An Autosteresoscopic 3D Display System Based on Prism Patterned Projection Screen

Wallen Mphepö, Yi-Pai Huang, Per Rudquist, and Han-Ping D. Shieh, *Fellow, IEEE*

***Abstract*—Using a 2-view Autostereoscopic 3D Projection display system, a radically designed projection screen film system coupled with a conventional projection display is herein presented and shown to produce a superior 3D effect than most current autostereoscopic and non-autostereo 3D display systems.**

***Index Terms*—Autostereoscopic, projection, screen, 3D.**

I. INTRODUCTION

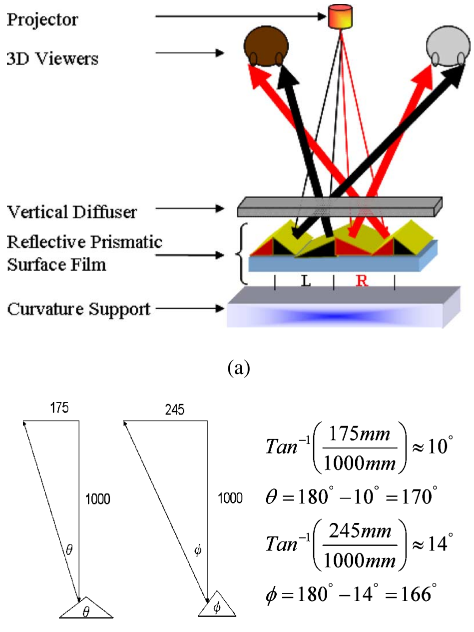
PRISM based 3D screens have been explored before to varying degrees of success and fabrication complexity[1], [6]. The herein proposed design's goals were specifically aimed at tackling the, until now, mutually exclusive properties of most parallax based autostereoscopic 3D displays i.e., staggeringly high display optical efficiency and drastically low levels of image crosstalk. By uniquely patterning a film stack onto a cylindrical projection screen so that the projected left and right images are reflected to their respective viewers locations without the need for barrier or lenticular lens, we were able to achieve a 0% image crosstalk [4] at $\sim$ 90% optical efficiency [4], [5] in the 3D viewing zones. Of which the viewing zones in this particular configuration are at the viewing distance 1150 ± 50 mm and 70 ± 10 mm side to side displacement for each pair of eye locations at the viewing distance.

II. BACKGROUND AND OBJECTIVE

The specific objective for the herein proposed display is to provide a significantly different 3D display system that simultaneously lowers crosstalk to unprecedented levels as low as 0% while keeping optical efficiency as high as 90% in the 3D viewing zones stated above. The method formulated herein takes advantage of mature technologies in projection displays and marrying them with a passive prism patterned projection screen design [3]. The prism patterned cylindrical projection screen's pattern then reflects the incident projected left and right images to multiple viewers' eyes within specific ranges of locations as in Fig. 1(a).

To illustrate, as shown in the Fig. 1(b), let:

- Viewing distance = 1000 mm
- Viewing zone for Left Eye & Right each = 70 mm
- Prism Angles θ and Φ



(a)

(b)

Fig. 1. (a) Illustration of our basic 3D solution concept where the red lines from the projector represent one right pixel falling onto the right reflective surface of the prism screen and reflected to the corresponding right eye locations of the viewers and similarly for the black lines representing the left pixel. (b). Example of the derivation of the prism angles where the vertical line represents the rays from the projector and the slanted lines the reflected rays from the reflecting prism surface. The horizontal line shows the distance from prism normal to reflected ray location at viewing zone.

For simplicity and illustration purposes of how prisms can be used to project rays to desired locations; in Fig. 1(b) the viewer's first eye is placed at 175 mm displacement to the left of a point normal to screen center and then the second eye location is then placed 70 mm farther from the first one at 245 mm. The difference between the two distances $245 \text{ mm} - 175 \text{ mm} = 70 \text{ mm}$ is thus used in this example as inter-ocular separation. Using a sample viewing distance of 1000 mm we can compute prism angles as in Fig. 1(b).

In order to get all the screen incident rays visible and not stray out of the viewing zones, the whole screen surface needs to be curved cylindrically so as to focus the screen peripheral pixels as in Figs. 2(b) and 4(a). The derivation of the curvature's X and Y coordinates is done by iteration and thus developed into a series of points that map the ideal cylindrical surface where the screen should be. Each new point on the cylindrical surface is computed based on the last previous points' locations as follows.

