2D/3D switchable displays

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ABSTRACT

A prerequisite for a wide market acceptance of 3D displays is the ability to switch between 3D and full resolution 2D. In this paper we present a robust and cost effective concept for an auto-stereoscopic switchable 2D/3D display. The display is based on an LCD panel, equipped with switchable LC-filled lenticular lenses. A demonstrator of this concept is made. We will discuss measurements and numerical simulations of the key optical characteristics of this display. The switching characteristics of LC-filled lenticular lenses are discussed and the overlap of the view distributions is introduced as a figure of merit for crosstalk. The 0.62 overlap in our present demonstrator design, gives an excellent 3D image quality, combined with a good depth impression.

INTRODUCTION

The realization of a 3D display for consumer applications is a long desired dream. Until recently, realization of a cost effective option for a consumer application was hampered by technological constraints and by the limited availability of 3D content. With the ongoing improvements in technology and with rapidly increasing processing power, the realization of a 3D display for consumer applications has come within reach.

In our opinion a viable 3D display concept should fulfill the following requirements:

1. The display should be auto-stereoscopic. It should allow freedom of movement for the viewer.

2. The display should be able to display uncompromised 2D content.

3. The 3D display technology should comply with mainstream technologies such as LCD and PDP.

The main display technologies fitting in this framework are multi-view LCDs and PDPs, equipped with either switchable parallax barriers or switchable lenticular lenses.

Multi-view auto-stereoscopic displays distinguish themselves from two-view displays by the motion parallax cue that is available. Several views are created and if the viewer moves to the left or the right, he will perceive different views. By placing the correct image information in those views, the viewer is able to look around objects.

Some general properties of 3D displays using barriers and lenticular lenses are described in literature (e.g. [1,2]). Switchable barriers can be made using conventional LC technology [1]. However, the transmission of such a display is roughly inversely proportional to the number of views.

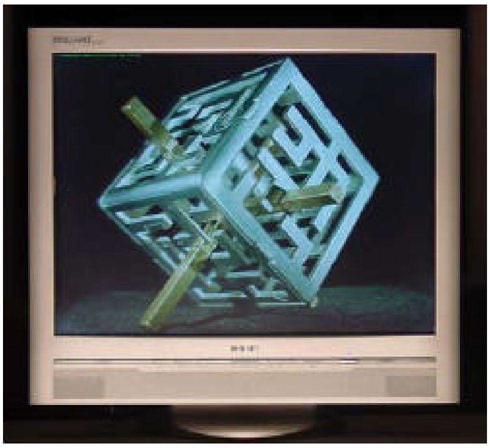

Figure 1 The 20.1” 2D/3D switchable display

Therefore, barrier displays either suffer from a poor brightness or have very few (e.g. two) views. The latter seriously hampers the available viewing zone and the viewing comfort. By using lenticular lenses a 3D display that combines a comfortable viewing zone with the full brightness of an LCD can be realized.

For switchable lenticulars, two principles have been proposed: active LC lenses, where the lens material itself is switchable [3] or passive birefringent lenses which have to be combined with a polarization switch [4].

Thus far, active LC filled lenticular lenses have received relatively little attention. In our opinion they form an attractive, robust and cost effective option for the realization of 2D/3D switchable display. We have implemented and optimized the active LC lens design and combined it with a standard LCD screen to form a 2D/3D display. A 20.1” demonstrator was presented at the IDW 2004 [5], see figure 1.

In this paper we discuss the design of 2D/3D switchable displays based on active LC lenses. We will focus on characterization of the key optical properties. The outline of this paper is as follows. In the first section we discuss the principle of 2D/3D switchable LCD's based on LC lenses. In the second section we present the characterization method of the display. Thereafter, we discuss some results of our measurements and compare these with our simulations. We will discuss the switching behaviour of our LC cell and in the last section we summarize our findings and draw some conclusions.

2D/3D Switchable Principle

Figure 2 shows the basic principle of an active LC filled lens. The lens consists of two plates coated with ITO. On the first plate a fixed negative lens structure is replicated using photo-polymerization. On both plates a poly-imide (PI) rubbing layer is applied to align the LC. The cell is filled with an LC of which the ordinary refractive index is matched with that of the replica.

