

Micro-projection dynamic backlight for multi-view 3D display

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A micro-projection dynamic backlight for multi-view three-dimensional (3D) display is proposed. The proposed backlight includes a light emitting diodes (LEDs) array, a lenticular lens array, and a scattering film. The LED array, the lenticular lens, and the scattering film construct a micro-projection structure. In this structure, the LEDs in the array are divided into several groups. The light from each LED group can be projected to the scattering film by the lenticular lens and forms a series of bright stripes. The different LED groups have different horizontal positions, so these bright stripes corresponding to different LED groups also have different horizontal positions. Therefore, they can be used as a dynamic backlight. Because the distance between the LEDs array and the lenticular lens is much larger than the distance between the lenticular lens and the scattering films, the imaging progress will make the width of the bright stripes much smaller than that of the LEDs, and the pitch of the stripes is also decreased. According to the 3D display theory, the bright stripes with small width and pitch help to increase the number of views. Therefore, the proposed micro-projection dynamic backlight is very suitable for multi-view 3D display. An experimental prototype was developed, and the experimental results show that the micro-projection dynamic backlight can correctly complete the directional projection of the parallax images to form a 3D display.

Keywords: dynamic backlight; 3D display; multi-view.

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1. Introduction

Autostereoscopic three-dimensional (3D) display is a trend of the display industry. Currently, it includes several technical categories: binocular parallax display^[1–4], integral imaging display^[5–7], volumetric display^[8], and holography display^[9,10]. However, autostereoscopic 3D display technologies currently face several problems, such as limitation of viewpoint, reduction of resolution, high costs, and poor compatibility. Considering the factors of cost and compatibility, a binocular parallax display is a better choice for commercial prospects. However, the resolution of traditional binocular parallax 3D displays is decreased with the increasing of the number of viewpoints. Many methods have been proposed to improve resolution, including polarized light technology^[11,12], directional backlight technology^[13–15], dynamic parallax barrier technology^[16], and so on. These techniques can effectively improve the 3D image resolution. Based on directional backlight technology, here we introduce a micro-projection dynamic backlight for multi-view 3D display. Compared with the conventional backlight, the proposed one can provide bright stripes with small width and pitch, which

help for increasing the number of views. Assembled with a transparent liquid crystal display (LCD) panel, the micro-projection dynamic backlight can provide a 3D image display with full resolution and a large number of views.

2. Principle and Structure

As shown in Fig. 1, the micro-projection dynamic backlight is composed of a light emitting diodes (LEDs) array, a lenticular lens array, and a scattering film. The LED array, the lenticular lens, and the scattering film construct a micro-projection structure. The LEDs in the array are divided into several groups. The light from each LED group can be projected to the scattering film by the lenticular lens and forms a series of bright stripes. The LEDs in each group have a calculated pitch, so the bright stripes formed by these LEDs will coincide precisely. The different LED groups have different horizontal positions, so these bright stripes corresponding to different LED groups also have different horizontal positions. Therefore, dynamically lighting different LED groups can form a dynamic backlight.

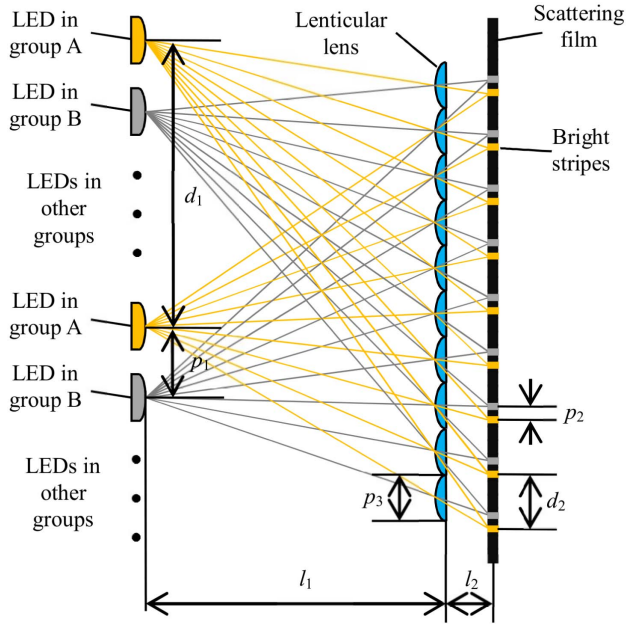


Fig. 1. Structure of the proposed micro-projection dynamic backlight.