From Fig. 2(a) we get

$$\text{Tan}\,\frac{\delta}{2} = \frac{P}{2L} \tag{1}$$

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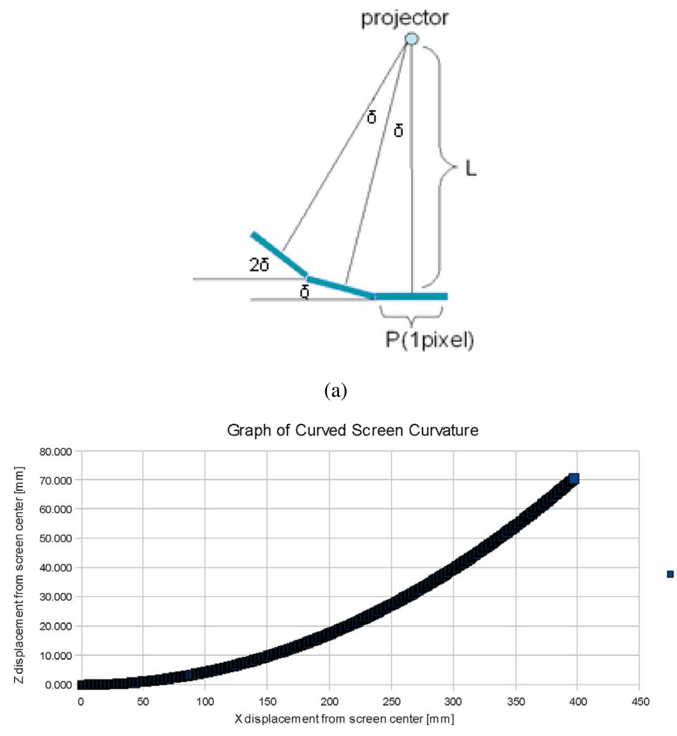


(a)

(b)

Fig. 2. (a). Projector location with relation to the curved prism screen's pixels' locations. (b). Derived mathematical iterative graph of the ideal cross section of the curved cylindrical screen surface structure showing the positive x symmetric half.

$$\begin{aligned} x_n = {} & \frac{P}{2} + P \bullet \cos[\delta] + P \bullet \cos[2\delta] \\ & + P \bullet \cos[3\delta] + \cdots + \frac{P}{2} \bullet \cos[n\delta] \end{aligned} \tag{2}$$

$$\begin{aligned} y_n = {} & \frac{P}{2} + P \bullet \sin[\delta] + P \bullet \sin[2\delta] \\ & + P \bullet \sin[3\delta] + \cdots + \frac{P}{2} \bullet \sin[n\delta]. \end{aligned} \tag{3}$$

where δ is the angle between pixel n and $n+1$ from the projector, and

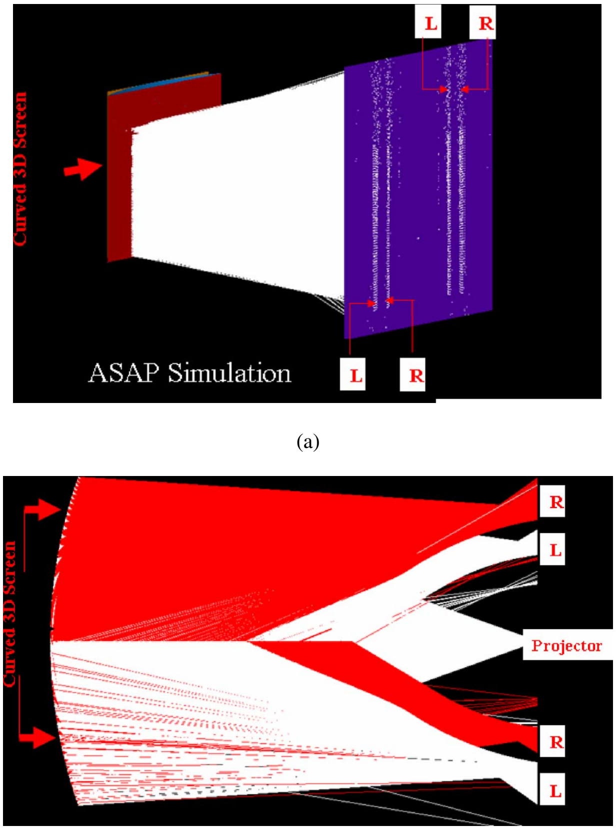
$$\begin{aligned} n &= 1, 2, 3, 4, \ldots, 512 \\ P(1 \text{ pixel}) &= 0.794 \text{ mm} \\ L &= 1150 \text{ mm}. \end{aligned}$$

III. Building and Simulating the Set Up

The basic prism concept as shown in Fig. 1(a) above was built in ASAP for simulations. The simulation results are shown in the Figs. 3(a), (b), and 4.