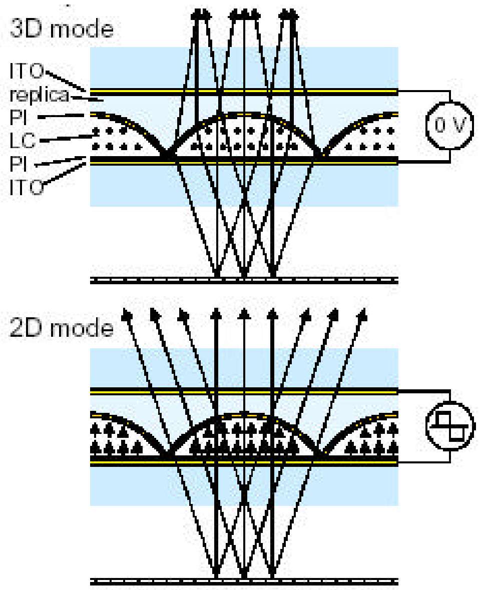

Figure 2 Principle of an active lenticular lens

At zero cell voltage, the extraordinary refractive index axis of the LC is aligned in the direction perpendicular to the plane of the drawing. If the light from the underlying LCD display is polarized perpendicularly to the plane of the drawing, it encounters an index change from high to low resulting in a positive lens-action.

If a sufficient voltage is applied over the cell, the axis of the LC is aligned parallel to the lens axis. Since the ordinary refractive index matches the refractive index of the replica layer, the lens is effectively switched off.

Figure 3 shows the design details of the demonstrator. A 9 views design according to [2] is used. The lenses are slanted under an angle of α=arctan(1/6). The lens pitch is 1.5 times the (RGB) pixel pitch p(disregarding a small view point correction). This particular combination has the advantage that the resolution penalty of a factor 9 is equally distributed over the horizontal and vertical direction [4]. As an example, figure 3 also shows the light distribution of view 5. Indeed the effective resolution has decreased by a factor of 3 in both directions. The perceived dotwidth equals the width of the lenticular lenses. The areas that are left blank contain information from the neighboring views that is not visible in this view.

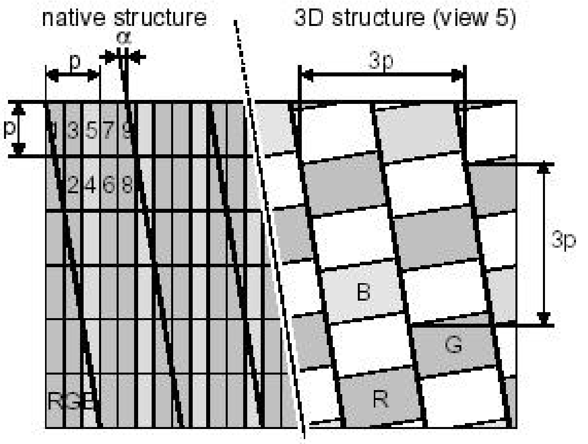

Figure 3 Layout of pixels and lenses

Display Characterisation

A key optical property of a 3D display, is the distribution of the views. To measure this distribution, a characterization setup has been built. This setup comprises a digital measurement camera and a mechanical rotation unit, which rotates the camera around the display. The rotation unit is placed on an X – Y translation stage, so that the center of rotation of the camera can be controlled with respect to the display. The angular resolution of the system is approximately 0.2 degrees.

Figure 4 shows the measured angular intensity distribution of the central view in 3D mode, for our 20“ switchable 2D/3D monitor with 1200x1600 RGB pixels of 85x255 µm.

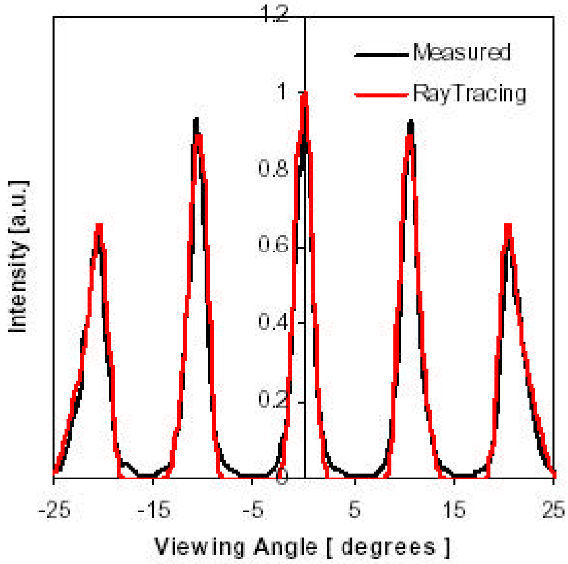

Figure 4 Measured and simulated view distribution

In order to validate the measured data, a numerical simulation by means of ray tracing has been performed, using a simulation tool described earlier [6]. The simulated view distribution is also shown in figure 4. The stack of elements used in this simulation is shown in figure 5. The LC material has been replaced by an isotropic material with the extraordinary index of refraction of the LC material.

