ОБЪЕМНЫЕ ДИСПЛЕИ

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УСТРОЙСТВО И ХАРАКТЕРИСТИКИ МНОГОРАКУРСНОГО ОБЪЕМНОГО ТВ ДИСПЛЕЯ

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Разработан дисплей, обеспечивающий получение объемных изображений несколькими наблюдателями без использования очков при их свободном перемещении в пределах одной комнаты. Устройство состоит из одиночного жидкокристаллического дисплея, отображающего стереопару по методу пространственного мультиплексирования, и задней подсветки, перемещаемой сканирующей оптикой нового типа и управляемой индикатором, расположенным на голове наблюдателя. Это осуществляется с помощью семейства соосных элементов и ярких белых светодиодов. Обсуждены операции сканирования и мультиплексирования. Описан прототип дисплея, использующего четыре электромагнитных индикатора положения, размещенных на голове, и согласованную с ними оптическую систему.

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THE CONSTRUCTION AND PERFORMANCE OF A MULTI-VIEWER 3DTV DISPLAY

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De Montfort University is developing a 3D display that is capable of supplying 3D to several viewers who do not have to wear special glasses, and who are able move freely over a room-sized area. The device consists of a single liquid crystal display that presents a stereo-pair by employing spatial multiplexing, and has its conventional backlight replaced by novel steering optics controlled by the position of a head position tracker. This is achieved using arrays of novel coaxial optical elements in conjunction with high-density white light emitting diode arrays. The operation of the steering and multiplexing optics will be explained. The prototype display, which uses a four-target electromagnetic head tracker, and incorporates a folded optical system, will be described.

Introduction

The De Montfort University (DMU) 3D display is autostereoscopic and enables several viewers to see stereo over a typical room-sized area. A display meeting these requirements will be more complex than those intended for single, often static, viewers, as used for computer monitor or arcade game applications for example [1–3]. The display operates by producing regions in the viewing field, referred to as ‘exit pupils’, where a left image only, or a right image only, is seen on a single direct-view liquid crystal display (LCD). The screen assembly comprises a multiplexing screen that separates light on to alternate odd and even rows of pixels on an LCD where the left and right eye images are displayed.

The positions of the exit pupils are determined by the output of a head position tracker that controls novel steering optics, located behind the LCD, that replaces the normal backlight. This approach presents the *same* stereo-pair to each viewer. Although this does not provide motion parallax, it does have the advantages of requiring the minimum amount of information being displayed and simple image capture and processing, therefore making the display particularly suitable for television applications.

Head-tracking research is not being carried out as many other groups are pursuing this work. We therefore use an off-shelf electromagnetic multiple target head tracker, and our research concentrates on display development.

1. Principle of operation

The DMU 3D television display uses a novel configuration for generating multi-viewer, full freedom of viewer movement, autostereoscopic television. The approach uses two main components, a spatially multiplexed LCD front screen and an optical steering array. The steering array consists of light emitting diod (LED) sources, focused by novel optics, that direct and target pairs of exit pupils through the front screen to the eyes of each viewer. Different left and right images are directed to the eyes of the viewers, enabling 3D to be seen without the use of special glasses.

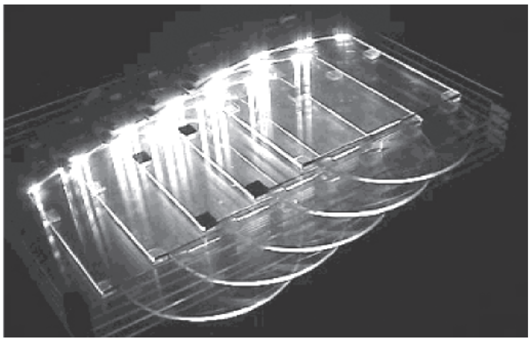
Possibly the simplest solution to displaying a stereo pair would be to employ temporal multiplexing, by presenting left and right images sequentially on the screen and alternating the illumination source position. This is not easily achieved in practice, as currently available LCDs are not sufficiently fast to run in this mode without the appearance of flicker. Another means of producing two images is to use two separate LCDs and combine their images with a semi-silvered mirror. This method was employed by Sharp some years ago [4]. This configuration enables full LCD resolution, but has the disadvantage that the display is necessarily large in relation to the screen size.

