Establish a six-primary color display without pixel-distortion and brightness loss

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ABSTRACT

Recently, color reproduction stages are developed greatly, such as liquid-crystal displays, LCD TV, LCD projectors, DLP projectors, and etc. Wide-color-gamut displays are distinguishing feature of many display manufacturers. Many researches about multi-primary color displays are proposed, but there are still some problems which are not solved. This study proposed a novel multi-primary projection display system using two projectors. One of the two projectors is modified by changing two dichroic mirrors inside. The modified projector is combined with the other to a new six-primary color display. This study applies equal-luminance boundary theorem to construct gamut volume and evaluates the merit between gamut volume and brightness. By this method, the cut-off wavelength of dichroic mirrors can be found out. In the past, to align the images of the two projectors is pre-distorted to compensate the trapezoidal distortion. This study proposes to eliminate trapezoidal distortion by using the offset of the projector. This study directly changes dichroic mirrors to maintain the brightness and contrast, and solves lower brightness and contrast resulted from adding filters before. Additionally, this study uses a reflection mirror to twist projection path and also constructs a stage to align projection images more accurately.

Keywords: Multi-primary Color Display, Color Gamut, Color Mapping, Projector

1. INTRODUCTION

The display techniques are two important issues recently. One is the large size of the display. The large panel of LCD in market is all-providing gradually, and its technique has developed well. The other is how to enlarge the color gamut and to represent the image well. The methods to enlarge color gamut are divided into two ways mostly. First is using purer tri-primary colors, which are purer chromatic light. Second is adding one more primary color to form multi-primary color gamut [1-4]. The second way enlarge more color gamut easily and higher brightness. Recently the LED is developed vigorously and has been using for display backlight. The multiprimary display of LED backlight is workable expectably in the future. Therefore, the platform of multiprimary color display is needed for researching color reproduction of multiprimary color. The multiprimary display platform has been studied and proposed in several forms. In 1991, the optical system of multiprimary color display of liquid crystal display projector using diffraction grating was proposed [5,6]. The one pixel contains seven color sub-pixels, and light of slit array replacing microlens array diffracts seven light beans into seven sub-pixels via diffraction grating to form a multi-primary color display. The slit array causes the image as line-shape structure, therefore, the image quality is bad. Therefore, the platform of six-primary display with two projectors is proposed in this paper. The projection frame is aligned by arranging the offset between two projectors, and inner dichroic of one of these two projectors are also changed. The color gamut of the six-primary display is bigger, and its brightness and contrast of projection frame are maintained and sharp. In order to find optimized cut-off wavelength, we construct gamut volume [7] and evaluate merit function of gamut volume and gamut brightness. We also design a mechanism to let frame of two projectors overlap, and can adjust position and tilt angle of projectors.

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2. THE MULTIPRIMARY DISPLAY DESIGN

2.1 Projector

The proposed platform used two liquid crystal (LC) projectors (Everest EX-1720), which projector contains three piece of LC panel, to composite six-primary color display. Its inner optical path of LC projector is shown as Fig. 1. As the S-polarized light arriving in the first dichroic mirror, the light beam of the first primary color (red) is reflected from the first dichroic mirror, and the light beam transmitting through the first dichroic mirror goes to the second dichroic mirror. The light beam of the second primary color (green) is reflected from the second dichroic mirror, and the light beam transmitting through the second dichroic mirror is the third-primary color (blue). All of the primary lights passed through LC panel, overlapped color images by X-Prism, and then forming image by projector lens.

