoscopic display using novel PIXCON pixel configuration.

display.

PIXCON type displays have all of the benefits of LCD technology, but are able to generate window structures appropriate to flat panel observer tracked autostereoscopic displays.

3•2 Electronic (No Moving Parts) Tracking in PIXCON displays

Mechanical tracking systems with moving parts increase system cost and reduce robustness. A system which can track a moving observer with no moving parts would clearly be of great benefit. Such a system has been proposed and implemented at SLE using PIXCON technology[15].

The method of operation of such a display is shown in **Fig. 8.** The PIXCON and lenticular screen based flat panel display produces an array of three contiguous windows arranged in repeating lobes at the viewing plane. Each window can be individually addressed with the appropriate view information. The window size is set to be 2/3 the average interocular separation, so that an observer at the window plane nominally has one eye in the centre of one window while the other eye is at the boundary of the other two windows.

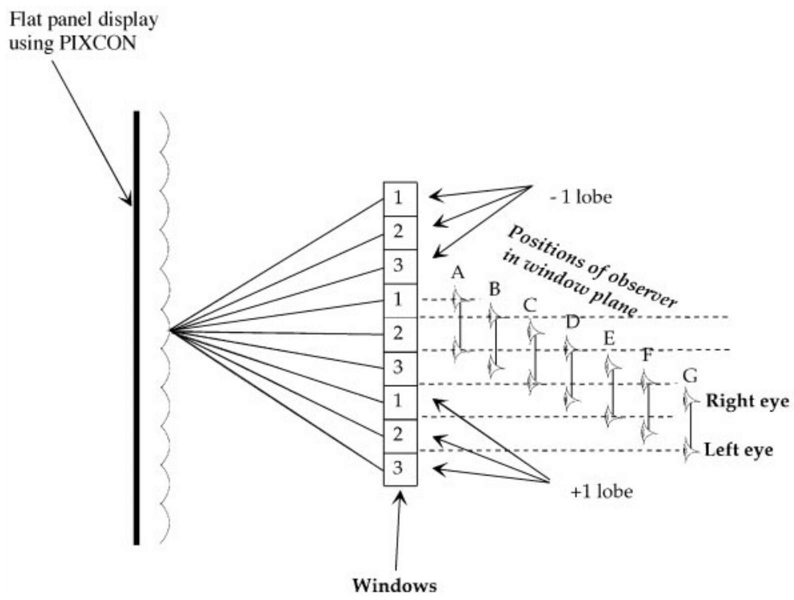

Fig. 8 Electronic tracking using PIXCON display.

Considering an observer at position A, window 1 contains right eye data while windows 2 and 3 contain left eye data. The horizontal contiguity of the PIXCON panel means that there is no intensity fluctuation as an observer crosses the window boundary, assuming both windows contain the same view information. The observer's left eye at the window boundary thus sees an artefact free left image and the right eye in the middle of window 1 sees an artefact free right image. As the observer moves laterally, the eyes fall into just two of the windows. At a point at which both eyes are equidistant from the window boundaries, the information on the middle window is swapped. Hence, when the observer has moved to position B, windows 1 and 2 contain right eye data while window 3 contains left eye data. This process continues for a range of observer positions, as shown in **Table 1**.

The use of three windows minimises the resolution loss in electronically tracked systems. Four or more windows will improve the optical performance of the display, but further reduce the effective display resolution.

Table 1 Channel date for each observer position inelectronically tracked display (Obsever is moving in window plane).

Observer position	Right view windows	Left view windows
A	1	2+3
B	1+2	3
C	2	3+1
D	2+3	1
E	3	1+2
F	3+1	2
G	1	2+3

Such a display has been implemented in the laboratory based on the PIXCON panel in full colour with successful results. Moving images have also been demonstrated, with full look-around.

4. Image look-around

In each of the displays described above an image look-around functionality has been implemented. This has been achieved by using the observer position data from the tracking sensor to control the images presented to the viewer.