With the advent of high-resolution LCDs, it is possible to present two full resolution TV quality images simultaneously on one panel. The DMU display uses this approach and presents left and right images on alternate pixel rows. This scheme is referred to as spatial multiplexing (as opposed to temporal multiplexing where the images are presented sequentially). By using spatial multiplexing, light from individual light sources must be manipulated independently for the left and right images before it reaches the screen. The simplest method of achieving this is with the use of a parallax barrier that consists of a mask with horizontal apertures. Light from one source can only fall on the left image pixels, and light from the right source on the right pixels if the light sources are displaced vertically. Although the barrier is simple to produce, it can theoretically only pass a maximum of 50% of the light, and considerably less if the light sources are the arrays that are used in the DMU display.

A more efficient means of multiplexing uses a lenticular screen with lenses horizontally disposed. This enables all of the light to be captured and also has the advantage that the light sources require only a small separation in the vertical direction. This is a particular advantage where the light sources are not simple lamps, but are optical arrays that have considerable height in relation to their spacing. The main innovation of the 3DTV display is the light steering optics. These optics are used to ‘steer’ beams of light (exit pupils) to the eyes of each viewer through the spatially multiplexed LCD, with left and right eye beams passing only through the left or right image rows of the screen respectively. Two arrays of optics are used, one for the left and one for the right LCD image. Each array consists of ten optical elements and illumination sources arranged in two stacks of five elements. An illuminated single stack of five elements is shown (Fig. 1a).

Our 3D display produces an exit pupil for each eye of each viewer; these exit pupils are shown tracking moving

(a)



(b)

Fig. 1. Demonstrator arrays (a) and targets (b).

‘viewer eye’ targets (Fig. 1b). This could be achieved with the use of multiple mobile illumination sources and a large lens, however the function of a single lens can be performed by an array of smaller lenses, each with its own light source (Fig. 2a). Each lens forms an approximately parallel beam so that an eye located in the exit pupil region will perceive illumination across the complete width of the array. The exit pupil can be moved laterally by moving the light sources laterally. Movement of the pupil in the *z*-direction is achieved by altering the spacing of the sources – the closer the pupil, the greater the spacing of the sources. Simply having multiple illumination sources can produce multiple exit pupils. This configuration has the advantage over a single lens as exit pupils can be produced over a large area with illumination sources that are confined to a single plane.

Other problems with conventional lenses are those of spherical and off-axis aberrations. These problems can be overcome with the use of coaxial optics where the illumination source and refracting surfaces are cylindrical and have a common axis (Fig. 2b). Extreme rays are blocked by an aperture, which is also centred on the axis. In this way, there can be no off-axis aberrations, and the aperture limits spherical aberration. The edges of these apertures are faded in order to eliminate the appearance of vertical banding. The light source consists of a linear array of white light emitting diodes whose illumination is determined by the output of a head position tracker. Light is contained within the optical elements by total internal reflection. In this way an ar-

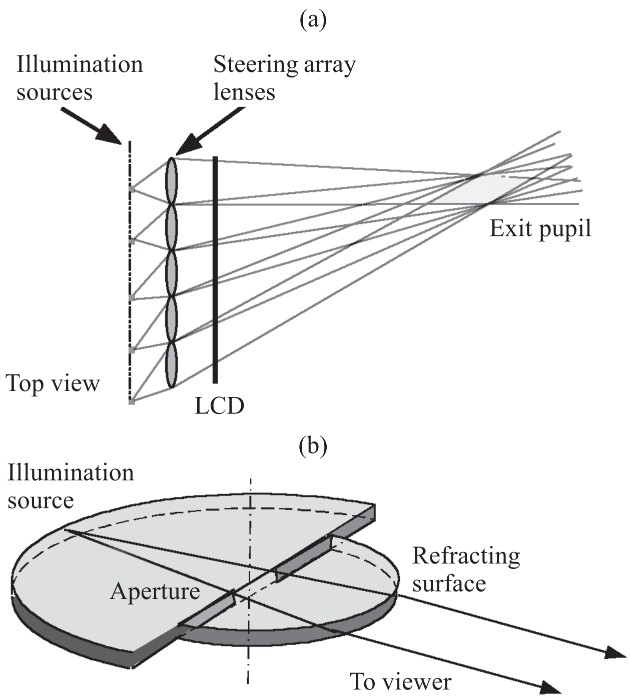


Fig. 2. Optical array elements. a – steering array, b – coaxial optical element.

ray of coaxial optical elements enables the placement of several independently steered exit pupils over a large area. As the each element of the optical array has its own illumination array, the illumination is effectively a two-dimensional matrix that enables two-dimensional control of the pupil positions so they can be steered in both the x and z-directions.

