Display Development in the Advanced Displays Laboratory at NTU

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Abstract— The "Towards the Reality of 3D Imaging and Display" project aims to produce the first viable glasses-free (autostereoscopic) 3D display systems. In order to do this we must determine what are the minimum requirements of any autostereoscopic display.It must be realised that *any* autostereoscopic display, which includes amongst others; holographic, multiview, light field or head tracked requires the control of light with direction emitted from the screen. With a glasses display this is not an issue as the separation of the two different images required is carried out in the region of the viewers' eyes so the same light can be emitted in all directions from each point on the screen. Other research carried out in the Group includes quasi-3D where a slanted lenticular screen provides a type of 3D where there is no "sweet spot" and the effect is seen in all positions In addition to autostereoscopic display; near-to-eye systems are also under investigation.

1. INTRODUCTION

Ideally, a perfect representation of the original scene captured could only be faithfully reproduced by presenting what is known as motion parallax in both the horizontal and vertical directions. Motion parallax is the ability to look around, or over objects as an observer would do in natural viewing conditions. The requirements for an autostereoscopic display can be simplified by dispensing with motion parallax in the vertical direction as it can be assumed that the orientation of the viewer is generally the same as that of the screen. The display can be further simplified by presenting the same stereo image pair to every viewer, in a similar manner to current glasses-type displays.

The operation of the display will be dependent on the available enabling technologies, available content and content delivery method; for this reason we are investigating various display types and developing new enabling technologies.

After consideration we determined that three basic display types are the most likely contenders for producing the first generations of autostereoscopic display. Each has its own merits and disadvantages and also has different time scales before likely implementation as a commercial product. The three most likely candidate display types we considered suitable are; computational multi-layer displays, head tracked displays and super multiview.

Multi-layer displays were first investigated around 2000 by a Russian company called Neurok [1] and several patents were taken out. This work does not appear to have led to a successful commercial product but this line of research was taken up by MIT who have been working on it for the past few years [2] These displays are an example of *light field* display where an original scene can be reproduced in a hologram-like manner but without the complexity of using holographic techniques. There are many ways in which this type of display can be implemented and some embodiments are capable of producing full parallax.

Head tracked displays [3] require the minimum amount of information; a simple stereo pair only is all that is required in order to show 3D and also is compatible with existing content and delivery infrastructure These displays have certain disadvantages, one of these being the difference between where the viewers' eyes are focussing and where they are converging (known as accommodation/convergence conflict) [4] but the effects of this can be overcome with careful editing of the content. The principal advantages they offer are they can use existing displays without giving a loss of resolution and the amount of data handled is the minimum required tor the presentation of 3D.

Super multiview (SMV) displays are an extension of today's state of the art multiview displays. Current multiview displays [5] have the advantage of simple construction but have the disadvantage of resolution loss where there is a trade-off between the number of views displayed and the perceived display resolution. The 3D quality in terms of depth of field increases with the number of views, but unfortunately the resolution becomes reduced. Slanted lenticular multiview displays based on state of the art 4K panels do not provide a quality that is sufficiently good for a commercially viable

3D display. It must also be borne in mind that the resolution reduction will be less acceptable to consumers as they become accustomed to the superior resolution of 4K displays; for example viewing distances could tend to become shorter as users adapt to the higher resolution.

2. COMPUTATIONAL MULTI-LAYER DISPLAYS

The research within this project modifies the Tensor Display developed at MIT in order to make it suitable for commercial 3D displays. The display comprises arrangements of light emitting, light directing and light modulating layers. Patterns displayed on the modulating layers are derived by a computational framework in order to embed high-dimensional multi-view data into the screen's optical configuration, achieving higher quality as display update speed increases. The computational framework is amenable to implementation on modern GPUs, making the complex computation required possible with near-term hardware.

Computational multi-layer displays represent another new approach toward next-generation 3D displays. These are light field displays where in one embodiment the conventional parallax barrier, which has low light throughput and low resolution, is replaced by a dynamic barrier which adapts to the picture content. The so-called high-rank 3D display uses a stack of semi-transparent LCD layers and is able to generate different light rays in each direction from the same point of the screen [6]. Each LCD layer contains a different pattern and the whole stack can approximate the light field of a given scene and re-create the scene with a hologram-like appearance. The patterns on each LCD are obtained through a computationally expensive optimization, which exploits the fact that the light field of a natural 3D scene can be described by a set of low-rank matrices. The technique has been expanded to multiple layers and refractive optics, such as directional backlighting in the Tensor Display design.

