Journal of the Optical Society of Korea, Vol. 4, No. 1, March 2000, pp. 58-61

Investigation of viewing zone parameters for full color transmission type holographic screens

Ji-eun Bahn, Sanghun Shin, Yong-jin Choi, V. I. Bobrinev, and Jung-young Son

Korea Institute of Science and Technology, Seoul 130-650, KOREA
E-mail : bahnji@kist.re.kr

(Received December 17, 1999)

Viewing zone shape and size perform a key role in creating viewing comfort for the viewer. The horizontal and vertical sizes of viewing zones, formed by a full color transmission type holographic screen with a stereoscopic image projection are investigated. The screens have been recorded as holograms of a narrow stripe shaped object with different width; to extend the vertical size of the viewing zone the holograms were exposed two times with the hologram shifting between exposures. The viewing zone parameters were measured as a function of the stripe width of the object and of the exit pupil size of projection optics for several holographic screens having the size of the 30 × 40 cm^2.

I. INTRODUCTION

In the perception of 3 dimensional (3-D) images, various cues offer 3-D information to a viewer. Among them, binocular parallax and motion parallax are most effective. This is why most stereoscopic and multiview 3-D image display systems use binocular parallax as their main perception mechanism [1]. To obtain binocular parallaxed images, stereoscopic display systems, which do not require wearing special eye-glasses to view the images, i.e., autostereoscopic display systems, should be able to form a viewing zone for each eye. The viewing zone is a small area in space, where the light from the left or right eye image is converged and displayed on a screen or a display device. The displayed image can be seen only if the viewer's eye is within the viewing zone [2].

A holographic screen is a holographic optical element which can be used to project high resolution full color 3-D images [4]. The screen is recorded as a hologram of the object in the form of a narrow elongated diffuser with the reference beam diverging from the point source , the object being coplanar with the reference beam point source. When the recorded screen is illuminated by a white-light-projector, each spectral component of the white light is diffracted to a specific direction by the screen and forms a real image of the diffuser. The image corresponding to each spectral component is shifted somewhat from other spectral component images.

If the length and position of the diffuser are properly designed, there exists a region where all different spectral images of the diffuser are partially overlapped and a full color viewing zone is formed, wherefrom, the viewer can see the color image displayed on the screen. Since two projectors are needed for a stereoscopic image, the viewing zone corresponding to each projector should be separated from the other by our inter-eye distance. If size of the viewing zone is too small and shape is unbalanced, very restricted movements are allowed for the viewer. If the viewing zone is too wide, two viewing zones can overlap, and consequently, only twin images appear instead of 3-D images [1,3]. Hence, size and shape of the viewing zone are essential parameters of the autostereoscopic display systems because they determine comfort of viewing.

In this paper, viewing zone parameters are investigated for full color holographic screens for different recording conditions.

II. THE SIZE OF VIEWING ZONE AND THE OBJECT

From the standpoint of viewer's comfort, viewing zone size needs to be as big as possible. But for the autostereoscopic display systems, the horizontal extension of each viewing zone is limited by the viewer's inter-eye distance, which is approximately 6.5 cm. Therefore the viewing zone's horizontal size can not exceed 6.5 cm.

A recording setup for a full color holographic screen

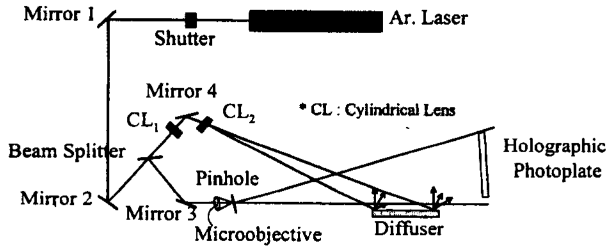


FIG. 1. The holographic screen recording setup.

is shown in Fig. 1. A laser beam is split into a reference beam and an object beam by a beam splitter. The reference beam is focused by a micro-objective on a pinhole to clean the beam and to form a diverging reference beam covering the entire surface of the photoplate, which is located a pre-determined distance from the beam.

For the case of the object beam, beam dimensions in vertical and horizontal directions on the diffuser surface are controlled independently by two cylindrical lenses, CL_1 and CL_2. Lens CL_1 has a horizontal axis and it is used to control the illuminated stripe width on the diffuser surface. Lens CL_2 has a vertical axis and it extends the object beam horizontally to illuminate the necessary length of the diffuser surface. An Ar-laser of 1.5-watt power and the PFG-01 holographic plates are used for recording 30 × 40 cm^2 size holographic screens with 4 different object beam widths of 5 mm, 1 cm, 2 cm and 3.5 cm. The measurements have been done to determine the viewing zone size and light leakage to the neighboring viewing zone as a function of the object beam width on the diffuser surface.