2. Prototype construction

A working prototype was constructed (Fig. 3) comprising three main components, these being two 10-element optical arrays, two folding mirrors that extend the effective width of the array, and the screen assembly. The display is mounted on an optical bench, and although a production model would be around the same size as a current rear-projection television, no attempt has been made make this version compact.

The two 10-element steering arrays are located at the back of the display with one array positioned above the other in order for their outputs to be separated by the multiplexing screen. Each array is made up from two of the assemblies that are shown in Fig. 1a that are mounted so that they form a continuous source of light across their width. Two folding mirrors are arranged either side of the light path between the arrays and the screen assembly to provide virtual images of the array either side of the array itself. As the array has the ability to produce exit pupils over a large area, it can also form pupils in the mirror-image positions of the actual positions – the mirrors can reflect these in order to produce the virtual arrays.

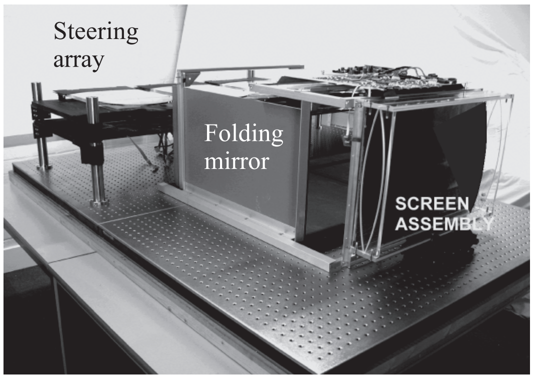


Fig. 3. Prototype 3D display.

The screen assembly consists of a lenticular multiplexing screen, the LCD, and a large cylindrical lens at the front. The multiplexing screen and LCD are mounted on a rigid aluminum frame that allows precise adjustment of the relative positions of the two components. The LCD has a UXGA (1200×1600) resolution, which enables two 576-line images to be interlaced.

3. Prototype results

The prototype has proved to be extremely useful in identifying the areas where future research must be concentrated. The most important of these are: image brightness, vertical banding caused by the variation of image brightness across the screen and crosstalk (where the incorrect eyes see left and right images).

Brightness: The image of the first prototype is not very bright and user trials were carried out in subdued lighting conditions. This problem should be solved with the development of higher brightness LED technology.

Banding: As the original contiguous LCD backlight is effectively replaced by an array of discrete LED illumination sources, the appearance of banding is a potential problem. Variation in intensity and color between the devices gives rise to the appearance of vertical banding. The variation in LED colour was more noticeable than the variation in LED brightness. However, when there is an image on the screen, especially if it is moving, the effect becomes barely noticeable.

Crosstalk: This is possibly the most important problem to be addressed. The major contributors to crosstalk are scattering within the optical elements and diffraction at the LCD. Diffraction at the LCD is a much more serious problem as shown (Fig. 4).

It should be noted that there is less diffraction vertically than horizontally, hence for a second prototype the LCD will be rotated through 90° so that the horizontal scattering, which causes crosstalk, is negligible.

A plot traversing the light output of an exit pupil at the position of the eye of a viewer was taken to examine the diffraction and crosstalk of the complete prototype (Fig. 5a and 5b). The broken line shows the inten-