IV. Experiment and Results

To test the basic concept's ability to separate the left and right pixels as hypothesized with our proposed system, two large pixels one red for Left view and one green for Right view were vertically interlaced using freely available image interlacing software. The resulting interlaced image was then projected onto the prism patterned cylindrical screen using the above computed and simulated parameters. Photographs at the



(a)

(b)

Fig. 3. (a) An ASAP simulation's 3D perspective of the 166°–170° prism, vertical diffuser, 90% optical efficiency, 0% crosstalk, 1150 ± 50 mm. viewing distance. (b). An ASAP simulation's aerial perspective for the: 166°–170° prism, vertical diffuser , 90% optical efficiency, 0% crosstalk, 1150 ± 50 mm. viewing distance clearly showing the separation of the left and right viewing zones.

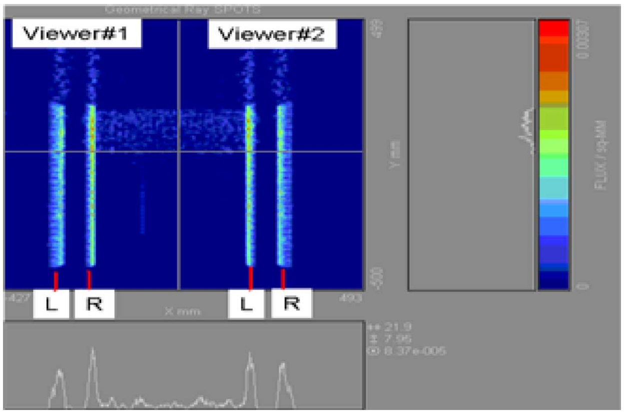


Fig. 4. Shows Intensity distribution for the: 166°–170° prism, vertical diffuser, 90% optical efficiency, 0% crosstalk, 1150 ± 50 mm..

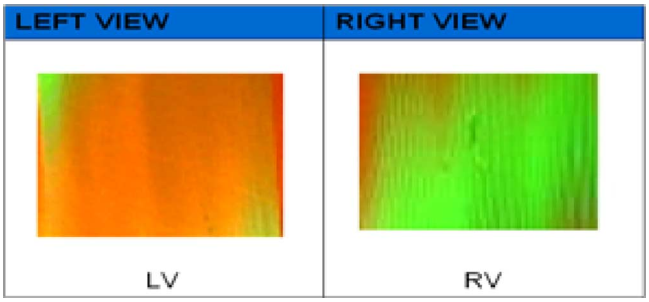


Fig. 5. Images of the viewing zones from singular viewing positions showing the clearly observable image crosstalk.

respective viewing locations were then taken to see the screen's effect [2], [4], [5].

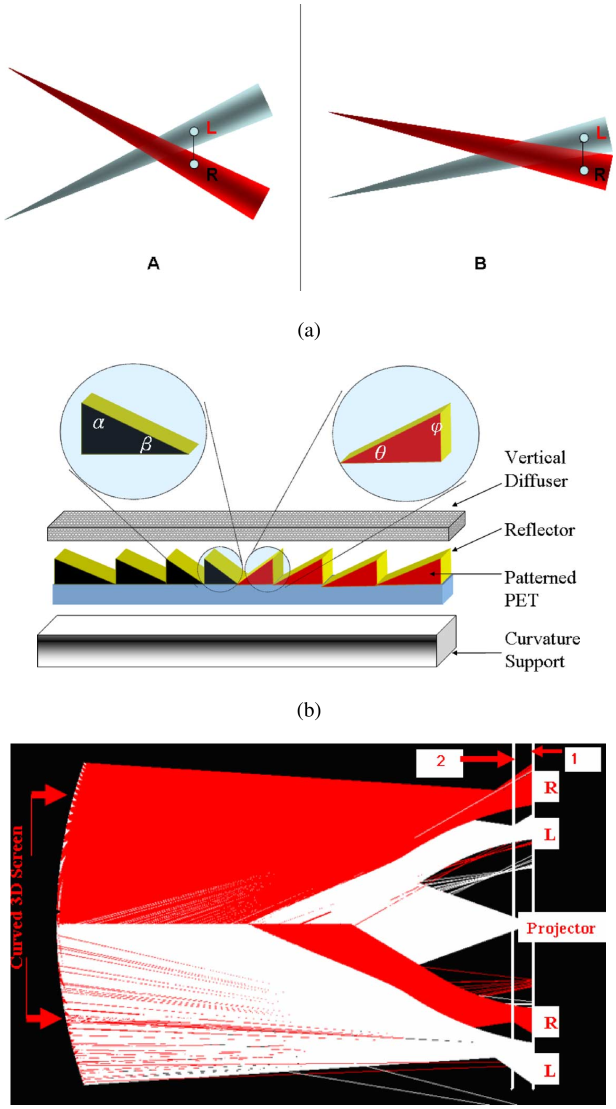
Initial results of the experiments showed an unexpected significant amount of crosstalk as seen in Fig. 5. However, by recomputing and reconfiguring the prism pairs we were able to increase the sharpness of the reflected rays' intersection as illustrated in part A of Fig. 6(a). This is possible because all the angles shown in Fig. 6(b) i.e., alpha, beta, theta and phi can be manipulated to change the characteristics of the reflected rays. Thus the angle of intersection of the left and right reflected rays can be increased to increase sharpness of separation for the same inter ocular distance LR in Fig. 6(a). This ultimately reduces crosstalk as in A. However, reducing the angle of intersection results in increased crosstalk, as shown in part B of Fig. 6(a). One of the possible reasons why increasing intersection angle reduces crosstalk is that the configuration as shown in A has a higher tolerance to surface machining errors on the cylindrical screen surface than configuration B since they are more distinctly separated.