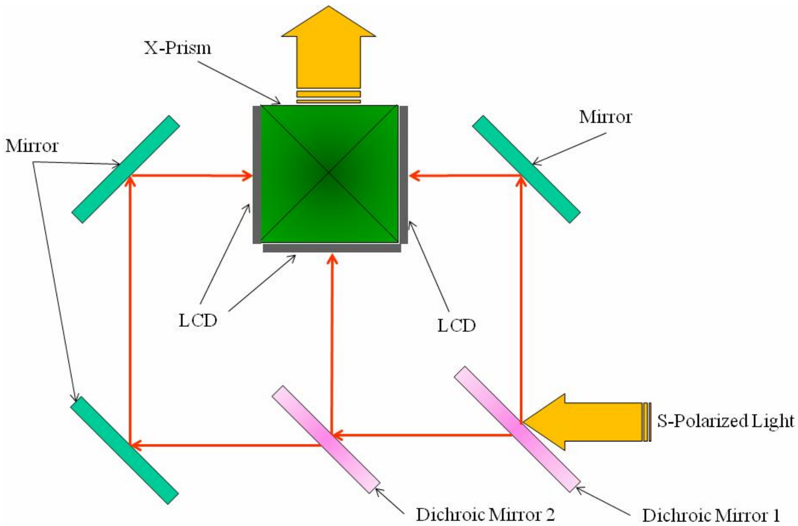


Fig. 1. The inner optical path of LC projector

2.2 Projector Frame

The projective imaging frame of our research was not central symmetry with projective lens. In figure 4-2, we can see the frame had up offset. From Fig. 2 and equation (1) to equation (3), we can know the relationship between projective distance and frame length.

$$\theta_1 = \tan^{-1}\left(\frac{76.7}{197.4}\right) = 21.23° \qquad (1)$$

$$\theta_2 = \tan^{-1}\left(\frac{6.3}{197.4}\right) = 1.83° \qquad (2)$$

$$\alpha = \theta_1 - \frac{\theta_1 + \theta_2}{2} = 9.7° \qquad (3)$$

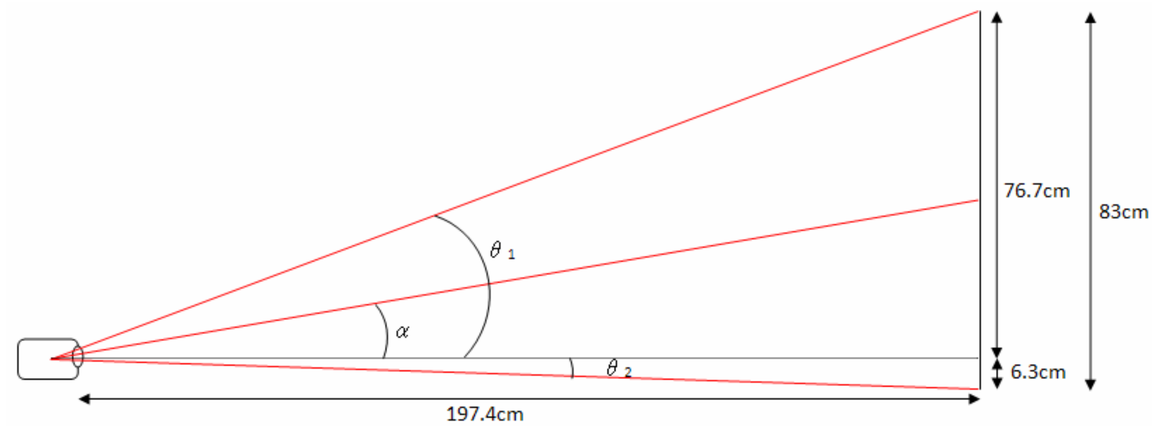


Fig. 2. The frame of the projector

2.3 Frame Overlapping of two projectors

The research used two projectors to form an overlapping imaging frame by two imaging frames. In the past, to align the imaging frames of two projectors is pre-distorted to compensate the trapezoid distortion. This research proposed to eliminate trapezoid distortion by using the offset of the projector. In this research, the projective imaging frame was up offset. So, we overlapped two imaging frames by putting one of the projectors normally and suspended the other (The suspenseful one will make the imaging frame down offset). We can know the offset angle of imaging frame by equation (1) and (2). The two projectors distance was d, as Fig. 3 showing, which decided by twice distance between two optical axils intersection and projector center.

