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A novel illumination system design for application in the integrated screen 3D display

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Abstract

A mini-projector prototype employing a LED light source, a nontelecentric structure, and an LCOS panel for application in the integrated 3D display was fabricated. A seamless image was obtained by tilting an array of mini-projectors. Seamless quality was created by the excellent uniformity of the projection intensity on the mini-projector's screen, which was simulated as 98.34%. Great uniformity can be realized by optimizing the design of the light source and the optics configuration, which is the key to such realization.

Keywords: illumination system, mini-projector, 3D display, integrated screen

1. Introduction

The 3D display has been well received as an indispensable part of the growing display technology. In recent years, the 3D display technology has developed rapidly because of the advancement in 3D digital technology, optical projection technology, and illumination design. The illumination system design for improving the display uniformity has emerged as an issue in the integrated-3D-display technology. In the past, the 3D display system mainly utilized the configuration of a single projector, and the image uniformity was degraded as the screen size increased. This drawback can be avoided by reducing the single projection size and by increasing the total area by connecting several mini-projectors, as shown in Fig. 1.

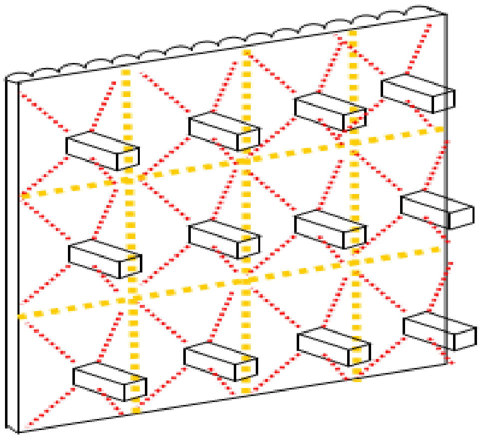

Fig. 1. Diagram of a 3D image array.

2. Experiment

There are various imaging elements in a projection system, and the design of such a system can vary much. In general, a projection system includes components, such as a LED light source, a Rod, illumination lenses, a polarizer, a panel, projection lenses, and a screen. Therefore, carefully choosing each element to optimize the brightness uniformity and the projection efficiency is an essential and elaborate process. In this study, the specifications of the components were determined through theoretical calculation and experimental verification, and are shown in Table 1.

The system design is divided into two main parts, the light source part and the optics configuration for maximizing the performance of the projector, each of which is described in detail in the following subsections.

2.1 Light source

A white-light LED is well suited as a light source in a

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Table 1. Component specifications

Rod	3×4×5 mm^3
Paraxial F-number	3.5
Image height	8.25
Magnification	-3.3
Exit pupil position	60 mm in front of the panel
Total length	<85 mm
Imaging components	0.59” LCOS panel

projection system due to its broad emission spectrum. The light source that is used in the mini-projector is a LE_W_E3A LED with a luminous intensity within the range of 280~820 lumens. A collector in the LED is usually employed to increase the light-gathering efficiency, and the LED light is actually irradiating on a hemisphere and not in all directions. The LED is then placed close to the Rod to minimize the loss of light. The LED light enters the Rod, reflects several times inside the Rod, and, as a consequence, has a uniform illumination output from the Rod. The dimensions of the Rod that were applied in this study were 3×4×10 mm, the inner wall was plated with Ag, and the reflectivity was about 97~98%. The uniformity of the beam energy distribution was significantly enhanced after the light passed the Rod, as displayed in Fig. 2.

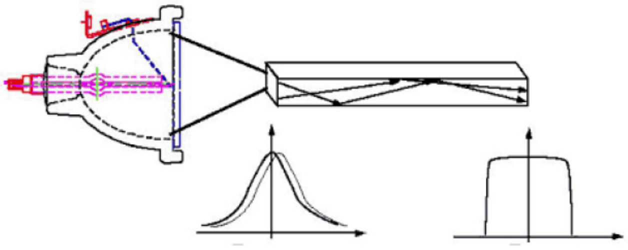

Fig. 2. Distribution of the original beam energy and its output from the Rod.

2.2 Illumination lenses design

Light is emitted from the LED, travels through the Rod as well as the illumination lenses, and finally focuses on the panel. The layout of this part is shown in Fig. 3, and the illumination F/# is set at 3.5 to optimize the light collection. A 0.59” LCOS panel (14.986mm) is used in this system, which has an RGB color filter on top of each pixel. With the known cross-sectional area of the Rod (3×4 mm^2), the etendue estimation can be obtained using equations (1) and (2).