Lateral (x) position data has been used to index into stored image sequences, replaying an appropriate image when the observer moves. This has been useful for simple look-around of medical images such as Magnetic Resonance Imaging (MRI) and Computer Aided Tomography (CAT) scans of the human head and synthetic images generated with computer graphics animation packages. Thirty images were used in each sequence and each image indexed to a specific lateral eye position in front of the display.

It was found that with thirty images displayed over a viewing freedom of 400mm, significant image rotation was observed in scenes with reasonable depth. This resulted in the observer perceiving image flipping each time they moved to see a new angle of view on the item displayed.

We have also used the (x,y,z) co-ordinates of the point between the two eyes for look-around with three degrees of freedom. This was used as the view point for synthetic cameras rendering real time computer graphics images of a scene. The viewer could look left and right or up and down around an object on the screen. In addition the viewer’s longitudinal movement (z) position was accounted for removing the otherwise normal depth compression/expansion effect as the viewer moved in and out from the display. The tracking position data was sufficiently accurate (better than one new view per millimetre of movement) and the image update rate fast enough (to 60Hz) so that smooth look-around with no image rotation artefacts was observed.

The computer systems used to implement image look-around have been standard systems with no modifications to the hardware, they include: Personal Computers, PCI bus, Pentium based systems; Silicon Graphics Indigo-2 and a Silicon Graphics Infinite Reality Onyx graphics computer.

The use of observer tracking to control image presentation is an important part of improving the quality of autostereoscopic displays and when the cost is justified it increases image realism significantly.

5. Applications for 3D displays

Recent progress in 3D display research has led to an increasing awareness of market requirements for commercial systems. In particular areas of display cost and software input to the displays are now of great importance to the programme.

Possible areas of application include games displays for PC and arcade units; education and edutainment; Internet browsing for remote 3D models; scientific visualisation and medical imaging.

Conclusion

The requirements for artefact free observer tracking of autostereoscopic displays centre around the quality of the optical windows produced by such displays. Any degradation of the windows will increase display flicker; reduce viewing freedom; increase the constraints for accuracy and response speed of the tracking sensor, control and actuation systems; and increase the display tolerancing requirements, increasing display cost.

Table 2 Comparison of observer tracking autostereoscopic display systems developed at SLE.

	Macro-Optic Twin-LCD display	Micro-Optic Twin-LCD display	PIXCOM Flat panel display
LCD Panels	2 Sharp TFT LCD type	2 Sharp TFT LCD type	1 Sharp TFT LCD type
Panel model number	LQ9RA03	LQ10M211	Novel pixel configuration: PIXCON*
Panel size	Diagonal 8.6"	Diagonal 10.4"	Diagonal 8.6"
Pixel pitch	0.286 x 0.181 mm (RGB Delta format)	0.33 x 0.33 mm (RGB Stripe Format)	0.270 x 0.220 mm (RGB stripe format)
Colours	Full analogue RGB grey scale	Full analogue RGB grey scale	Full analogue RGB grey scale
Image input format	Component video PAL or NTSC	Component video VGA, PAL or NTSC	Proprietary interface
Nominal viewing distance	750mm	750mm	750mm
Longitudinal viewing range	550-900mm	550-900mm	550-900mm
Lateral freedom at window plane	230mm	>480mm	>450mm
Tracking method	Waveguide illuminator	Mechanical	Mechanical or Electronic

* Not commercially available

Note : 14" diagonal panel versions of Twin-LCD displays have also been demonstrated

Some of the display systems researched at SLE and the implementation of high quality tracking in these displays have been described. These displays are summarised in **Table 2.** The main achievements of the programme to date include:

- The Macro-Optic Twin-LCD system produces fast and accurate observer tracked images using bulk optical elements
- The Micro-Optic Twin-LCD display system uses a new optical system to significantly reduce the cost and bulk of the Twin-LCD display while improving the off-axis window quality and therefore display performance.
- PIXCON technology development has lead to a major improvement of window quality in flat panel autostereoscopic display.
- Mechanically tracked flat panel displays have shown excellent results using PIXCON technology.
- A new class of electronically tracked display using the PIXCON technology has been developed to produce observer tracking with no moving parts.

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