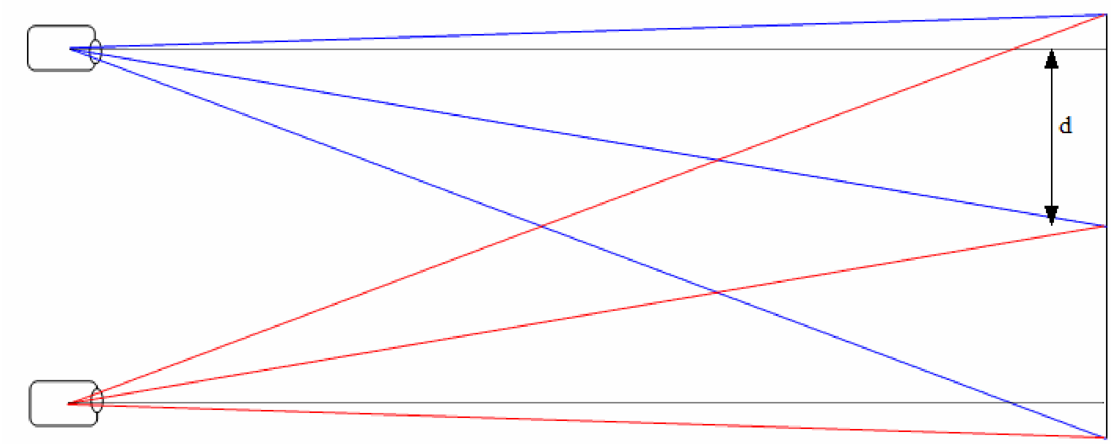


Fig. 3. The frame of two projectors

2.4 Mechanism Design

The research desired to design a six primary display which 50 inch. According to equation (4), the projective distance approximate 2 m that caused the mechanism length too long. We utilized reflective mirror to transfer optical path, as Fig. 4 showing.

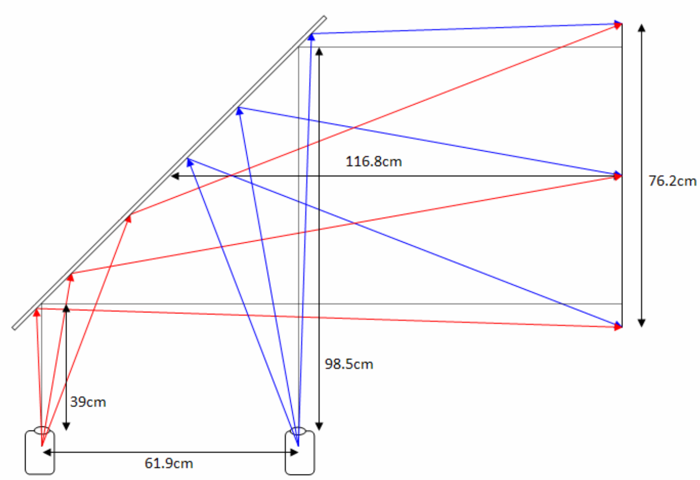


Fig. 4. The frame of the six-primary color display

$$\frac{50\times {}^{3}\!/_{5}\times 2.54}{\tan(21.23^{\circ})+\tan(1.83^{\circ})}=181.2(cm) \tag{4}$$

The distance between two projectors was about 60.9 cm from equation (5). When we put the angle of reflective mirror as 45 degree, the distance between two projectors and reflective mirror were 98.5 cm and 39 cm respectively. The length of reflective mirror needed 93.8 cm at least because we wanted to reflect both frame of projectors to screen, which is been obtain by equation (6).

$$181.2\times 2\times \tan 9.7^{\circ}=61.9(cm) \tag{5}$$

$$(61.9+98.5\times \tan 1.83^{\circ}+39\times \tan 1.83^{\circ})\times\sqrt{2}=93.8(cm) \tag{6}$$

The width of the reflective mirror related to the distance between two projectors. Width of the farther reflective mirror needed at least 55 cm, and the nearly one were at least 21.8 cm, which are calculated from equation (7) and (8). Ideally, the reflective mirror was a trapezoid mirror (The edge of up and down was 55.2 cm and 21.8 cm respectively; the height was 93.8 cm). Practically, in this research the area of trapezoid was bigger than the ideal case (Using two trapezoid mirrors as reflective mirrors; the edge was 90 cm and 60 cm respectively and the height was 65 cm of the one, the other had the edge 100 cm and 54 cm and 70 cm of height).

$$98.5\times(\tan 21.23^{\circ}+\tan 1.83^{\circ})\times\frac{4}{3}=55.2(cm) \tag{7}$$

$$39\times(\tan 21.23^{\circ}+\tan 1.83^{\circ})\times\frac{4}{3}=21.8(cm) \tag{8}$$

In order to modulated position and angle of projector accurately, we put two platform under projector (One was XY horizontal platform, the other was $\theta_x\theta_y$ tilt platform).