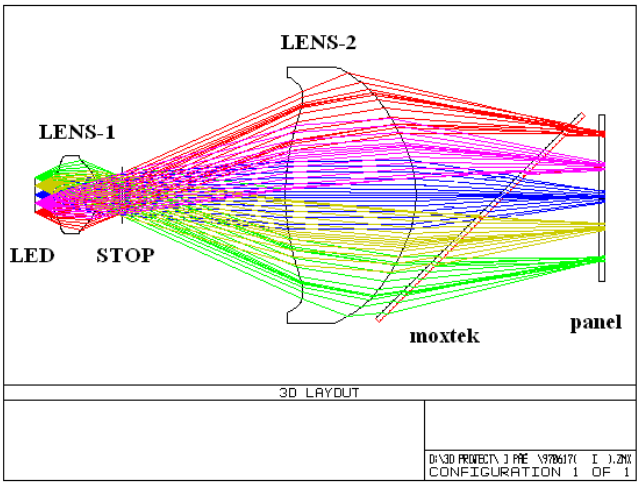

Fig. 3. Layout of the illumination lenses.

$$E_{Panel} = A_{panel} \times \Omega_{panel} = \frac{\pi A}{4(F/\#)^2} = \pi \times \left(\frac{14.986}{2}\right)^2 \times \frac{1}{4 \times (3.5)^2} \quad (1)$$

$$E_{Rod} = A_{Rod} \times \Omega_{Rod} = \pi \times \left(\frac{5}{2}\right)^2 \times \sin\theta \,, \quad (2)$$

where E_{panel} is the etendue of the panel, E_{Rod} the etendue of the Rod, A_{panel} the cross-section area of the panel, A_{Rod} the cross-section area of the Rod, Ω_{panel} the solid angle of the panel, A_{Rod} the solid angle of the Rod, and θ a half angle of the output light. The Rod size was then determined to be 3×4 mm.

The angle (Ω_{Rod}) for capturing the light was calculated to be 25.35˚ from equations (1) and (2). The maximum object height was limited to half the Rod diagonal, and the maximum image height to half the panel diagonal. The maximum object and image height in this case were 2.5 and 7.493 mm, respectively. The projected area had to be larger than the panel, and the image height input in the ZEMAX merit function was 8.25 mm. Two aspherical lenses, lens1 and lens2 (illumination lenses), as shown in Fig. 3, were applied to produce a uniform projection on the panel. Illumination lenses made of PMMA material were chosen due to their transparency to visible light, resistance to humidity, and hardness. Following the two aspherical lenses is a polarizing film PBS02 (moxtek) tilting at 45˚. The polarizing film polarizes the incoming light to enhance the contrast. Finally, a uniform projection with a high contrast can be obtained through the design efforts.

The exit pupil position was located 60 mm in front of the panel, and the length from the LED to the panel was set at 85 mm. The projection lenses, capturing the reflected light from the panel and then the moxtek, were adjusted accordingly to sharpen the projected images on the screen. The complete framework of the projection system is shown in Fig. 4.

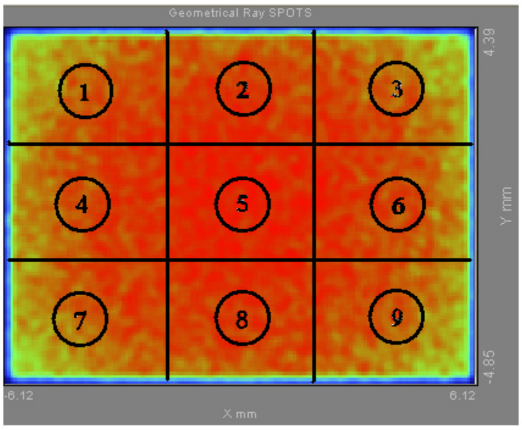

Fig. 4. Simulated illumination distribution on the panel.

3. Results and Discussion

A simulation of the projection energy distribution on the panel based on the layout in Fig. 3 and the specifications of the components was performed, and the results are shown in Fig. 5. The panel was divided into nine equal regions in this simulation. As an indicator, the ratio of the averaged energy of the surrounding regions (regions 1~4 and 6~9) to the central region (region 5) was 85.902%, which indicates excellent uniformity of the projection.

Another simulation of the projection energy distribution on the screen was carried out, and the results are shown in Fig. 6. Again, the ratio of the averaged energy of the eight regions surrounding the screen to the central region was calculated to be 98.34%, which means that an almost-even energy distribution on the screen was achieved. The contrast was also calculated to be 100:1 in this simulation. The appreciable improvement of the uniformity on the screen over that on the panel is mainly attributed to the extra collimating effect of the projection lenses.

