Journal of the Optical Society of Korea, Vol. 4, No. 1, March 2000, pp. 62-65

Multi-viewing zone screen for multiview 3-D displays

Jung-Young Son*, Vadim V. Smirnov* and, You-Seek Chun**

*Korea Institute of Science and Technology, Seoul 136-791, KOREA
**Department of Computer Science, Chung Nam University, Taejeon 305-764, KOREA

(Received December 17, 1999)

A new type of multi-viewing zone screen for multiview 3-D display is described. The screen is made by stacking a Fresnel lens and a reflective prism array plate. The screen performs both focusing and beam dividing functions and directs very narrow light beams to three viewing zones for three spectators. The results of experimental testing of the screen have demonstrated that current technology of Fresnel lens and prism grooves on PMMA(Ploymethyl Methacrylate) allows manufacture of a screen having a pixel size of about 1-2 mm. This size is reasonable enough for a screen with dimensions about 1m size. Optical qualities of Fresnel lenses and grooved prism arrays achieve an angular resolution for the screen of several angular minutes.

I. INTRODUCTION

Screens for non-glasses type multiview 3-D display based on the time sequential image projection have to form a sharp image of a striped LC shutter, which is located of the exit pupil of the imaging objective of the display system. [1,2] The image area is a viewing zone of the display system. A serious problem of these displays is creating many viewing zones for many viewers. Many viewing zones have been realized with a lens raster screen [2] and with a holographic screen, which combine parameters of several overlaid optical elements like focused lenses or spherical mirrors. [3,4] However these screens have many drawbacks. The first type of screen can really be applied only to stereo systems because of low resolution of its narrow cylindrical lenses. A holographic screen has a good resolution but there are many problems of manufacturing and usage for full color projection, which is defined by high spectral and angular selectivity of the screens. [5]

Another way of creating several viewing zones is using several projectors in parallel corresponding to the number of viewers. [6] However the method is also difficult to implement because the system becomes too complicated and expensive.

A new type of multi-viewing zone screen is described in the paper. [7] The screen consists of a focusing optical element (Fresnel lens) and a reflective (or transmission type) beam dividing prism plate. The screen allows the creation of many viewing zones according to the number of prism arrays.

The results of testing the first experimental sample of the screen are described below. Both elements of the screen were made from PMMA by diamond cutting. The reflective beam dividing prism plate has 3 systems of grooves and reflects the illumination beam to three viewing zones. The screen was developed for a new16-view TV display with sequential image projection and its optical parameters correspond to conditions of image projection and viewing in the display system.

II. DESCRIPTION OF DISPLAY

The principal optical scheme of the 16-view 3-D display system is shown in Fig. 1. The different view images displayed sequentially on the CRT screen are projected by the relay objective to the screen plane. A striped LC shutter is in the exit pupil plane of the objective and opens a corresponding striped window for definite image view on CRT screen. The ultimate reflective screen can be a focused mirror, for example. The screen has to make an image of the LC shutter, which is a viewing zone for a spectator. Its eyes can see different view images through the different parts of the viewing zone and perceives it as a 3-D image. It is obvious that the screen described can form only a single viewing zone.

The principal scheme of display with the screen having three viewing zones is depicted in Fig. 2 (top view). The optical projection part of the display is the same as before in Fig. 1 and is not shown. The screen consists of a Fresnel lens and a prism array beam splitting plate

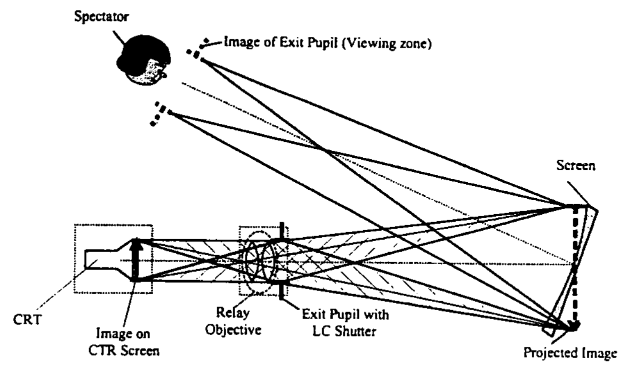

FIG. 1. The Basic Optical Configuration for 3-D Image Display.