3. DICHROIC DESIGN

3.1 Simulation

In order to design optimized cut-off wavelength of dichroic mirrors, we defined a merit function to find the optimized solution of gamut volume and brightness. Merit = (ratio of gamut and NTSC standard) × (brightness enhance proportion). Our lamp spectrum as Fig. 5.

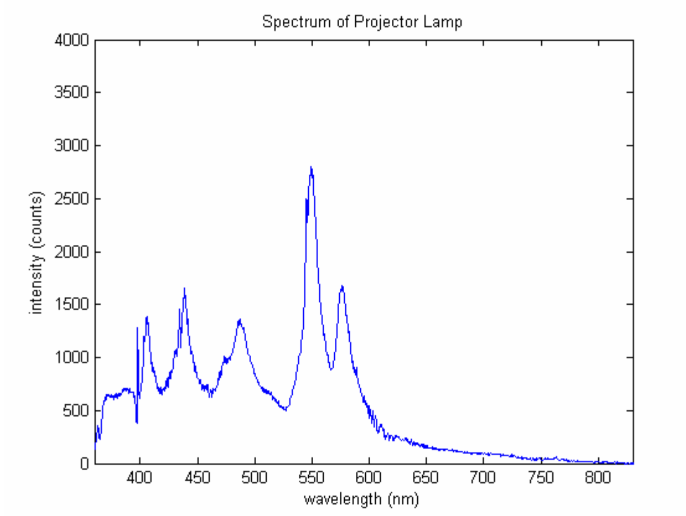


Fig. 5. Lamp spectrum

Our simulation divided to two parts which were spectrum energy loss and no spectrum energy loss. In spectrum energy loss case, we simulated three cases: case 1 is with red color filter, Case 2 is without red color filter; brightness energy loss less than 20% and case 3 is without red color filter; brightness energy loss less than 10%. In No spectrum energy loss case (which means no red color filter), we simulated two cases: case 1 is divided lamp spectrum to three (as Fig. 6.), Case 2 is divided lamp spectrum to four; red light and blue light mixed to form a primary light (as Fig. 7.). In Fig. 6, the gamut volume was biggest (90% of NTSC) when wavelength were 451nm and 553nm. In Fig. 7, the gamut volume was biggest (87% of NTSC) when wavelength were 481nm, 553nm and 570nm.

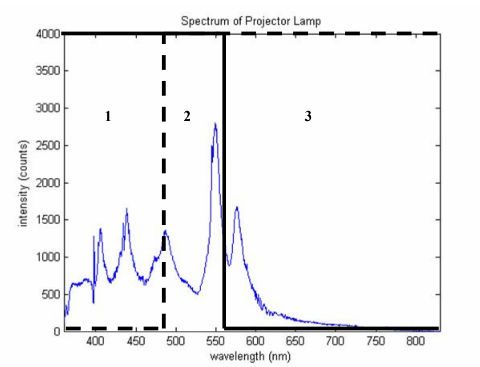


Fig. 6. Divide lamp spectrum to three

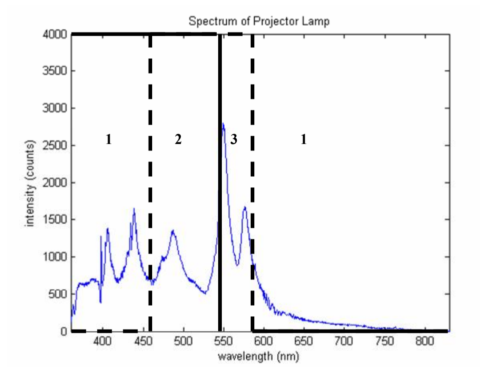


Fig. 7. Divide lamp spectrum to four

Our simulation steps were: step1 choose cut-off wavelength of dichroic mirrors. Step 2 calculates new three primaries. Step 3 composes new three primaries and three primaries of the other projector. Step 4 establish color gamut by six primaries and calculating volume. Step 5 Choose different cut-off wavelengths and comparing their color gamut.