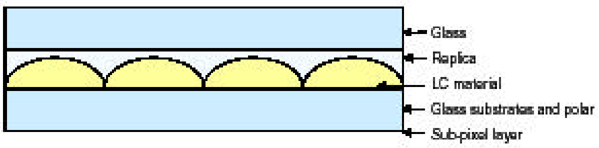

Figure 5 The stack of elements, used in the numerical ray tracing

We use an effective glass thickness including the polar of the LCD of 3.1 mm, with a lenticular design for a 9 view system with slant angle arctan(1/6).

The measured and the calculated view distribution are in good agreement, with respect to peak shape, height and position. However, the measured data show a small shoulder that is not present in the simulated data. We attribute this to scattering effect of the anti glare foil of the LCD panel.

An important characteristic of 3D displays is the view separation. This determines the amount of crosstalk and, hence, the disparity which can be created on a 3D display without blurring the image. As a figure of merit for the crosstalk we introduce the overlap between the neighboring views.

The overlap is given by :

$$O = \frac{\int F \cdot G}{\sqrt{\int G^2} \cdot \sqrt{\int F^2}}$$

where F and G are the intensity distributions of neighboring views.

In figure 6 the view distribution of two neighboring views is depicted, the crosstalk region is shaded in grey. The bottom graph shows the function F . G, which represents the crosstalk.

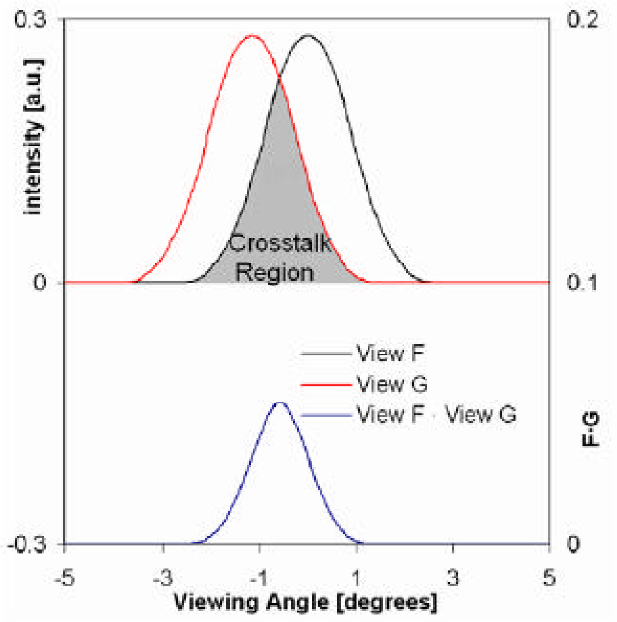

Figure 6 Overlap between two neighboring views

Figure 7 shows the overlap of the views as a function of the viewing angle. Both the measured and the calculated values are plotted. In this case the value of the x-axis is the value where the crosstalk product (F.G) reaches a maximum. Again the measurements and the calculations are in very good agreement. From the graph it is clear that the overlap has a minimum at a viewing angle of 0° and increases with increasing viewing angle. The increase of the overlap is attributed to aberrations (coma). At large viewing angles, the overlap approaches one.