Suppose that the distance between the LEDs and the lenticular lens is l_1 , so then the distance between the lenticular lens and the scattering film is l_2 . The distance between the LEDs in the same group is d_1 , and the distance between the formed bright stripes is d_2 . The pitch of the lenticular lens is p_3 , the pitch between the adjacent LED groups is p_1 , and the pitch between the formed stripes corresponding to the adjacent LED groups is p_2 . According to the geometric relationship in Fig. 1, these parameters can be calculated by Eqs. (1)–(3):

$$d_1 = \frac{p_3 \times (l_1 + l_2)}{l_2}, \quad (1)$$

$$d_2 = \frac{d_1 \times l_2}{l_1}, \quad (2)$$

$$p_2 = \frac{p_1 \times l_2}{l_1}. \quad (3)$$

According to the above geometric relationships, more optional bright stripes can be provided in a period d_2 , which will enable more viewpoints to be achieved. By increasing d_1 and p_3 in the same proportion, more groups of LEDs can be accommodated in the LED array, thus realizing more viewpoints. Therefore, the structure is optimized for the lenticular lens array with large pitch. In addition, reducing the aberration of the lenticular lens is helpful for reducing the width of the bright stripe and then increasing viewpoints.

As shown in Fig. 2, each LED will form an image on the scattering layer through a lenticular lens unit. Suppose that the focal length of the lenticular lens unit is f , the width of the LED is w_1 , the distance between the LED and the lenticular lens is l_1 , the distance between the lenticular lens and the scattering film is

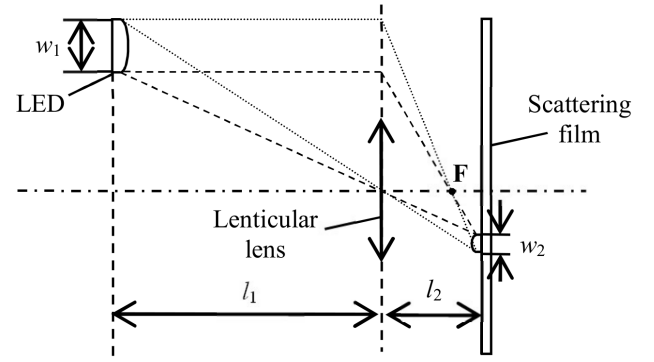


Fig. 2. Imaging process of the LEDs.

l_2 , and the width of the formed image, which is the width of the bright stripe, is w_2 . According to the imaging principle of the lenticular lens, the following equations can be obtained:

$$\frac{1}{f} = \frac{1}{l_1} + \frac{1}{l_2}, \quad (4)$$

$$w_2 = \frac{w_1 \times l_2}{l_1}. \quad (5)$$

Because the distance between the LEDs array and the lenticular lens l_1 is much larger than the distance between the lenticular lens and the scattering film l_2 , the imaging progress will make the width of the bright stripes w_2 much smaller than that of the LEDs w_1 . Therefore, according to Eqs. (3) and (5), bright stripes with small width and pitch can be obtained.

The bright stripes constrained by Eqs. (3) and (5) can be used for multi-view 3D display. Figure 3 shows a recommended multi-view 3D display based on the proposed micro-projection dynamic backlight. The structure of the recommended multi-