3.2 Experiment

According to the simulative result of simulation, we designed and fabricated two dichroic mirrors, as Fig. 8 and Fig. 9 showing. We measured spectrum of dichroic mirror by fiber spectrograph. The measured platform of color filter spectrum is as Fig.10 showing. Transmittal spectrums of the two dichroic mirrors were like Fig.11 and Fig.12 (transmitted ratio was 50% at 482 nm and 557 nm respectively). The error was possible due to measure and coat, but the error range was ± 4 nm.

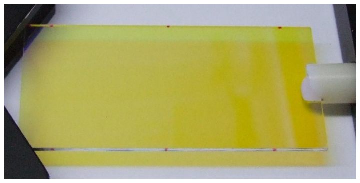


Fig. 8. The first color filter

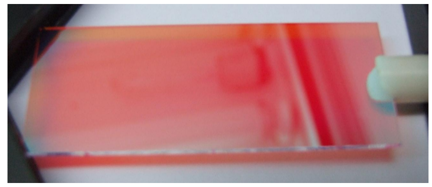


Fig. 9. The second color filter

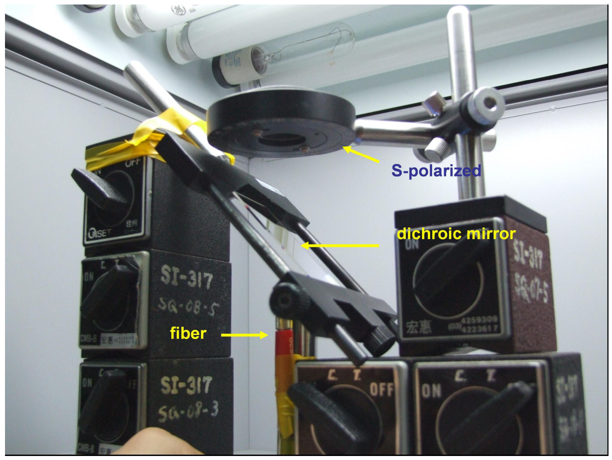


Fig. 10. The measured platform of color filter spectrum

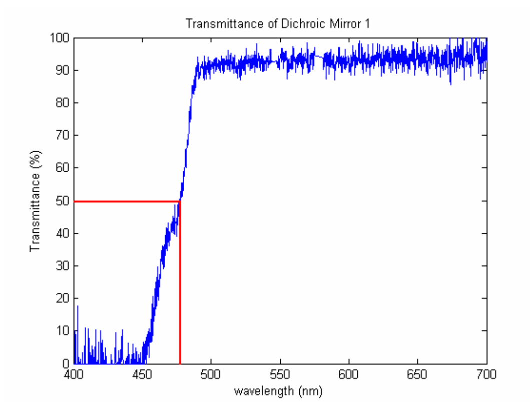


Fig.11. The spectrum of first color filter

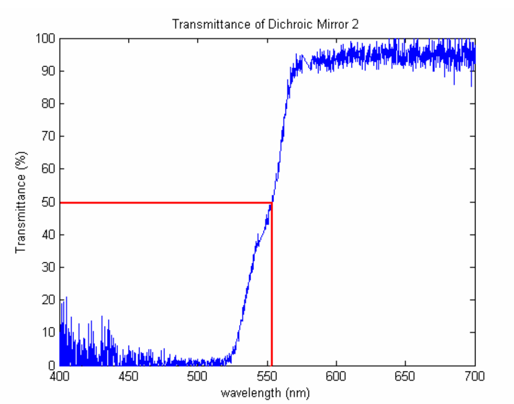


Fig.12. The spectrum of second color filter

Fig.13 was the six primary platform in this research. Fig.14 was a modulative platform for modulating tilt and position of projector (The upper was $\theta_x\theta_y$ modulative platform and the lower was XY horizontal modulative platform). Firstly, we checked two projectors at the same horizontal and then modulated imaging frame of projectors respectively. Modulate tilt platform to a fixed height (knob B). First, make two plates mutual parallel (knob A and knob C). Second, make imaging frame rectangularity gradually (knob A and knob C). Finally, make two imaging frame overlap (Point D and E of Fig.14).

