Head Tracked Multi-user 3D Display using an RGB Laser Illumination Source

Surman P.[1], Sexton .I[1], Hopf K.[2], Buckley E.[3], Lee W.[1] and Bates R.[1]
1. Imaging and Displays Research Group, De Montfort University, The Gateway, Leicester LE1 9BH, UK
3dtv@cse.dmu.ac.uk
2. Heinrich-Hertz-Institut, Einsteinufer 37, 10587 Berlin, Germany
hopf@hhi.de
3. Light Blue Optics, St Johns Innovation Centre, Cowley Road, Cambridge, CB4 0WS, United Kingdom
edward@lightblueoptics.com

Abstract: *A 3D display that incorporates a head position tracker and an RGB laser as the backlight for an LCD and is described. The display provides 3D to several viewers, each of whom does not need to wear special glasses and is able to move freely over a large area. It operates on the principle of forming regions in the viewing field, referred to as exit pupils, where either a left image or a right image is seen on the screen. These exit pupils follow the positions of the viewers' eyes by using the output of the head tracker to control the backlight optics.*

Keywords: Autostereoscopic; 3D Display; RGB Laser; Liquid Crystal on Silicon (LCOS); Head Tracking; LCD Backlight.

Introduction

There are several ways in which 3D that does not require the wearing of special glasses (autostereoscopic) can be achieved. These range from simple two-image methods that have a single pair of fixed viewing zones through to full holography. A display that will be suitable for niche market applications in the near future and also television in around eight years time will lie somewhere between these two extremes.

There are several techniques for presenting stereoscopic images to several viewers. The three basic methods are: **holographic** where the image is produced by wavefront reconstruction [1], **volumetric** where the image is produced within a volume of space that may be either real or virtual [2] and **multiple image** displays where two or more images are seen across the viewing field.

The ideal stereoscopic display would produce images in real time that exhibit all the characteristics of the original scene. This would require the wavefront to be reproduced accurately and could only be achieved using holographic techniques. The difficulties of this approach are the huge amounts of computation necessary to calculate the fringe pattern, and the high resolution of the display, which has to be of the order of a wavelength of light (around 0.5 micron). Although holography may ultimately offer the solution to providing 3D images, the problem of capturing naturally-lit scenes will first have to be solved and holography is unlikely to provide the basis of a viable 3D display in the near future.

Volumetric displays have the ability to display motion parallax in both the vertical and horizontal directions [3]. This enables several viewers to see a 3D image that exhibits no rivalry between the accommodation and focus of the eyes. However, volumetric displays suffer from several disadvantages. In general the images are not opaque so that points of the image that lie behind a displayed surface will be seen through it. Whilst this might be acceptable for certain computer - generated images, it is not suitable for the display of real video images. Also, volumetric displays cannot show surfaces that have a non-Lambertian intensity distribution. Again, this would not be suitable for real images, as a proportion of the content in these images invariably has regions with non-Lambertian distribution. These images would have an unnatural appearance.

Multiple image displays fall within four fundamental categories, these are: holoform in which a large number of views give smooth motion parallax and hence a hologram-like appearance [4], multi-view where a series of discrete views is presented across viewing field [5], multi-beam where discrete beams of light radiate from points in the screen [6] and binocular where two views only presented in regions that may occupy fixed positions [7] or follow viewers' eye positions using head tracking [8] [9] [10] [11]. Holoform displays must present a very large amount of information in order to provide motion parallax. Multi-view displays, although potentially very simple to construct, do not provide stereo over the complete viewing area and also have a limited depth of field.

For these reasons the head-tracked binocular option has been chosen. This is particularly suited to television applications as it requires the simplest image capture, minimum transmission bandwidth and imposes the least demand on the display device in terms of resolution.

Principle of Operation

The display locates the viewers' head positions and uses this information to direct exit pupils to the locations of the viewers' eyes. An eye located in the left exit pupil region, denoted by the upper diamond-shaped green region in Figure 1., will see left image over the complete screen area. Similarly, a right image is seen by an eye located in the lower red region. The display optics is capable of producing several exit pupil pairs that can be moved independently of each other.

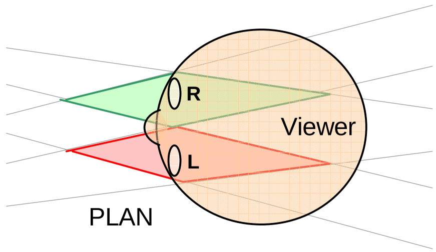

Figure 1. Exit Pupils

The display consists of a direct-view LCD whose backlight is replaced by optics that form the exit pupils under the control of a head position tracker. An image-pair is produced on a single LCD screen either by the use of spatial multiplexing where left and right images are produced in alternate pixel rows, or by temporal multiplexing where left and right images are produced sequentially. Figure 2. shows that a screen located behind the LCD enables light from two separate sources to be directed to the appropriate rows. This screen may either consist of a mask with horizontal apertures or a lenticular screen with horizontally-aligned lenses. The pitch of the screens is slightly less than twice the vertical pixel pitch.