In conjunction to the above, we also added extra conservative measures to further reduce crosstalk. The inter-ocular separation was also changed from 65 to 70 mm and we moved the viewing locations 50 mm closer to the screen to coincide with the maximum separation of Left/Right reflected rays' points lying on Line 2 marked in Fig. 6(c). This line of points is clearer in the simulation results than computations. Points lying on marked Line 1 are on the original computed viewing distance. Please see Fig. 3(b) for comparison. By moving eye locations to points of maximum Left/Right rays separation we reduce the amount of overlap between the Left and Right pixels, thus lowering the crosstalk. Viewing points along Line 2 in this configuration could be said to be lying on the *"sweet spot"* of the design.

Only after these above modifications was the crosstalk then virtually eliminated as in Fig. 7.

V. CONCLUSION

The overall effectiveness of the prism patterned screen to separate the left and right image pixels as a proof of concept has been presented. However, this alone or the fact that it is scalable for higher numbers of views does not make this configuration a great autostereoscopic 3D display system. What does is that it achieves 0% crosstalk in the 3D viewing zones, located at viewing distance 1150±50 mm and 70±10 mm side to side displacement in this particular case, at ~ 90% optical efficiency. This is in high contrast to all prior related technologies that always made it an almost text book standard given to assume that image crosstalk is inversely proportional to optical efficiency. Last but not least, increasing the number of views only lowers the resolution for each individual viewer by at most one half of the projection display's native resolution no matter how many



(a)

(b)

(c)

Fig. 6. (a). Exaggerated perspectives for illustration of how increasing the angle of intersection of the left and right reflected rays can increase the sharpness of reflected rays' separation for the same inter ocular distance LR which ultimately reduces crosstalk as in A. On the other hand reducing the angle of intersection results in increased crosstalk as in B. This is possibly because the configuration in A has higher tolerance to surface machining errors of the cylindrical screen surface than configuration B. (b) Prism structures for multiple viewers screen and the angular parameters that can be varied in order to change the characteristics of the reflected rays from the prisms' surfaces to increase or reduce the angle of intersection of the left and right rays, where PET stands for Polyethylene terephthalate (sometimes written poly(ethylene terephthalate)), commonly abbreviated PET. (c) An ASAP simulation's aerial perspective for the: 166°–170° prism, vertical diffuser, 100% optical efficiency, 0% crosstalk, 1150 ± 50 mm viewing distance showing the Maximum Left/Right rays separation line marked 2 and the original computed viewing distance line marked 1. By moving to the points of maximum left right rays' separation we reduce the amount of crosstalk.

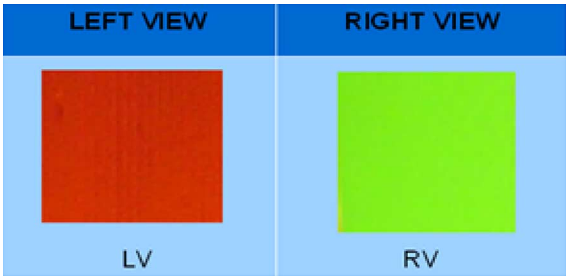


Fig. 7. Images of the viewing zones from singular viewing positions after screen modifications to correct.

views are included – and therein lies a possible paradigm shift. On the other hand, this system has been optimized for a 70-mm inter ocular separation as a proof of concept thus clearly more work needs to be done to optimize it for the ideal 65 mm apart from also improving stability and the size of the autostereoscopic 3D viewing zones to allow for more head movement. These issues, among others, are part of our future work on this project.

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