Figure 1: Image of test object on tensor display.

We are currently working on two variants of these displays (the image of one of these is shown in Fig. 1); further options include:

2.1. Fast Content-adaptive Display

Improvement in performance will be sought by investigating faster devices so an obvious choice will be with the use of a fast OLED panel. As an OLED is an emissive display it will provide the first layer as the illumination source. In the directional backlight embodiment of the computational display this will have a lens array mounted in front to convert position on the display pixel plane into emergent angle. In order for a faster directional backlight to improve the display performance the transmitting layers must also operate at the same frame rate.

2.2. Head Tracked Content-adaptive Display

In its present form the content-adaptive parallax barrier embodiment of the computational display can only supply motion parallax over a relatively small angle. This is sufficient for a single user but it would be desirable to make the images available to several users located over a large viewing field. This can be achieved with the use of head tracking to direct 'sweet spots' to the vicinities of the viewers' eyes. The output of a multi-user head tracker will control the positions of the sweet spots.

3. HEAD TRACKED DISPLAYS

These displays produce exit pupil pairs where a left image is seen across the complete area of the screen in one pupil and a right image in the other. The head tracker ensures that the pupils are always located in the region of the appropriate eyes so the exit pupils follow the viewers' eye positions. Although head tracked displays have been developed over many years there are none serving several viewers. Two types of display are under development where both have an LCD dynamic backlight whose output is controlled by a multi-user head tracker.

3.1. Array Display

The array display uses a lens array Fig. 2) where a series of intersecting collimated beams crosses a user's eye to form an exit pupil. Moving the array illumination pattern laterally shifts the exit pupil in the X direction; increasing or decreasing its pitch moves the pupil in the Z direction, and several exit pupils can be formed by producing several illumination patterns. The array is functionally two-dimensional and is configured as a series of linear arrays, each one containing around 100 white LEDs. The maximum number of diodes lit at any given time is approximately 50. The optical array structure in the initial prototype is large and is currently being redesigned into a more compact flat panel form suitable for a consumer product.

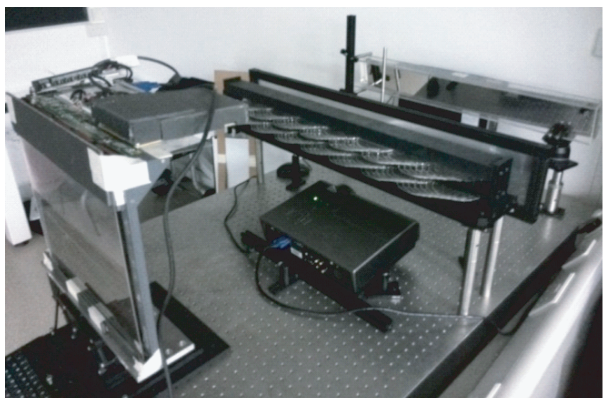

Figure 2.

3.2. Dynamic Display

In the dynamic display a column of the image is scanned laterally by illumination derived from an RGB laser illumination source that provides highly controllable light that is regulated by a spatial light modulator (SLM) (Fig. 3). As the column traverses the screen light beams only exit in certain directions so that they are directed to the eyes and the beams "home-in" on the eyes during the scan. In this period a left image is shown on the screen. During the next scan when a right image is shown, the beams shift slightly to the right so that right eyes only see the image. The front screen comprises conventional lenses and a vertical diffuser used in conjunction with a Gabor superlens. This is a lens that consists of layers of microlenses and has different imaging properties to a conventional lens and can provide angular magnification so that the 150 mm width of the SLM can be magnified to cover the width of the viewing field (~ 3 m).

The displays under development are true multi-user head tracked devices having the advantages of; non-intrusive head tracker full resolution, standard video content, large depth of field and 2D/3D switchability etc.. These displays use standard stereoscopic content that that can be captured with a simple camera pair. If sufficiently fast LCDs do eventually become available, the displays are capable of displaying motion parallax to several users by displaying a different image-pair for each user during each 16.7 ms period.