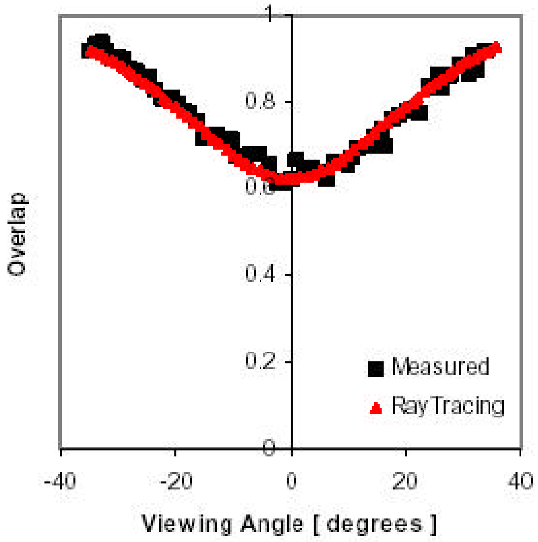

Figure 7 Overlap as function of the viewing angle

From the graph we learn, that for increasing viewing angles, the 3D effect will decrease and finally will disappear. The overlap can be decreased by further optimization of the lenticular design. The overlap between the central view and one of it's neighbouring views is 0.62 for the measured view distribution and 0.63 for the calculations. This overlap is sufficient for a good 3D image.

Another important property of the 2D/3D display is the view distribution in the 2D mode. To switch the LC lens in the 2D mode, a symmetrical square waveform of 500 Hz is applied to the LC lens. Figure 8 shows the view distribution of a switchable 2" 2D/3D display for a number of switching voltages. At a level of 12 V_{pp}, the changes of the orientation of the LC material become noticeable in the view distribution. This effect continues until 26 V_{pp}, when the lens is effectively switched off.

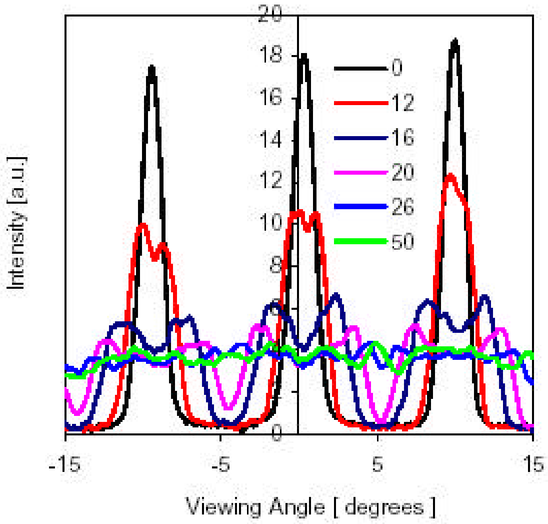

Figure 8 View distribution in 2D mode

A further increase to 50 V_{pp}, does not significantly change the view distribution.

In Figure 9 the view distribution of the central view is plotted in the 3D and the 2D mode. As a reference, the view distribution for the original display without lenticular is also plotted. The reference measurement shows a somewhat smoother view distribution, indicating a small remaining lens effect of the LC lens in the 2D mode. The impact of this residual lens effect on the 2D image quality is small. Moreover, this lens effect can be decreased, by optimizing the refractive indices of the replica layer or the LC material.

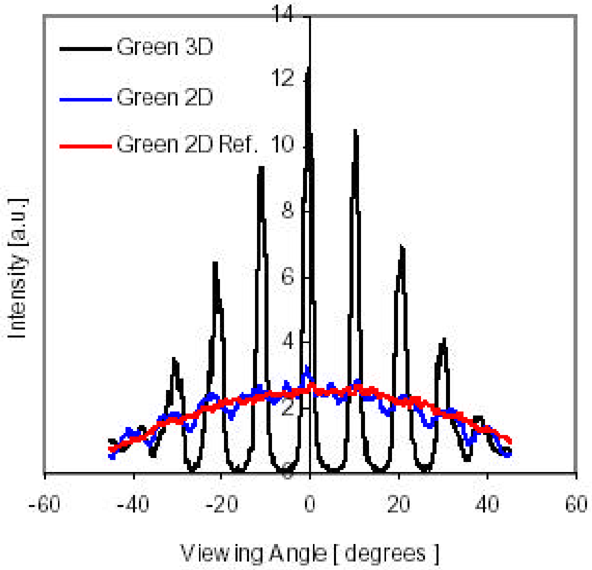

Figure 9 View distribution 2D/3D vs 2D

SUMMARY AND CONCLUSIONS

In this paper we discussed the key optical characteristics of 2D/3D switchable displays. Numerical and experimental results of these characteristics are in good agreement. We have introduced the overlap between the view distributions as a figure of merit for crosstalk. In our present design an overlap of 0.62 gives a good 3D performance. The LC lens effect can be switched off by applying a low frequency, low voltage signal to the lens. This results in a very good 2D image quality, which can be further optimized by adapting the refractive indices of the replica layer or the LC material.

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