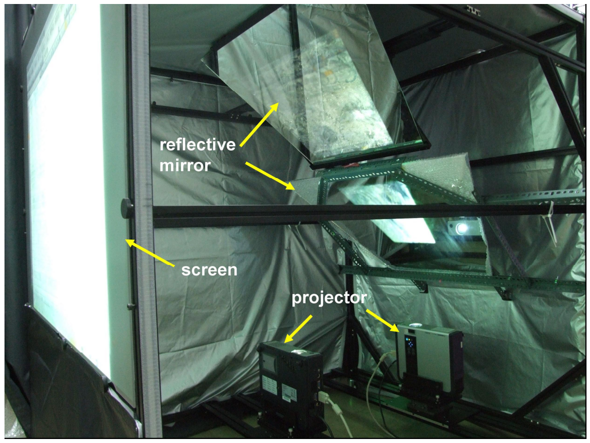


Fig.13. The platform of six-primary color display with two projectors

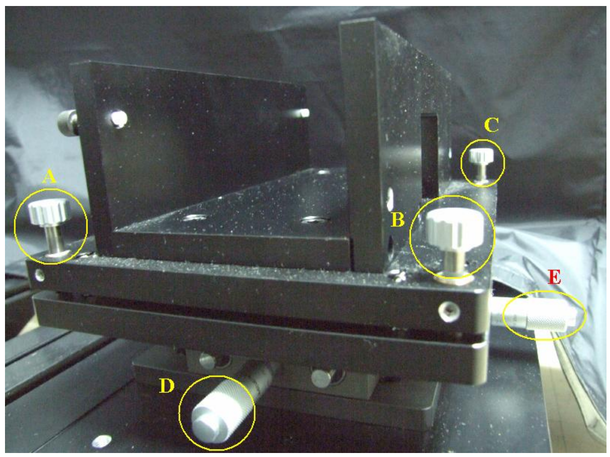
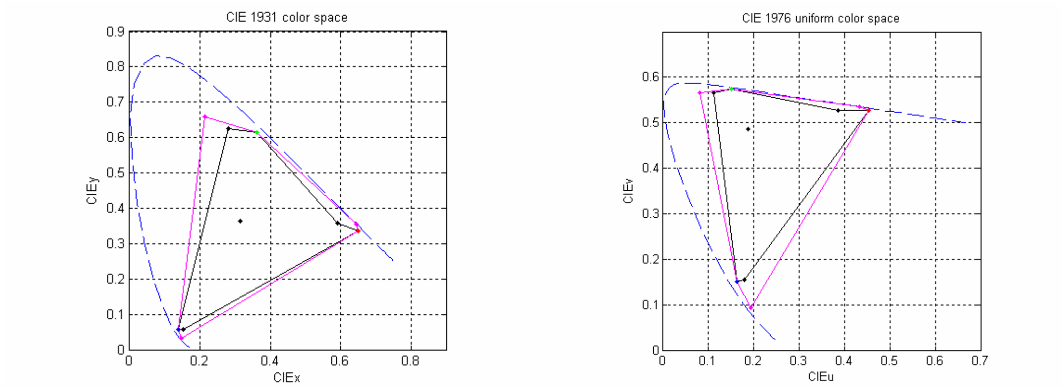


Fig.14 The modulative platform for modulating tilt and position of projector

In this study, we compared two conditions as red color filter in projector and no red color filter in projector. Firstly, we retained red color filter and used two pieces of dichroic mirrors which we fabricated. Measuring chroma of projector by Minolta CL-200 (table 1) then drew CIE 1931 xy chroma figure and CIE 1976 u'v' chroma figure which compared with previously simulation as Fig.15 showing. Secondly, we drew out red color filter and retained dichroic mirrors then measured chroma of projector (table 2) and drew CIE 1931 xy chroma figure and CIE 1976 u'v' chroma figure (Fig. 15).