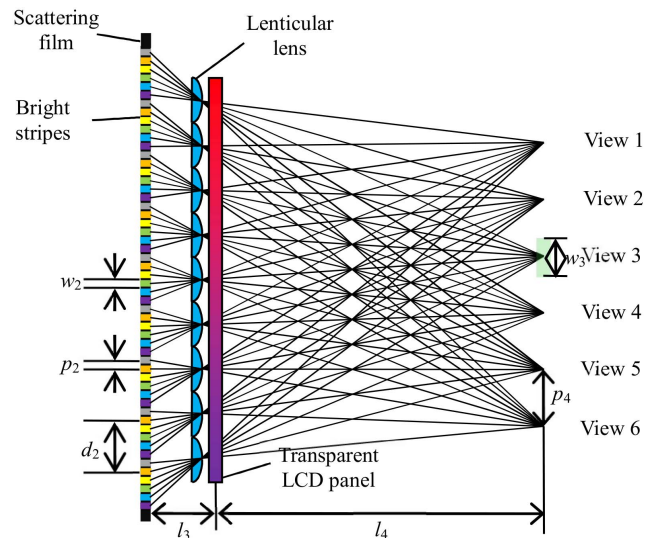


Fig. 3. Multi-view 3D display based on the proposed micro-projection dynamic backlight.

view 3D display consists of a proposed backlight, a lenticular lens, and a transparent LCD panel. As we discussed before, the LED groups of the micro-projection dynamic backlight can provide a series of bright stripes on the scattering film. These bright stripes can provide light energy for display. The lenticular lens can project the light from the bright stripes into views, and the transparent LCD panel can provide parallax images. Furthermore, the scattering coefficient of the transparent LCD panel is very low, so it will not influence the light transmission.

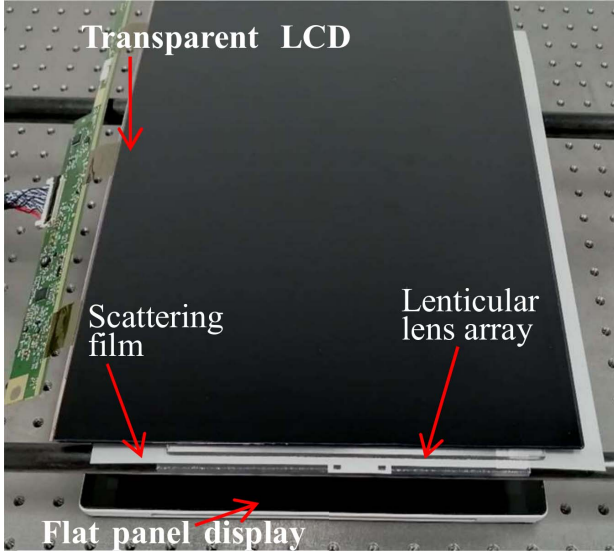


Fig. 4. Experimental setup.

The light from the bright stripes for an LED group can be projected by the lenticular lens and concentrated into a viewpoint. Simultaneously, the transparent LCD panel shows the corresponding parallax image. Then, this parallax image can be observed at the viewpoint. Therefore, multi-view 3D display can be achieved by lighting the LED groups and providing the corresponding parallax image.

Suppose that the distance between the scattering film and the lenticular lens is l_3 , the optimal view distance is l_4 , the pitch of the viewpoints is p_4 , and the viewing range for each viewpoint is w_3 . According to the geometric relationship in Fig. 3, p_4 and w_3 can be obtained as

$$p_4 = \frac{p_2 \times l_4}{l_3}, \quad (6)$$

$$w_3 = \frac{w_2 \times l_4}{l_3}. \quad (7)$$

Therefore, firstly, because the proposed micro-projection dynamic backlight can provide bright stripes with a small pitch of p_2 , according to Eq. (6), the pitch of viewpoints p_4 can be decreased, and the recommended 3D display has more views than that when directly using an LED array to provide light. Secondly, because the bright stripes have a small width of w_2 , then according to Eq. (7), the viewing range for each viewpoint w_3 is limited, which helps for crosstalk reduction. Thirdly, the proposed micro-projection dynamic backlight can project parallax images with full resolution by time-multiplex, so it is helpful for resolution promoting.

Table 1. Parameters of the Prototype.