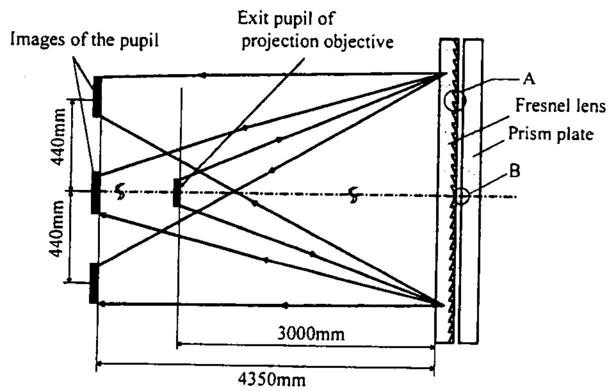

FIG. 2. Principal Optical Scheme of Display(top view).

with reflective coating on the prism surfaces. The projecting distance is 3m, both Fresnel lens and the prism plate make images of the LC shutter with 1.45 times magnification. Diameters of LC shutter and viewing zones are 140 and 203 mm respectively. Because the prism plate has three systems of grooves three viewers can watch the volume TV image with the screen.

Although the reflective type multi-viewing zone screen is considered, it is obvious that a screen can perform as a transmission type if there is not a reflective coating on the prism plate. Many screens with different numbers and directions of grooves can be made as well by using the same principle. [7] The structure of the screen's components is shown in detail in Fig. 3. Parts A and B depict the sections of the Fresnel lens and the prism plate, respectively. The grooves width for the Fresnel lens is 300μm an angle α_n of the grooves, wall slope is equal to the average virtual radius R=1756.2mm of the Fresnel lens surface. N=1, 2,.. are the numbers of the ring grooves of the Fresnel lens. We have to mention that the real profile of the lens has aspherical shape to minimize spherical aberration for definite condition of the lens usage.

The pitch of prism grooves is 600μm; the slope angles of the prism grooves are 0^o and $\pm 2^o 53'$. Those angles define 440mm distance between central and side

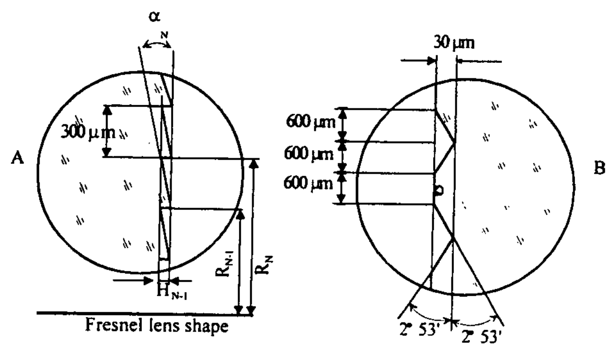

FIG. 3. Fresnel Lens(A) and Prism Plate Structures(B).

viewing zones.

The optical requirements of the screen were derived from the next considerations. Because the width of the each LC shutter's sub-zone is about 8mm, we can assume that the spatial and angular resolution of the screen has to be not worse than 1mm in the LC shutter plane, corresponding to 1.15 angular minute. Optical calculation shows that a Fresnel lens with needed resolution can be achieved. Concerning the optical quality of the prism arrays the flatness of the walls of grooves, which can be realized with current cutting equipment, is about 10 fringes within 100mm-aperture. [8] It corresponds to 1.1mm transversal aberration in the viewing plane. The tolerance $\pm$ 1 angular minute to the parallelism of the walls of the grooves can be kept during the manufacturing as well. [8] Summarizing the above, we proposed making the screen with spatial resolution about 2mm in the plane of the LC shutter image. It is corresponding to the screen's angular resolution of about 3 angular minutes.

Another specific problem of the periodical screen components relates to possible appearance of a moire pattern. [9] The problem exists because the optical beam after passing through the Fresnel lens has periodical spatial modulation from the Fresnel lens structure (bottoms of the lens grooves scatter the light and make narrow dark circular fringes in the screen plane). Then the beam has got two more spatial modulations when it is reflected by prism the plate and when it is going again through the Fresnel lens. Since the structures of the Fresnel lens and prism plate grooves are not similar, they do not make visible moire fringes. However the sequential modulation of the beam with the Fresnel lens structure can be visible as a fringe pattern overlying the image. Greater differences in the structures of the modulation will reduce the period and width of those parasitic fringes. The solution of the moire problem is to increase the distance between Fresnel lens and prism plate because in this case overlaid structures become more different.

Another drawback of the optical elements caused by cutting technology is a higher level of scattering, which reduces the contrast of images. That parameter of the screen has been specified in the experimental part of the work.