An experimental setup to measure the viewing zone size and the interference is presented in Fig. 2.

Both distances from the projector to screen and from the screen to the viewing zone were fixed to 130 cm. While projecting white light onto the screen by the projector with an objective exit pupil diameter of 2.8 cm, the intensity distribution in the viewing zone was measured. The width of the viewing zone is defined as the region where the intensity distribution is more than half of its maximum value near the center. Since the exit pupil of the projector has finite size instead of being a point source, the viewing zone will be formed as

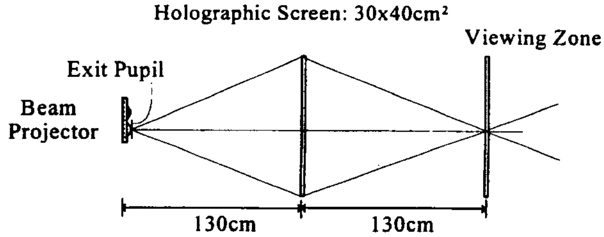


FIG. 2. Experimental setup.

TABLE 1. Viewing zone size in horizontal direction as a function of the object beam width. (Unit: cm)

Object beam width	0.5	1	2	3.5
Viewing zone with unmasked projector lens	3.6	5	5.5	7.5
Viewing zone with masked projector lens	1.5	2.6	3	5.5

the convolution of the real image of the object beam and the image of the exit pupil. Table 1 shows the results of the measurements.It is seen from Table 1 that the viewing zone size becomes larger as the object beam width increases. In the third line of the Table 1, the viewing zone size with a vertical slit type mask of 0.5 cm opening size is shown. Comparing the same column numbers in lines 2 and 3, it can be seen that the differences in two numbers are in between 2.0 and 2.5 cm. These values are comparable to the difference in the objective's exit pupil size, i.e., 2.3 cm.

In the human visual system, the inter-pupil distance between left and right eyes is approximately 6.5 cm. Hence, the viewing zone size in the horizontal direction cannot be more than 6.5 cm to avoid the overlapping of viewing zones corresponding to left and right eyes. The viewing zone of 7.5 cm size (last row in Table 1) is so wide that the viewing zones for left and right eyes overlap each other and as a result, ghost images can be seen through the screen. For the case of projecting white light from a point source like a Xe-short arc lamp to the holographic screen with 0.5 cm diffuser beam size, the viewing zone size becomes 0.7 cm. Fig. 3 shows a photograph of the viewing zone formed by the arc lamp.

Taking into account that the border of the viewing zone is not sharp, the experimental results quantitatively agree to the expected size of the viewing zone, i.e., the size given by the convolution of images of the object beam on the diffuser surface and the exit pupil. The light intensity at 6.5 cm away from the center of the viewing zone for the object beam sizes, as presented in Table 1 has been measured to estimate the degree of mutual influence of neighboring viewing zones. If the intensity at 6.5 cm is very small compared with that

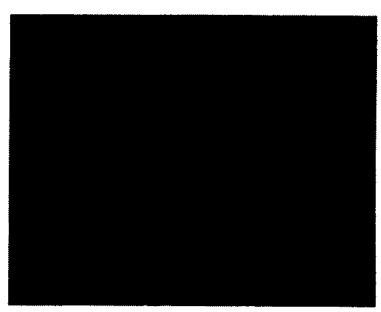


FIG. 3. Viewing zone formed by a white light point source (Xe short arc. lamp).

TABLE 2. The light intensity ratio at 6.5cm from the center of the viewing zone with 4 different object beam sizes. (Unit: cm)

Object beam size	0.5	1	2	3.5
Light intensity in the neighboring viewing zone (relative units)	0.038	0.074	0.0865	0.16

at the center of the viewing zone, the ghost image is invisible even if the viewing zones are touching each other. The measured intensities divided by the center intensity are listed in Table 2.

As shown in Table 2, the intensity ratio increases as the object beam width increases. The intensity at 6.5 cm is less than 10 % comparing with the intensity at the center up to 2 cm of the object beam size. For these cases, one cannot see ghost image, but for 3.5 cm case, ghost images appear when stereoscopic images are projected on the screen.

III. THE VIEWING ZONE SIZE OF DOUBLE-EXPOSED HOLOGRAPHIC SCREEN

Since viewers have different heights and changing posture can change their eye positions in the vertical direction, it is necessary to increase the viewing zone vertical size as much as possible. To extend the viewing zone in the vertical direction, the multi-exposure method has been practiced in our experiments. The recording setup for the holographic screen is the same as in Fig. 1. However, for the second exposure, the photoplate has been shifted a certain distance from the reference beam - diffuser axis after the first exposure as shown in Fig. 4.