A mini-projector prototype employing the proposed projection system design was fabricated, and images of such prototype and its framework are shown in Fig. 7. The size of the whole system was 18×8×5 cm^3, which is remarkably compact. The light emitted from the LED and passing through all the optical components created a projected area of 113×151 mm^2 in the prototype. As a result of the great projection uniformity in the single mini-projector, a seamless image consisting of nine pictures simultaneously taken by an array of nine mini-projectors was obtained, as

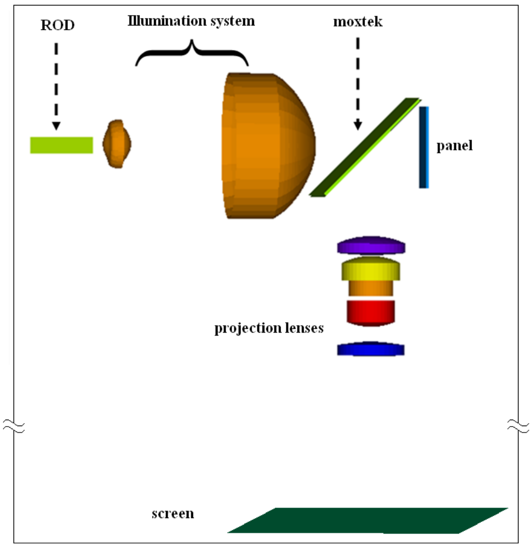

Fig. 5. Projection frame.

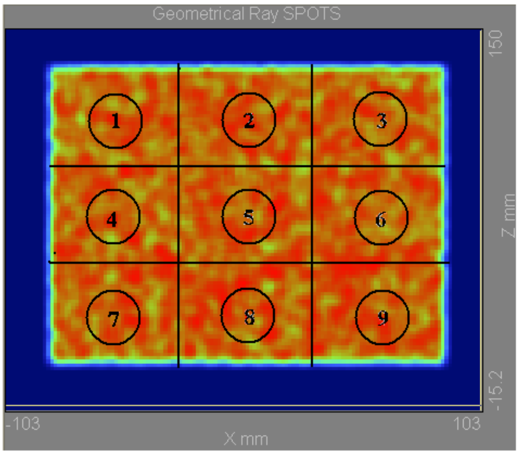

Fig. 6. Simulated illumination distribution on the screen.

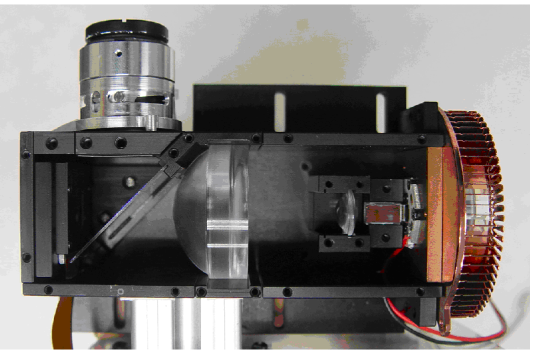

Fig. 7. Framework of the mini-projector.

shown in Fig. 8 (right). Compared to the image (Fig. 8 (left)) acquired by a regular system, the imagine quality produced in the proposed projection system was significantly superior and impressive.

The projection efficiency of the mini-projector was estimated, with the percentage loss of the light intensity in each component taken into account. The details and results are presented in Table 2, which reveals a projection intensity of only 2.62 lumens on the screen out of the initial LED light intensity of 280 lumens. The low collection efficiency, low panel reflectivity, and large polarization loss are the major losses in this system and are responsible for the low projection efficiency of less than 1%. Further efforts at reducing the aforementioned three intensity losses will improve the projection efficiency.

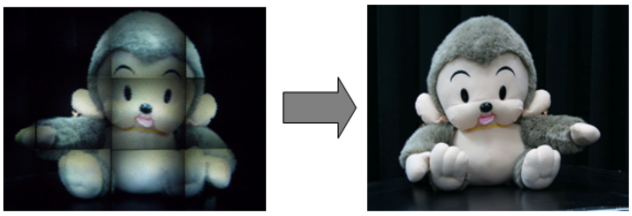

Fig. 8. A seamless image (right) was obtained in the proposed unique projection system consisting of nine tilting mini-projectors, compared to the image (left) acquired by a regular system.

Table 2. Estimation process of the projection efficiency of the mini-projector

LED lumens	280 (l m)
Rod	(97%)3=91.3%
Collection efficiency	18.33%
Illumination LENS	(96%)4=84.93%
PBS transmittance (moxtek)	85%
Panel reflectivity	19%
Polarization loss	50%
Projection lenses loss	(98%)10=81.71%
Final lumens	2.62 (l m)

4. Summary

The uniformity of the LED projection system with a nontelecentric structure and an LCOS panel was greatly improved by delicately designing the light source and optics configuration. The projection uniformity was simulated as 98.34%. A mini-projector prototype based on the proposed design was fabricated, and a seamless image was obtained with an array of nine tilting mini-projectors. It is consequently very promising to build a seamless display with a large size by tilting mini-multiple projectors for the integrated 3D display applications. The system, however, has a low projection efficiency of less than 1%. A two-panel structure seems a good way of reducing the polarization loss, even at the expense of high cost. Future efforts will be exerted to cut the major losses to further enhance the system performance.

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