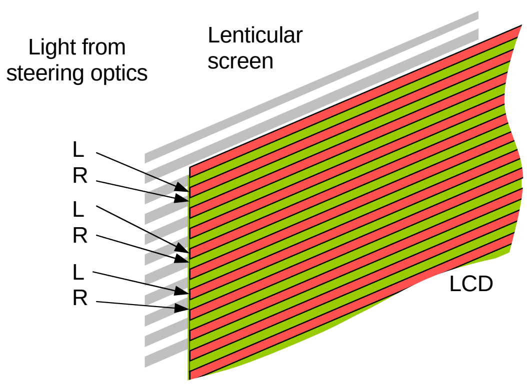

Figure 2. Spatial Image Multiplexing

It is possible to form exit pupils with a large Fresnel lens located in front of the LCD [8]. However, this requires moving light sources and is also subject to off-axis aberrations that limit the usable viewing area. The light sources would have to move in the z-direction to accommodate the variation in the distance of the viewer from the screen and also the housing size would be large. These problems can be overcome with the use of an optical array as in Figure 3. The lateral position of the exit pupil is determined by the horizontal positions of the light sources, and the distance by the pitch of the sources - the larger the pitch the closer the pupil.

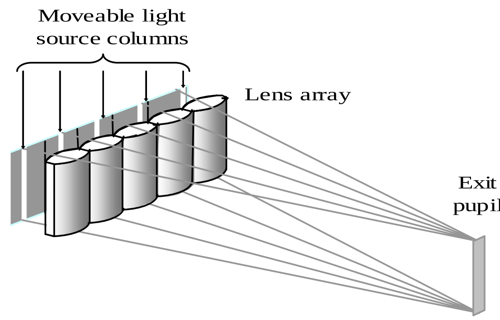

Figure 3. Optical Array

First Prototype

These principles were used in the construction of an autostereoscopic multi-user prototype. If the array was in the form depicted in Figure 3, severe off-axis aberrations would still be present. These can be overcome with the use of coaxial optics where the illumination and refracting surfaces in each element are cylindrical and have a common vertical axis that is located at the centre of an aperture. An array of these elements is shown at the top of Figure 4.

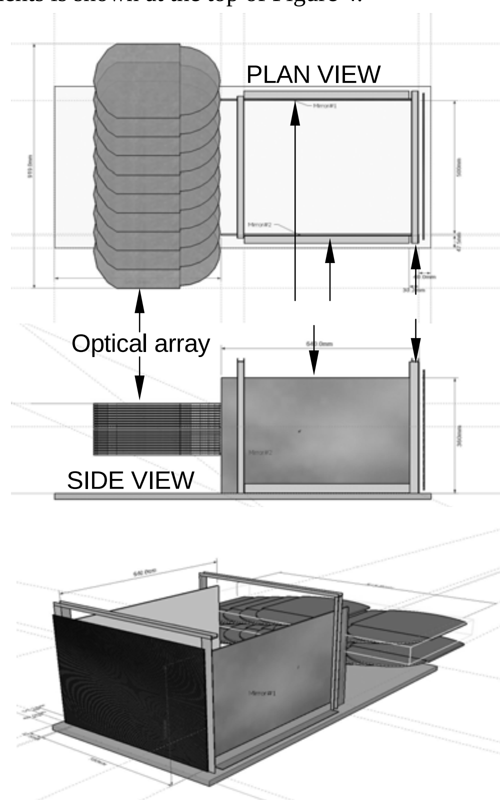

Figure 4 Prototype Multi-Viewer Display

The display incorporates two ten-element arrays, one for left images and one for the right. The arrays are arranged one above the other and their virtual widths are increased with the use of two side folding mirrors. Spatial multiplexing is achieved with the use of a lenticular screen and Illumination is supplied by around

5,000 white LEDs located around the back surfaces of the optical array elements.

A Polhemus four-target electromagnetic head tracker is used to locate the positions of the viewers' heads; this requires the wearing of pickups on the viewers' heads.

The performance is relatively poor but the prototype demonstrates the principle of operation and where future investigation is required. Crosstalk is severe due to the use of an LCD that has a fine microstructure giving excessive diffraction. The appearance of vertical banding in the image is caused by variation in the light output and color of the white LEDs. The image is dim due to the difficulty in gathering a sufficiently large proportion of the light output from the LEDs.

Current Work

The limitations of the first prototype are being addressed by a six member European Union-funded consortium. The primary areas of work are: a multi-user head tracker that is not intrusive to the viewers, an RGB laser illumination source, miniaturized optics and an LCD that has low horizontal diffraction and can run in the field-sequential mode.