The exposure time for both exposures is same. Total exposure time has been arranged so as to optimize the diffraction efficiency of holographic screen.

The expected viewing zone shape is depicted in Fig. 5. For the case of single exposure, only the central part will be a white light region as shown in Fig. 5(a). Forming a viewing zone in the double exposure case is analogous to the single exposure case, however, two white regions will overlap at the center of the viewing zone as shown in Fig. 5(b).

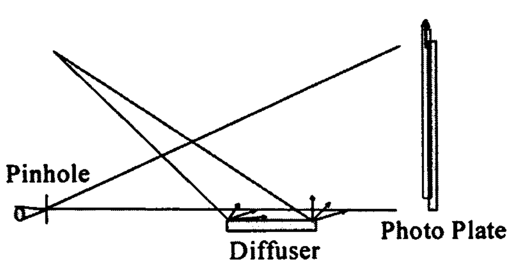


FIG. 4. Scheme of shifting photo plate for increasing the vertical size of viewing zone.

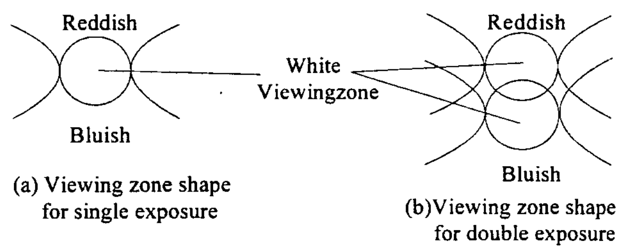
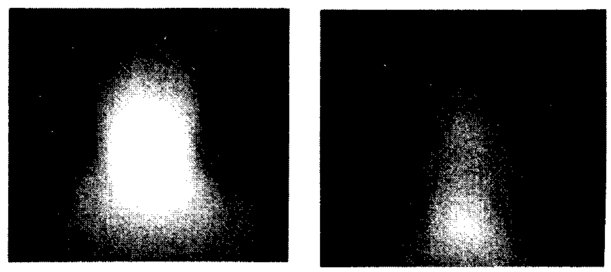


FIG. 5. Camparison of viewing zones for single and double exposed holographic screen.



(a) Single exposure of the hologram (b) 5cm shifting

FIG. 6. Photograph of viewing zone.

TABLE 3. Vertical size of viewing zone for 5 different shifting distances. (Unit: cm)

Hologram shift	0	1.5	2.5	3.5	5
Vertical size of viewing zone	6	6	7	10	13

If the shifting of the photoplate exceeds a certain value, there will be two separated viewing zones. For the estimation of the viewing zone sizes in vertical direction, holographic screens of size 30 $\times$ 40 cm^2 were recorded with 5 different shifting distances. The size of the object beam on the diffuser surface is chosen such that the horizontal sizes of the viewing zone keep approximately 6.5cm for all cases. The output pupil size of the projector's objective is kept to 2.8 cm. The vertical sizes of the viewing zone for these screens measured with the set-up in Fig. 2, are listed in Table 3.

As shown in Table 3, the vertical size of viewing zone increases as the shifting increases, and it extends more than 10 cm, however, when the shifting exceeds 3.5 cm, the viewing zone is splitting into two zones. The split viewing zone is clearly seen when the shifting is 5 cm. This is shown in Fig. 6(b). Fig. 6(a) is a viewing zone for the single exposure case, i.e. no shifting case.

IV. CONCLUSION

The viewing zone size of the holographic screen can be changed in order to improve the viewer's comfort when he/she is watching the stereoscopic image. A wider viewing zone enables the viewers to move their heads to some extent and additionally it can eliminate image darkening in multiview projection systems based on many projectors. The vertical size of the viewing zone can be increased to more than 10 cm without any reduction of picture quality or deterioration of image by employing a double-exposure method.

To optimize the size and shape of the viewing zone, and to offer viewing comfort to viewers, many parameters and factors related to human vision should be studied carefully.

REFERENCES

[1] N. A. Dodgson, App. Opt. **35**, 1705 (1996).
[2] John P. W., Simon Rushton, Mark Mon-Williams, Vision Research **35**, 2731 (1995).
[3] A. M. Ariyaeeinia, Image Communication **13**, 201 (1998).
[4] V. I. Bobrinev, J. Y. Son, S. A. Shestak, and H. W. Jeon, The International Symposium on Advanced Imaging and Network Technology (Berlin, FR Germany, October, 1996).
[5] V. I. Bobrinev, J. Y. Son, S. A. Shestak, S. H. Hwang, and H. W. Jeon, App. Opt. **36**, 6605 (1997).