III. EXPERIMENTAL RESULTS OF THE SCREEN TESTING

An experimental sample of the screen with a cut ring shape (diameter 140mm × 100mm) was manufactured and tested. Focal distance of the lens is 2.6m, necessary for our multiview 3-D display. That kind of Fresnel lens is unusual, because the lens has a big focal distance and too small a tilt of groove walls to the surface of the lens substrate. The angular difference of angle α_n for the two next grooves was about 30 angular seconds; the experimentally reached tolerance of the angle was estimated as not worse than 5 angular seconds. The lens was made of PMMA with 300μm step of grooves.

The beam dividing prism plate was made in PMMA as well; its parameters were mentioned earlier. The relief prism surface has been aluminized to have reflectivity.

Both components of the screen were stacked with a small angle between them in vertical section. It allows removing the surface reflected beam from the central viewing zone. This problem can be easily solved in the future if antireflective coatings or a Fresnel lens on the substrate with a small verge is employed. The simplest way is making the Fresnel lens and the prism relief on opposite sides of a substrate or optically cementing the air gap between them.

The testing of the screen was done in an optical system similar to the 3-D display optical scheme of Fig. 2. The screen has 5 degrees angle tilt in sagittal (vertical) plane in respect to the optical axis of the projector. It is needed for vertically separating the level of viewing zones from the projector level. The white light source was used first instead of CRT. The screen was illuminated through relay objective with exit pupil diameter 140mm. Then three images of the pupil appear (see Fig. 4). Their diameters were 21 cm and distance to each other was 44cm, as expected. There were some differences in the brightness of images as shown in Fig. 4. These differences are related to a small difference in the width of the groove (left zone) and partially by the error in tilting angle of some grooves walls for the right viewing zone. Those problems can be eliminated in the future.

The resolving performance of the screen was estimated with an optical target, which simulated the LC shutter. The target was a ring shape mask with diameter 140mm. The 16 alternated transparent and opaque vertical stripes have 8mm widths of the stripes. The target was installed into the exit pupil plane of the relay objective.

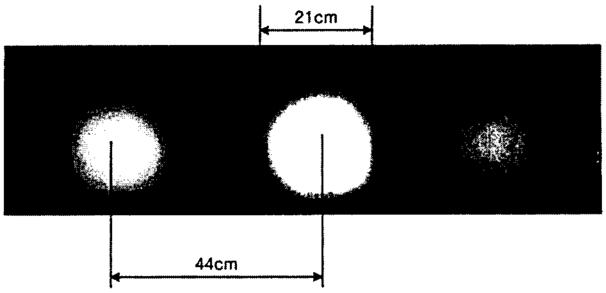

FIG. 4. Viewing zones of the screen.

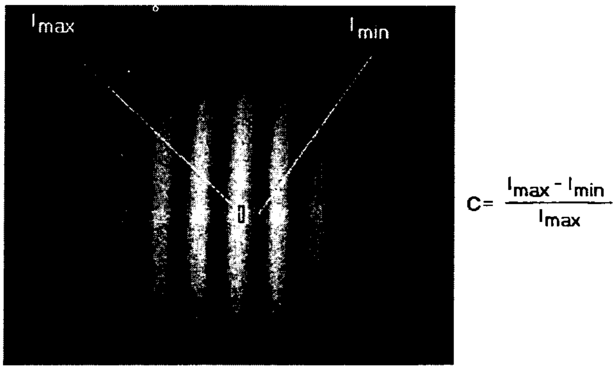

FIG. 5. Definition of a contrast C of image.

The resolution of the screen and a contrast of images of the optical target's stripes were measured. The resolution was estimated visually. The image of the target in the viewing zone can be viewed on a white paper screen installed in the plane, which was distanced 4.3m from the screen (see Fig. 5). The images of black and white stripes can be resolved reliably. This confirms sufficient resolution of the screen, although it defined by the total performances of the screen components and some aberrations of the Fresnel lens for tilted beams.

As it is known Fresnel lenses have a higher level of scattering compare to glass optics. The noise of the screen was estimated by a contrast C in images of the target's stripes. The photo receiver with a 2mm width of sensitive area was used for measuring the light intensity in the centers of white (I_{max}) and black (I_{min}) stripes in the image plane (see Fig. 5). The usual formula was used for the contract C definition:

$$C = I_{max} - I_{min}/I_{max}. \quad (1)$$

The experimentally defined C value is 65.5%, that is quite a reasonable value for most optical devices.

The Figs. 6 and 7 illustrate the quality of images on the screen. The photo in Fig. 6 was made of the center of a side-viewing zone of the screen.