Section	Parameters	Value
Backlight	Pitch of lenticular lens array p_3	0.99 mm
Backlight	Distance between the LEDs array and lenticular lens array l_1	58.99 mm
Backlight	Distance between the lenticular lens and the scattering film l_2	4.866 mm
Backlight	Distance between the LEDs in the same group d_1	20.26 mm
Backlight	Distance between the formed bright stripes d_2	0.13 mm
Backlight	Distance between the adjacent LED groups p_1	2.53 mm
Backlight	Pitch between the formed stripes corresponding to the adjacent LED groups p_2	0.049 mm
Backlight	Width of the LED w_1	0.95 mm
Display	Pitch of lenticular lens array	1.05 mm
Display	Distance between the lenticular lens and the scattering film l_3	3.774 mm
Display	Pupil distance p_4	65 mm
Display	Optimal viewing distance l_4	1200 mm
Display	Size of transparent LCD panel	21 inch

3. Experimental Results

The prototype is shown in Fig. 4. The flat display panel is used to simulate the LEDs array. Eight groups of bright stripes can be displayed on the flat display panel to simulate the LEDs array. The scattering film is made of polyethylene terephthalate (PET) diffusion film with a thickness of 0.125 mm. On the scattering film, a lenticular lens and a transparent LCD panel are placed in turn. The parameters of the prototype are shown in Table 1.

The lenticular lens array used in the experiment can realize 12 viewpoints theoretically, but only an eight-viewpoint prototype is developed due to the aberration of the lenticular lens array. If the lenticular lens array with larger pitch and smaller aberration is produced, the number of viewpoints can be further increased.

According to the above parameters, the LEDs array with a pitch of 2.53 mm and a width of 0.95 mm will form bright stripes with a pitch of 0.13 mm and a width of 0.049 mm on the scattering film. Matching the lenticular lens array, the prototype can form eight viewpoints. However, if LED chips are directly used to project light without the lenticular lens array in the backlight, only one viewpoint can be formed.

In order to verify the display effect of the 3D display, the images of numbers from “1” to “8” are used in the experiment, as shown in Fig. 5. The images of eight numbers are provided by the transparent LCD panel at eight moments, respectively, and are projected into eight different viewpoints. The display effect is shown in Fig. 6, the pictures of Figs. 6(a), 6(c), 6(e) to 6(o) are taken on the viewpoints, and the others are taken on the non-viewpoint, which is 65 mm to the left of the viewpoints. The experimental results show that the 3D display can complete a multi-view 3D display with full resolution correctly. The experimental results show that there is some crosstalk. The crosstalk is mainly caused by the following reasons: (1) the width of the bright stripe on the scattering film is larger than the theoretical value due to the aberration of the lenticular lens; (2) there is light scattering when the light passes through the optical elements; (3) there is reflected light on the surface of the optical elements, which will emit again after many times of reflection.

The optical simulation is also carried out, and the light distribution is simulated by using ASAP software, as shown in Fig. 7. In the simulation, the ISO light source in ASAP was used, and the divergence angle was set to 120 deg. The simulation results

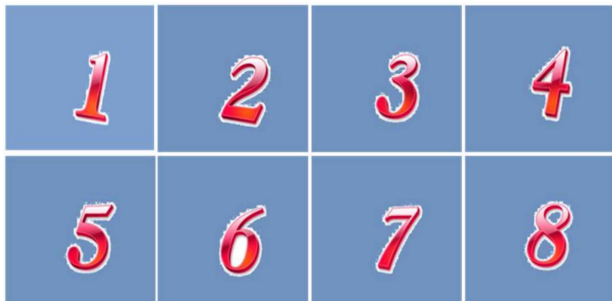


Fig. 5. Images of numbers from 1 to 8.

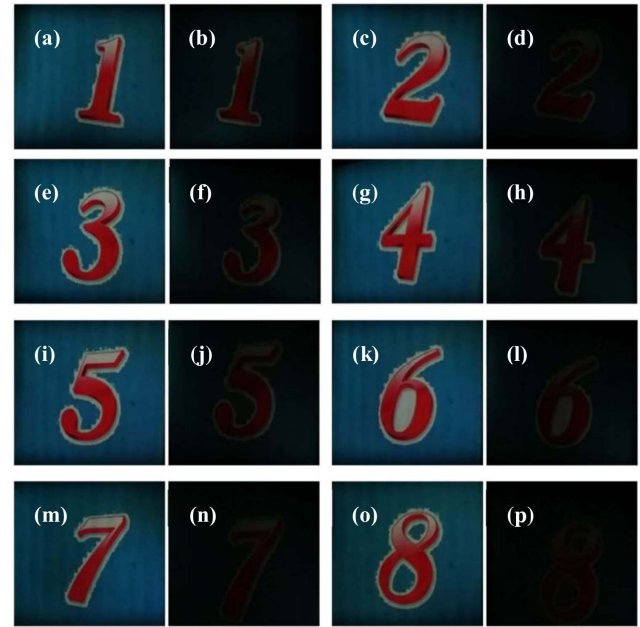


Fig. 6. Pictures captured at viewpoints and non-viewpoints.

show that the 3D display can complete the correct projection of the parallax image.