4. SUPER MULTIVIEW DISPLAY

SMV displays provide a large number of discrete perspective views over the viewing field so that continuous motion parallax is presented. One criterion for the width of each viewing zone this is that there are two views per eye pupil width. This would require the presentation of a number of views in excess 200; however it is envisaged that for the first generation of SMV display, the

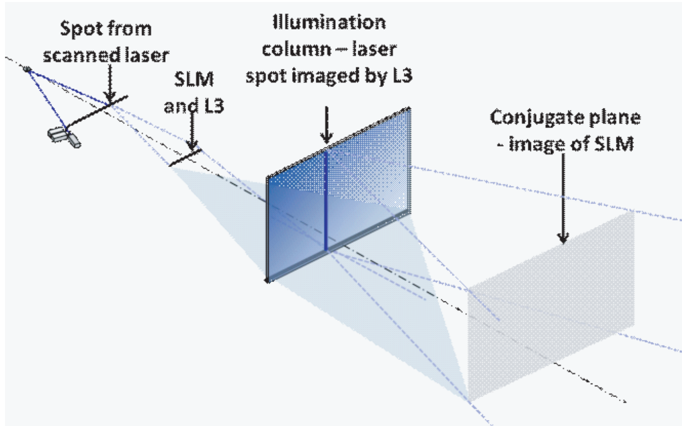

Figure 3.

presentation of greater than around 60 views, and *with full resolution* will provide a display that will have sufficiently good quality to be a marketable 3D display.

One approach to providing a large number of views is the brute-force method of using a large number of projectors whose images are projected on to a screen that reflects the light in the vertical direction only [7]. Such an approach is used in products by Holografika [8] and is also investigated by other research groups.

In the authors' opinion this is not the way forward due to size and complexity and we are developing display hardware and driver architecture (Fig. 4) where this function can be performed on a display *less than 10 mm thick* where each pixel acts as a minute projector that can send out different light beams in 60 or more horizontal directions. This cannot be achieved with straight spatial multiplexing as in current multiview displays, but employs spatio-temporal multiplexing that utilizes increasing speed potential of devices such as OLED displays.

The use of a fast OLED panel with modified sub-pixel design, in conjunction with a novel liquid crystal screen that is currently under development, enables the production of a display with an effective resolution in excess of 100 million pixels. The use of spatio-temporal multiplexing means that the effective resolution of the screen can be varied as necessary; as opposed to being fixed by the dimensions of the display sub-pixels as at present. This opens up the possibility of a more intelligent display driver that can adapt the resolution of the display in accordance with the requirements of the particular image being displayed. In this way the driver complexity and the bandwidth requirements can be reduced dramatically.

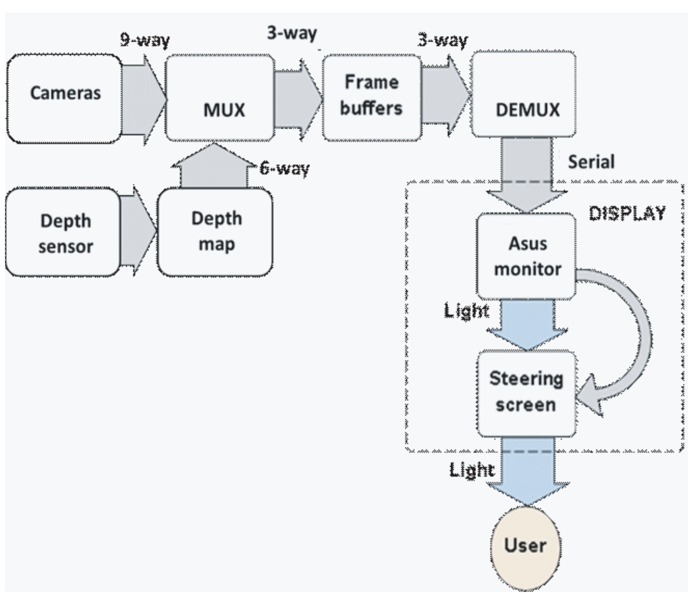

Figure 4.

