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The Experimental Investigations of the Big Size Holographic Screen in the Autostereoscopic Displays

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Results of an experimental study of possible ways to extend the capabilities of a big size transmission type holographic screen are presented. Different approaches to the problem of making a big size screen have been considered and tested experimentally. Up to 60 × 80 cm^2 screens have been recorded on a single photographic plate VRP-M. By attaching a mirror behind the screen, the reflection mode of operation has been obtained. In this arrangement some additional peculiarities appear in the screen, which can be used to extend the screen capabilities. The first possibility is to increase the screen size by mosaicking the subscreens in the reflection mode of operation. Screens of 120 × 80 cm^2 and 180 × 40 cm^2 have been obtained by proper alignment of 60 × 40 cm^2 subscreens. The second possibility is to move the viewing zone by rotation of the screen together with the mirror and thereby realize by the eye-tracking capability. Methods of increasing vertical size of the viewing zone have been considered. Along with the multi-exposure method, which was considered in previous papers, addition of the vertical diffuser with the optimized scattering angle has been tested experimentally. The vertical size of the viewing zone has been increased by up to 10−15 cm. Another method consists of usage of a diffraction grating with vertical dispersion to solve the same problem.

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I. INTRODUCTION

It was shown in our previous papers [5] that high quality color stereoscopic images can be displayed by means of an auto-stereoscopic display with a specially designed holographic screen. The screen is produced as a hologram of a narrow elongated diffuser, the diffuser length and the reference beam point source being disposed on the same straight line. When the screen is illuminated by a white-light projector, each spectral component of the incident light produces a real image of the diffuser. If the diffuser size and position are properly designed, the different color diffuser images are partially overlapped and the overlapping zone can be considered as the viewing zone, wherefrom the viewer can see the full color displayed image on the screen.

Recording of big size screens is a serious problem, because the screen aberrations become more visible and additionally the exposure time for screen recording becomes too big, as it should be proportional to the screen area.

A autostereoscopic display systems have a serious common drawback because the viewing zones are spatially fixed in front of the display. As a result, viewers do not have much freedom of movement when watching the stereoscopic images. To relax this problem an eye-tracking system can be used in the display to move the viewing zones according to the viewer's movement. Here we consider two ways of improving holographic screen capabilities: increasing the screen size and realizing the eyetracking capability by means of viewing zone movement. An additional problem of holographic screens is small vertical size of the viewing zone and as a result very serious confinement of the viewer's position when watching the image. Some experiments were done to extend the vertical size of the viewing zone.

Previously we described the multi-exposure method of increasing the vertical size of viewing zone. Here two new methods are described. The first consists of combining the screen with the holographic vertical diffuser. The second is use of a phase diffraction grating with low spatial frequency instead of a diffuser to make the scattering angle more definite. Both techniques have been realized experimentally with the extension

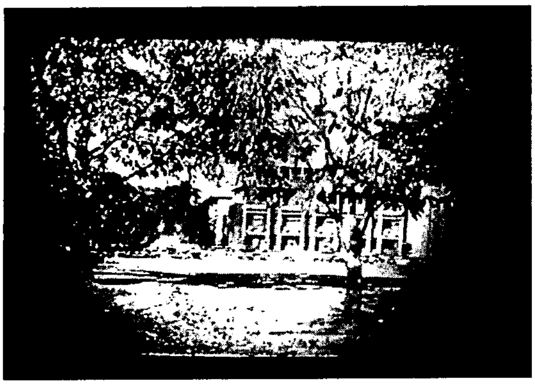


FIG. 1. Image on the screen of 60 × 80 cm^2.

of the vertical size of the viewing zone by up to 15–20 cm.

II. RECORDING OF THE 1-M SIZE SCREENS

To record a holographic screen with 1-m diagonal size the recording setup has been used as described in Ref. [1]. The distance from the point source of the reference beam to the hologram was 3 m. The diffuser was made of ground glass, front covered by an aluminum layer. Diffuser length was 50 cm, and it was 70 cm distant from the hologram. The screens were recorded on holographic photoplates VRP-M (Slavich, Russia). With an Ar-laser (λ = 488 nm) of 1 watt power the exposure time was 2–3 sec. The image projected on the screen is shown in the Fig. 1, with distance from projector to screen of 2.5 m and the same distance from screen to viewer.