Work is currently proceeding on the simplified version that is depicted in Figure 5. A single array only will be necessary provided a sufficiently fast LCD is available. The illumination source is switched synchronously in order to produce the sets of left and right exit pupils alternately.

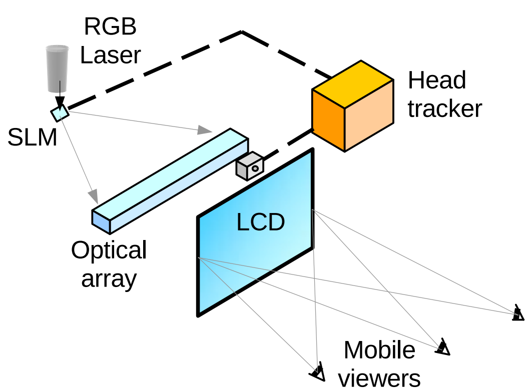

Figure 5. Current prototype

The large optical elements used in the original prototype are replaced by the miniature components shown in Figure 6. The illumination surfaces of the optical elements are flat therefore enabling the use of projection to supply the controlled input illumination.

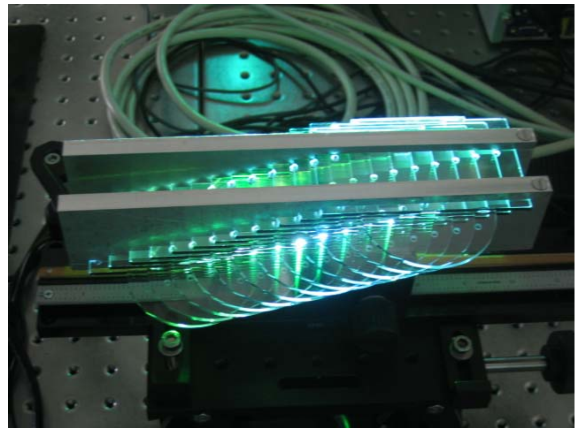

Figure 6. Miniature Optical Array

In the test array shown a conventional projector is used to replace the white LEDs of the previous version. However, as the illumination consists of regions that cover only approximately 5% of the area of the back of the array, a conventional projection system is inefficient as around 95% of the light is blocked.

This low light usage can be addressed with the use of a holographic projector where a computer-generated hologram is illuminated with coherent light. This has the advantage that the light delivered is controlled by diffraction rather than simply being blocked and the complete wavefront is made use of. Unlike conventional projection, this device utilizes a laser light source and a phase-modulating LCOS microdisplay on which a hologram pattern, rather than the desired image, is displayed. The hologram patterns are computer-generated such that, when the LCOS is illuminated by coherent laser light, the light interferes with itself in a complex manner through the physical process of diffraction resulting in the formation of a large, high-quality projected image. However, since the phase- modulating SLM devices are binary, a conjugate (mirror) image is produced, thus reducing the efficiency by half. Higher orders produced by the SLM pixellation effectively limit the diffraction efficiency to approximately 40%. It may however be possible to exploit the conjugate symmetry for this application, thereby doubling the efficiency to 80%.

A non-contact non-intrusive video based system that provides a near to real-time high-precision single-person 3D video head tracker has been developed by one of the MUTED partners for use in a single viewer head tracked display. This is currently being adapted for use as a multi-user tracker.

The fully automated tracker employs an appearance-based method for initial head detection (requiring no calibration) and a modified adaptive block-matching technique for head and eye location measurements after head location. The adaptive block-matching approach compares the current image with eye patterns of various sizes that are stored during initialization. Tracking results (shown as locating squares on the eyes) for three different users with three different scene backgrounds and illumination conditions are shown in Figure 7. As can be seen from the figure, the tracking algorithm also works for viewers that wear glasses.

Figure 7. Video Head Tracker in Operation

For automatic initialization the tracker finds the user's eye positions by either looking for simultaneous blinking of the two eyes, or by pattern fitting face candidates in an edge representation of the current video frame by applying a predefined set of rules. These face candidates are finally verified by one of two possible neural nets. After initial detection the eye patterns that refer to the open eyes of the viewer are stored as a preliminary reference. Irrespective of the initialization method applied the initial reference eye patterns are scaled (using an affine transformation) to correspond to six different camera distances (Figure 8 right images). The resulting twelve eye patterns are used by the head tracker to find the viewer's eyes in the current live video images (Figure 8 left images).

Figure 8. Tracked live (left) and reference (right) eye patterns

Conclusions

In this paper we have identified that the use of a head tracked 3D multi-user display offers advantages for a display that will be suitable for use within the next few years. We have concluded that the head tracking approach will fill the window of opportunity occurring over the next ten years and during which time 3D television will be introduced. The knowledge gained from trials on the first prototype is being used to produce an improved version where the principal problems of crosstalk, dim image and the appearance of banding in the image are being addressed. It is envisaged that at the conclusion of the current project in late 2008 the display will be close to being developed into commercial product.

Acknowledgements

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