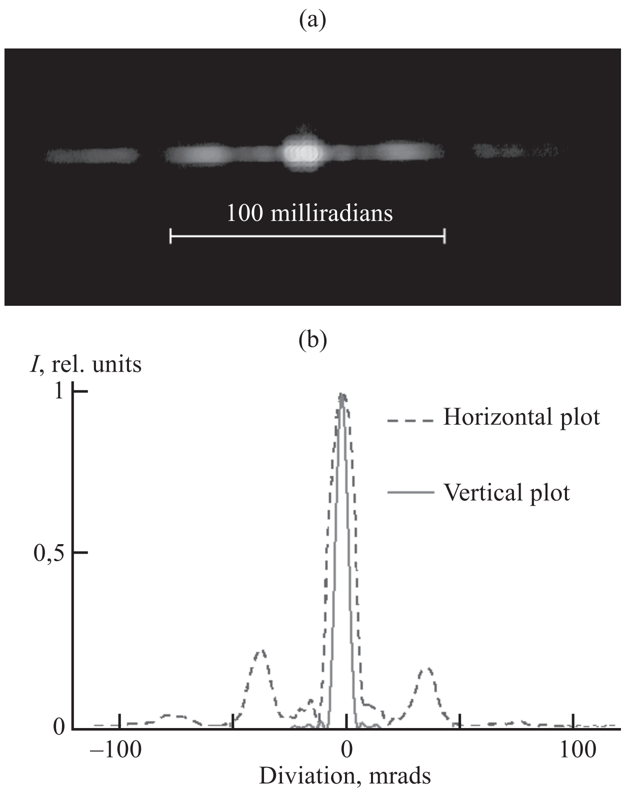


Fig. 4. Diffraction caused by the LCD. a – white light diffraction pattern of LCD. b – LCD diffraction plots.

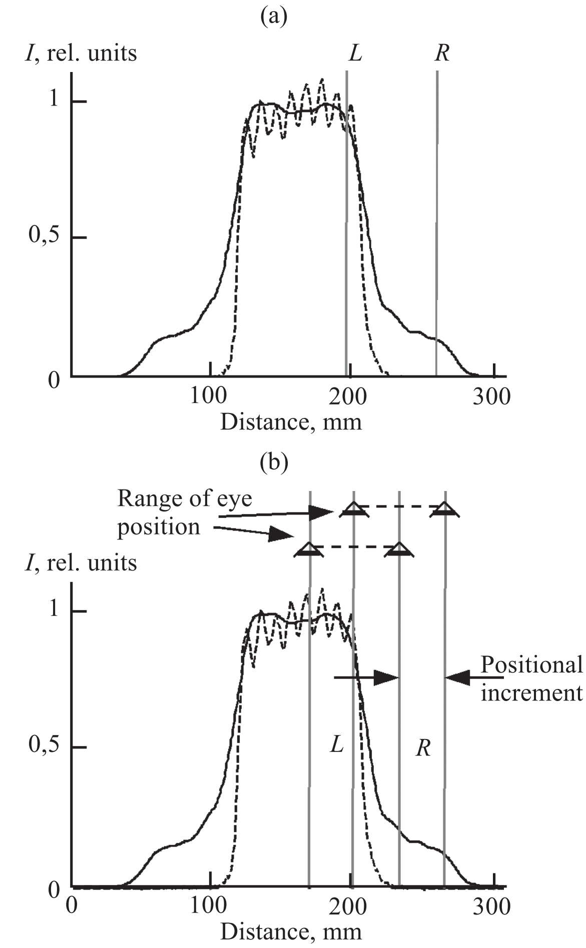


Fig. 5. Exit pupil intensity plots (the commentary is the texte).

sity profile of the exit pupil across the viewing field at 2 m from the screen position (but with the screen removed). The boundaries are relatively sharp. When light passes through the LCD, the continuous line gives the intensity profile. It can be seen that if one eye is located near the edge of the peak of the characteristic, the other eye, which is around 65 mm, away will still receive a considerable amount of light.

Conclusions

The display, whose principles are described, affords a viable solution to the difficult problem of producing multi-viewer 3DTV using currently available technology. The method described imposes the least demands on the amount of information displayed, as a minimum of two images are only required. In contrast, multi-view multi-image methods, where a series of images are presented across the width of the viewing field, give a reduced image resolution and also have large regions where 3D is not visible. Another advantage of our approach is that the key technologies of direct-view LCDs and white LEDs are progressing rapidly. Investigation by the authors has led them to the conclusion that a direct-view transmission display (as opposed to emissive) that uses the flexibility of light manipulation afforded by an effective two-dimensional matrix of illumination sources will enable a workable 3D television with a time to market of less than ten years. At the time of writing, LCDs of 55″ are available and white LEDs are becoming increasingly smaller, brighter and less expensive.

This first prototype built by DMU demonstrates the proof of principle of a multi-viewer two-image 3D display employing viewer tracking and spatial image multiplexing. It is proving extremely useful in identifying the areas where further research should be directed. Amongst these are: image brightness, light scattering caused by diffraction at the LCD, colour and brightness variation of the white LEDs and scattering within the array elements. All of these issues are solvable, and work is ongoing at DMU to produce an improved display, considerably closer to a production 3D television model.

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