III. THE REFLECTION MODE OF OPERATION OF THE TRANSMISSION TYPE HOLOGRAPHIC SCREEN

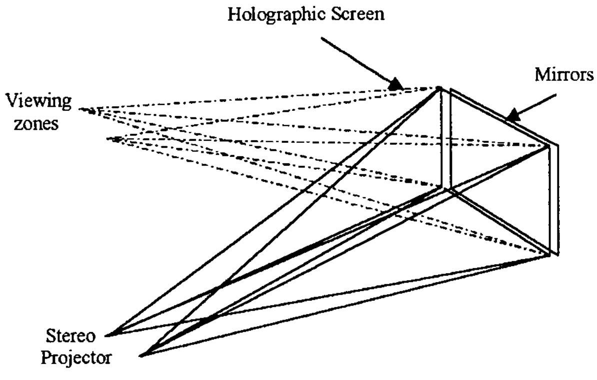


FIG. 2. The reflection mode operation of the screen.

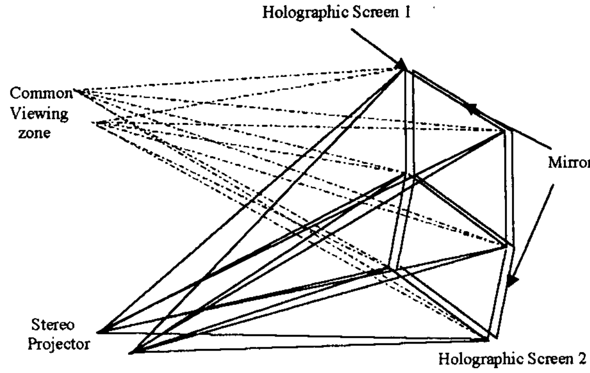


FIG. 3. The big size screen of two subscreens.

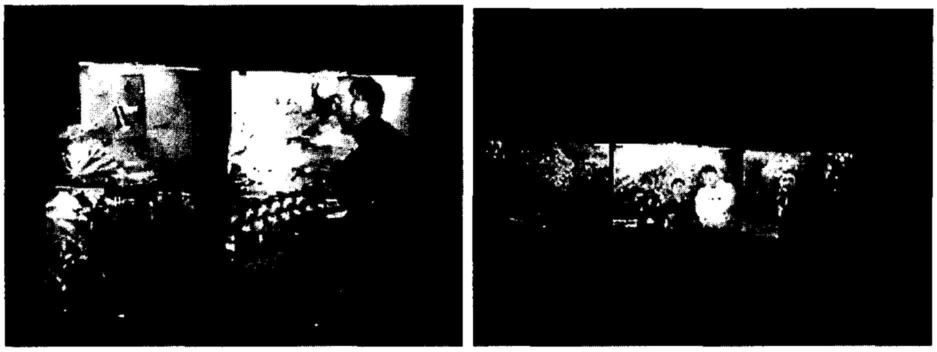
The transmission type holographic screen can be transformed into a reflection type screen by attaching a plane mirror to the backside of the screen. In this case, the diffracted light is reflected from the mirror and the viewing zone is formed on the same side of the screen as the projector, as is shown in the Fig. 2. The viewing zone position in the described display system can be controlled by rotation of the mirror-attached screen.

The viewing zone shifting by rotating the mirror-attached screen makes it possible to extend the holographic screen capabilities.

IV. MAKING THE BIG SIZE SCREENS BY MOSAICKING OF THE SUBSCREENS

To make the big size screen by mosaicking the smaller ones, it is necessary to adjust the subscreens in such a way that their viewing zones coincide, as it is shown in Fig. 3 for the case of two screens.

In an analogous way the additional screens can be added in the horizontal direction and screens from 2×2 subscreens or 3×3 and more subscreens can be made. It is very attractive that all subscreens can be recorded in the same setup without any additional readjustment. In the experiments we made the screen of 120 × 80 cm^2 from 4 subscreens of 40 × 60 cm^2 and 180 × 40 cm^2 from 3 subscreens disposed horizontally. The projection distance was approximately 3 m. In Figs. 4a and 4b the projected images are shown on the composite screens. The dark gaps between subscreens appear because each subscreen has been mounted on its own support and the distance between the subscreen edges was about 5 mm. It is



(a) (b)

FIG. 4. Image on the screen with 4 subscreens (a) and 3 subscreens (b).

possible to diminish the gap width by appropriate design of the supports and by cutting the subscreens' edges. It is necessary to point out that the viewing zone extension, especially in depth, is diminished as a result of the screen angle aperture increase.