Table1. The chromatic coordinates and intensity of three color filters with red color filter

	Color 1	Color 2	Color 3	Area rate
x	0.5899	0.2801	0.1524	118.79%
y	0.3576	0.6264	0.0582	
u'	0.3861	0.1125	0.1796	114.17%
v'	0.5266	0.5662	0.1543	
Intensity(lx)	135.5	622.2	56.5	

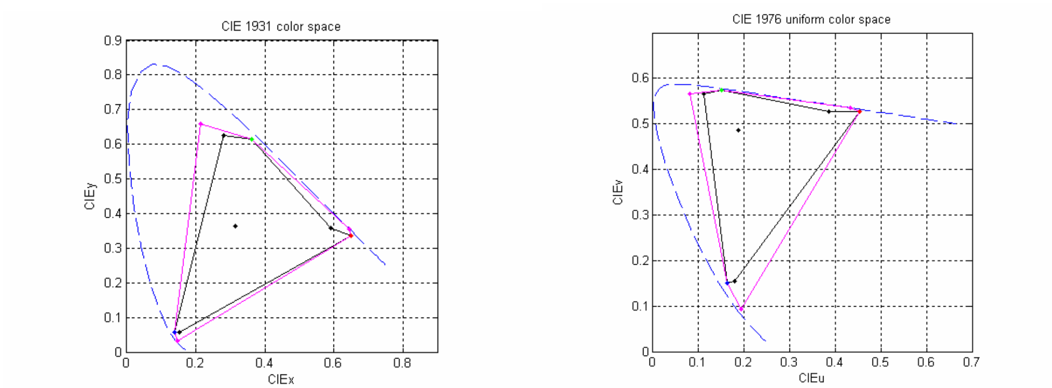


(a) (b)

Fig.15. The coordinates of the six color filter with red color filter in (a) CIE 1931 xy and (b) CIE 1976 u'v'

Table2. The chromatic coordinates and intensity of three color filters without red color filter

	Color 1	Color 2	Color 3	Area rate
x	0.5395	0.2703	0.1441	131.26%
y	0.4551	0.6457	0.0456	
u'	0.3861	0.1125	0.1796	125.31%
v'	0.5266	0.5662	0.1543	
Intensity(lx)	730.4	921.4	58	
Color volume rate	72.9%			



(a) (b)

Fig.16. The coordinates of the six color filter without red color filter in (a) CIE 1931 xy and (b) CIE 1976 u'v'

The color gamut practically had some difference with color gamut simulation result, because the transmit spectrum of dichroic mirror was set as ideal long wave through spectrum, but practically transmit spectrum of dichroic mirror was set as Fig.11 and Fig.12. If we changed ideal transmit spectrum to practical transmit spectrum, the simulation result is familiar with practical measurement (CIE 1931 xy color gamut enhance 130.27%; CIE 1976 u'v' color gamut enhance111.21%). When we retained red color filter, the color gamut was concave shape.

4. DISUSSIONS AND CONCLUSIONS

This study advanced a multi-primary display system which used 2 tri-primary projectors. Since we changed inner dichroic mirror of one of projectors, accounted to a new three primary colors which were composed a six primary display with the other non-corrected projector. We also designed a platform to deposit these projectors. According to lamp spectrum of projector, the cut-off wavelength of two dichroic mirrors are designed to produce new three primary and then color volume of display is simulated by equal-luminance boundary theorem. We can figured out color volume to express three dimension gamut range of display utilizing layer structure of gamut volume by applying coordinate of primary and the biggest luminance of each primary to plotted gamut surface. We defined a merit to find out an optimum cut-off frequency of dichroic mirror by choosing either color volume or luminance. Our simulation included when no red color filter in projector, color volume of spectrum energy losing 10% and 20% and color volume of light spectrum dividing to three parts and four parts. In Fig. 6, the gamut volume was biggest (90% of NTSC) when wavelength were 451nm and 553nm. In Fig. 7, the gamut volume was biggest (87% of NTSC) when wavelength were 481nm, 553nm and 570nm. With regarding to the experiment of our study, in CIE 1976 u'v' coordinate, the color gamut of six-primary display was 125.31% one contrasting to one projector. In CIE 1976 u'v' coordinate, color gamut of six primary of display was 122.95% one contrasting to sRGB. Color volume was 72.89% contrasting to NTSC. Therefore, our study contributed a very well experimental platform of multi-primary display under the two issues that are less of bright loss and image fringe sharp.

5. ACKNOWLEDGEMENTS

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