5. QUASI-3D (Q-3D) DISPLAYS

These displays show left and right images that are presented to different areas of the viewing field. This provides the 3D effect by showing true 3D and reversed 3D (pseudoscopic) to the viewer's eyes over different regions of the display. A sufficiently large proportion of the screen shows the correct depth in order to give the illusion that 3D occurs over the complete area of the screen. One disadvantage of this approach is that double images are inevitable and the disparity between the images must be kept low.

The optical design of the screen is simple; however the analysis and elimination of the appearance of Moiré fringing has proved to be fairly difficult but has now been solvedby optimizing the slant angle and other parameters of the lens sheet and rendering the images accordingly.

6. NEAR-TO-EYE DISPLAYS

The current concensus appears to be that near to eye devices will become a considerably more important display type than the currently more prevalent type where the display is effectively a "window" on the scens displayed. For this reason the Group has extended its research area into investigating near-to-eye display devices and has developed a freeform prism version using a small OLED microdisplay.

By studying the physiology of the human eye the authors have identified where current near-to-eye hardware technology is lacking. In terms of performance the hardware should ideally have a resolution that is in excess to the resolution of the eye of around 60 cycles per degree and provide a field of view that is around 210° horizontally and 110° vertically. This can be seen in Fig. 5 that is a modified perimetry diagram where the limits of peripheral vision are smoothed and the left and right eye plots are superimposed to provide the yellow region that is the area of stereo vision.

The limits of the peripheral vision of the left and right eyes are indicated by the red and green lines respectively. It can be seen in Fig. 5 that there there are large regions where stereo cannot be seen; however providing the image in these regions heightens the immersive experience. Overlaying the horizontal and vertical fields of view of a headset on this diagram provides a very graphic and useful indication of the performance of the display hardware.

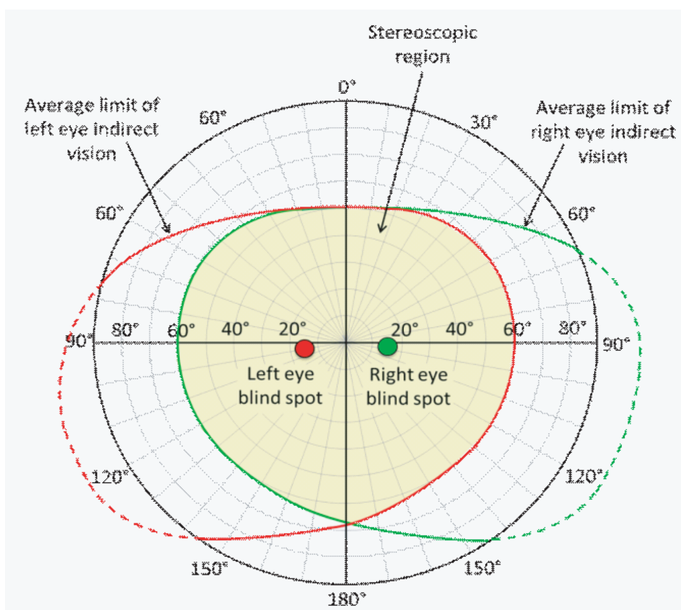

Figure 5.

7. CONCLUSIONS

Research in all areas of work is ongoing and the displays are at various stages of their development into commercial products. The multi-layer display images show noticeable depth; however this depth of field is relatively limited and the algorithms are being optimized to increase it. Computation in real time is necessary and we are investigating various strategies, for example saliency to speed-up the process. In its current form the array display is large and the optics are being reconfigured to make it flat panel. One difficulty that has been encountered with the Dynamic Display is the fabrication of the Gabor Superlens that is a multi-layered lenticular device. We are currently investigating redesign with a larger SLM where the superlens would not be necessary. The SMV display is probably further away from being a product than the others; however this offers the prospect of a flat panel display with large depth of field but with the minimum bandwidth requirement. Head mounted display design is in progress where the physiology of the human eye in terms of peripheral vision, the stereo vision region and distribution of retinal acuity is taken into account.

ACKNOWLEDGMENT

This research is supported by the Singapore Government under grant No. NRF-CRP11-2012-01.

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