V. THE EYE-TRACKING CAPABILITY OF THE HOLOGRAPHIC SCREEN IN THE REFLECTION MODE OF OPERATION

A disadvantage of autostereoscopic displays is the fixed position of the viewing zones. As a result the viewer has to be almost motionless when watching the stereoscopic image. To overcome this inconvenience an eye-tracking system can be used in such systems.

Different approaches can be applied to move the viewing zone [2–4]. The most straightforward approach is rotation of the whole display system, but this is too crude and usually it cannot be realized in practice. Another way in the projection type displays is movement of the projector exit pupil. Because the viewing zone is the image of the projector exit pupil, it is moved accordingly. Usually the necessary projector displacement is approximately equal to the viewer's displacement. In the displays with parallax-barrier or lenticular plates the viewing zones can be shifted by changing the plate position relative to the projected image.

In our experiments the displayed image quality on the transmission type holographic screen wasn't deteriorated substantially when the illuminating direction to the screen of the projector is changed approximately ± 10 degrees from the normal. The viewing zone is shifted at the same angle as the projector. Therefore by shifting the projector properly, it is possible to supply the display with eye-tracking capability. When the holographic screen is used in the reflection mode of operation, the viewing zone can be moved by rotating the screen with the mirror. The viewing zone displacement angle in this case is two times bigger than the screen rotation angle. If the screen together with the mirror is rotated ± 10 degree, the reflected image of the viewing zone will be shifted ± 20 degrees.

The experiments have been performed with 30 cm $\times$ 40 cm and 40 cm $\times$ 60 cm screens. No serious image deterioration has been observed when the reflected viewing zones have been deflected from the central position up to ± 35 degrees. The image on the 40 cm $\times$ 60 cm screen has been displayed by the stereo-projector from distance of 170 cm, so the allowed viewing zones' displacement was more than 1m from the central position. Additional experiments have shown that a good quality image can be displayed also if the screen is rotated by some angle in the vertical direction. The image deterioration is admissible if the vertical displacement of the viewing zones is up to ± 70 cm. The results for the 30 cm $\times$ 40 cm screen are similar. In Figs. 5 and 6 the images on the screen of 40 cm $\times$ 60 cm are shown. In Fig. 5, the image is shown as seen near the central screen position; in Fig. 6 the same image is shown as seen when the viewing zone is shifted horizontally 1 m from the central position.

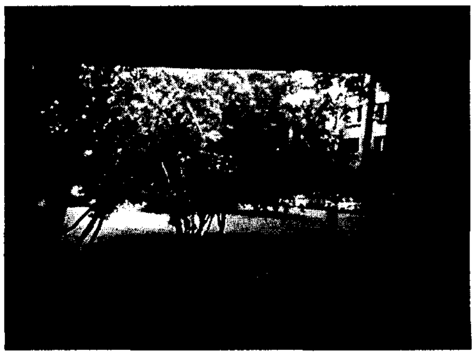


FIG. 5. The image on the screen in the central position.

FIG. 6. The image on the screen in the shifted position.

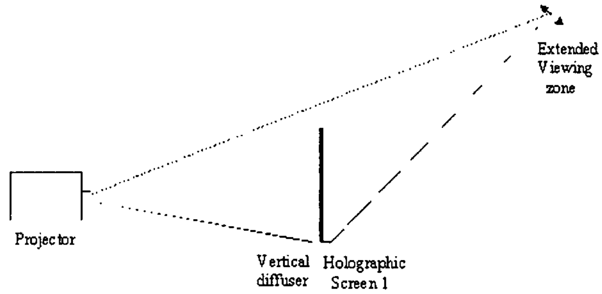


FIG. 7. Viewing zone extention by vertical diffuser.

To provide an image displacement angle of 35° it is necessary to rotate the screen and mirror together by 17.5°. With screen size of 40 cm × 60 cm the screen edge displacement is only 9.5 cm. For more real viewer head movements up to 50 cm, the necessary rotation angle of the viewing zone is 16° and the screen edge displacement will be not more than 4.5 cm.