Finally, two actual parallax images are selected to verify the display effect in adjacent views in the experiment. The adopted parallax images are shown in Fig. 8(a), and the display effect is shown in Fig. 8(b). The experimental results show that the full resolution parallax image can be correctly projected to the corresponding viewpoint to form a 3D image.

Experimental results show that there is a certain color difference, because the LCD display has directional characteristics, such as vertical alignment (VA) technology. The normal LCD displays use uniform backlighting, but in this experiment directional backlighting was used. The LCD panel suitable for directional backlighting can be made to eliminate color difference.

In addition, the experimental results show that the brightness distribution is non-uniform, because the micro-projection structure provides linear backlighting, which leads to the non-uniform distribution of brightness. A gradient transmittance mask, of which transmittance of the central area is lower than that of the two sides, can be added to the LED to improve brightness uniformity.

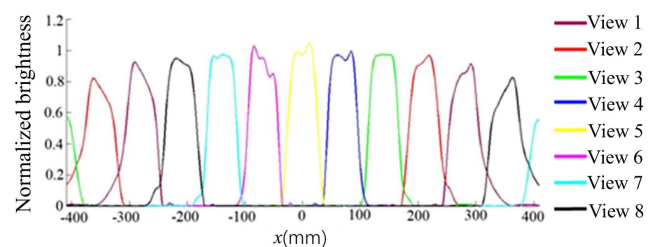


Fig. 7. Luminance distribution of the developed prototype.

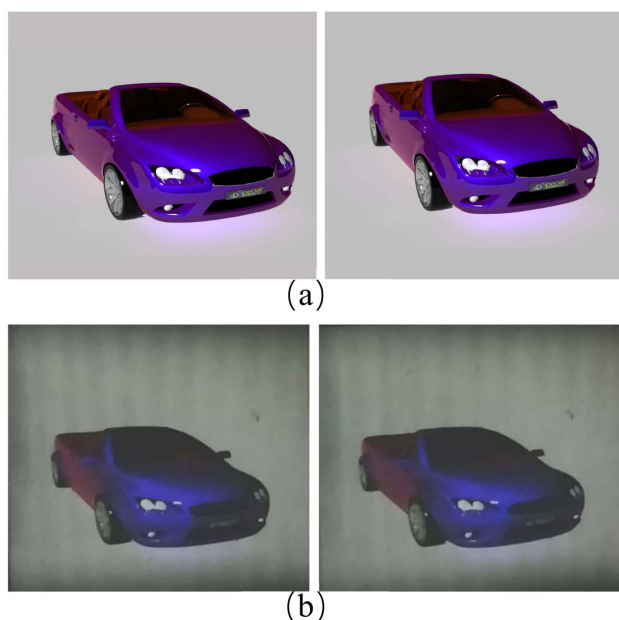


Fig. 8. Pictures captured at optimal viewing distance.

4. Conclusions

A micro-projection dynamic backlight for multi-view 3D display is proposed. The proposed backlight includes an LEDs array, a lenticular lens array, and a scattering film. The LED array, the lenticular lens, and the scattering film construct a micro-projection structure. The light emitting from the LEDs of the backlight converges through the lenticular lens array and forms a series of bright stripes on the scattering film. These bright stripes can provide light energy for 3D display based on the lenticular lens array. The lenticular lens can project the light from the bright stripes into views, and the transparent LCD panel can provide parallax images. An eight-viewpoint 3D display prototype based on the proposed backlight is developed. The experimental results show that the proposed backlight can correctly project the full parallax image to the corresponding viewpoint. The backlight can match any LCD panel to complete a multi-view 3D display with full resolution.

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