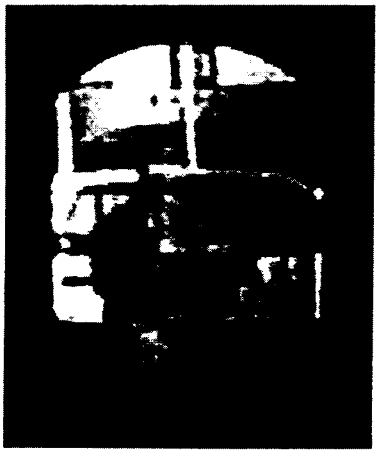

FIG. 6. Image on the screen with beam dividing prism plate.

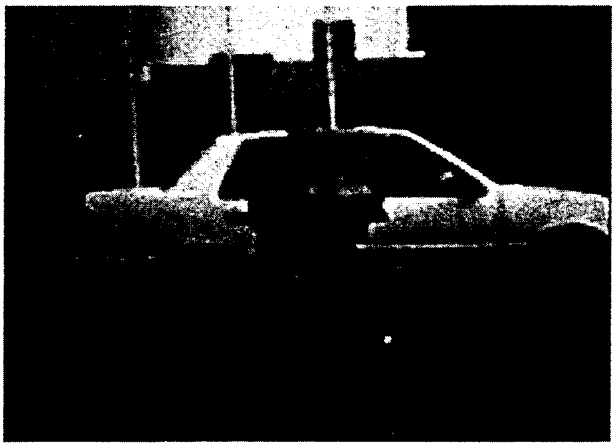

FIG. 7. Image on a white diffused screen.

We can see a full color image without serious visible distortion. The photo in Fig. 7 shows the same image when the multi-viewing zone screen was covered with a usual white diffused screen. The screen and image sizes are significantly larger in this case, but there are no visible differences in a quality of images in Figs. 6 and 7.

There is no visible color distortion, moire pattern or any diffraction effect related to the cutting structure of the screen's components.

The screen reveals good volume images when used for multiview 3-D projection.

IV. CONCLUSION

A new type of multi-viewing zone screen for multiview 3-D image display was manufactured firstly and experimentally tested. The screen consists of a Fresnel lens and a reflective beam dividing prism plate with three systems of prism grooves. Both components of the screen were made in PMMA by a cutting method. The screen has a high light efficiency, good enough resolution and reveals a good color performance, three viewers can see volume images simultaneously. The screens can be applied in many entertainment applications, large size 3-D simulating displays, different kind of visual indicators etc. Both reflective and transmission type screen can be made without any significant differences. Our experiment confirms that current technology for making Fresnel lens and prism grooves in PMMA allows manufacture of screens with size about 1m. We propose to make large size screens by mosaically combining smaller screens.

REFERENCES

[1] Jung-Young Son, Victor G. Komar, You-Seek Chun, Sergey Sabo, Victor Maiorov, L. Balasny, S. Belyaev, Michail Semin, M. Krutik, and Hyung-Wook Jeon, Proc. SPIE **3295**, 218 (1998).

[2] Jung-Young Son, Vadim V. Smirnov, Joo-Hwan Chun, Vladimir I. Bobrinev, Victor G. Komar, and You-Seek Chun, Proc. of Sixth International Symposium on Display Holography, Lake Forest College, Lake Forest, USA, (July 21-25, 1997) pp. 337-346.

[3] Vadim V. Smirnov, Jung-Young Son, and Vadim V. Novoselky, Proc. of the 3-rd Conference on Photonic Information Processing & International Workshop on 3-D Imaging Technology (Seoul, Korea, June, 1998).

[4] Takanori Okoshi, *Three-Dimensional Imaging Techniques* (Academic Press, New York, 1976).

[5] Jung-Young Son, Victor G. Komar, and Yong-Jin Choi, Proc. of Workshop on 3-D Display Technologies and Human Factor in the Third International Display Workshop (IDW'96), (Kobe, Japan, Novembe,r 1996) pp. 509-512.

[6] Seon-Ho Hwang, V.I.Bobrinev, Jung-Young Son, S.A.Shestak, and Hyung-Wook Jeon, Appl. Opt. **36**, 6605 (1997).

[7] Jung-Young Son, Vadim V. Smirnov, Jae-Soon Kim, You-Seek Chun, and Kyoung-Tae Kim, Viewing Zone Multiply with a Beam Dividing Prism, 3-D Conference (Tokyo, Japan, July, 1999) p.213.

[8] Putsha A.E. and S.I.Vavilov, State Optical Institute, Saint Petersburg, Russia (private discussion).

[9] D. Malacara, *Optical Shop Testing* (John Willy & Sons Inc., New York, 1992). p. 658.