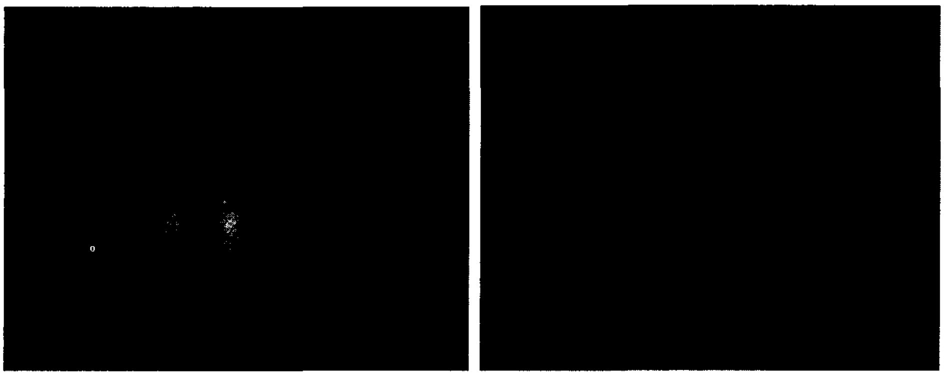
Therefore, big enough viewing zone displacements are possible by placing the mirror-attached screen together with the mirror on a rotating table. Addition of an eye-tracking system with a motor for screen rotation is a simple way to obtain a stereoscopic display with eye-tracking capability.

It is necessary to point out that the emulsion side of the holographic screen can be attached to the mirror. Therefore the described method additionally provides emulsion protection from mechanical damage or air pollution.

VI. INCREASE OF THE VERTICAL SIZE OF THE VIEWING ZONE

To increase vertical size of the viewing zone vertical diffuser, attached to the screen, has been used, as shown in Fig. 7. We made the diffuser from a photograph of the speckle pattern arising from ground glass illuminated by a narrow stripe of laser light.

The laser beam is extended in the horizontal plane by a cylindrical lens with a vertical axis. A second cylindrical lens with a horizontal axis is used to focus the light stripe on the ground glass surface, so that a thin horizontal line is illuminated. The scattered laser light pattern consists of vertical speckles with random horizontal sizes. After photoplate development and bleaching, each speckle can be considered as a tiny cylindrical lens with random focal distance. The photoplate as a whole is now a mono-directional diffuser. The scattering angle of the diffuser is defined by the spatial spectrum of the speckle pattern recorded on the photoplate. It is proportional to the length of the laser light line l on the ground glass and inversely proportional to the distance from ground glass to the photoplate H in the course of diffuser recording. The scattering angle can be approximately defined as $2l\lambda/H\lambda_r$, where λ is the projector light wavelength and λ_r is the diffuser recording laser wavelength. The appropriate scattering angle was obtained when the ground glass was illuminated by a light line of 3 cm length with the distance from ground glass to the photoplate of 1m.



(a) (b)

FIG. 8. The screen's viewing zones (a) and the viewing zones extention with grating (b).

The viewing zone vertical size was increased by up to 10−15 cm. The holographic screens and diffusers were recorded on a PFG-01 photoplates with an Ar-laser of 488 nm wavelength. Another way to extend the viewing zone height is to use a diffraction grating instead of a vertical diffuser. The grating period should be such that the diffracted beam is deflected from the zero-order at a distance approximately equal to the viewing zoneheight. It means that the viewer should see the diffracted image of the projector exit pupil being abutted to the zero order image. Because of nonlinearity of the photoplate, second and higher orders can be seen. Better results can be obtained if all orders higher than 2 are suppressed. In Figs. 8a and 8b the viewing zones are shown for the screen alone and with grating. The gratings have been recorded in the same photoplate, as screen itself. The photoplate processing was the same as for the diffuser. The vertical size of the viewing zone has been increased by up to 15−20 cm.

VII. CONCLUSION

The results of the experimental investigations of big size holographic screens are presented. Full color screens up to 1m diagonal have been recorded on a single photoplate. Different screen facilities have been disclosed including mosaicking of the screens to increase the total screen size and a possible way to realize eye tracking in the reflection mode of operation. Different methods to increase the vertical size viewing zone have been proposed and tested experimentally.

In the course of further investigations it is proposed to pay more attention to screen durability, as some screens become darkish after some time because of the residual photosensitivity of the bleached photoplates.

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