

Design of Color Filters for 4-Primary Systems Based on DLP

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Abstract

To find the optimal expansion of the color gamut of a display, we investigated various 4-primary display systems based on DLP. Via comparing the volume of the color gamut in a 3-D uniform color space-CIELUV, the best 4-primary system on the premise of keeping the existing three primaries is brought forward.

1. Introduction

The objective of this paper is to design the color filters for a 4-primary double-DLP system, and to obtain an optimal color gamut in the 4-primary system.

As known, most three-primary displays are incapable of accurately reproducing highly saturated colors. These conventional systems suffer from a color gamut limitation within the triangle spanned by the primary colors.^[1] Though by using more saturated primaries (Figure 1(a)), it's still impossible to cover all the perceivable colors, even with the penalty of a corresponding significant decrease in lumen efficient.^[2,3] Another method to expand a display's color gamut is the use of more than three primaries (Figure 1(b)). Recently, various designs for so-called multi-primary displays have been presented in literature.^[2,4,5]

Since the 3D color space CIELUV (Figure 2) has been constructed for the purpose of being perceptually uniform, with the equal distances in any direction in the color space representing roughly the same visual difference for a human observer, so rather than simply based on chromatic saturation, the volume of the

gamut in CIELUV was proposed as the optimum color performance criterion.^[6]

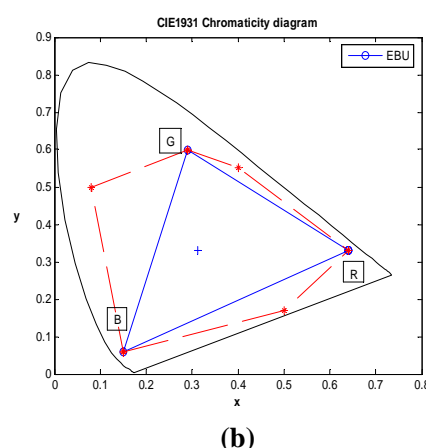
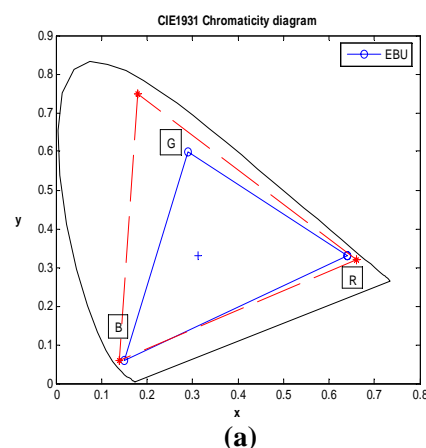


Figure 1 Two methods to expand the gamut of displays (a) purer primaries (b) multi-primary

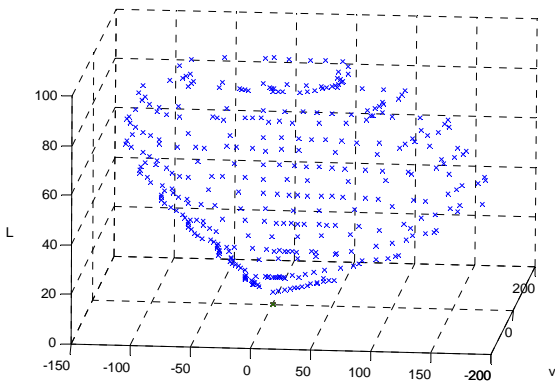


Figure 2 CIELUV color space

Convenient for additional primary test by changing filters, a double-DLP-based display is taken up as the experiment platform instead of CRT or LCD displays.

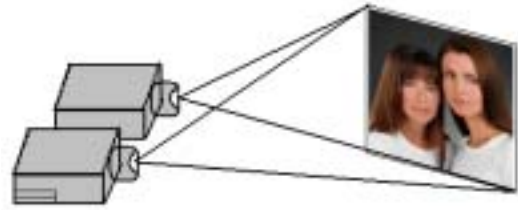
2. Experimental

2.1 Optical Setup

The basic idea for this 4-primary system is to use a double-DLP system (Figure 3)—one with the original RGB-primary filter, and the other with additional filter. Since it's difficult for us to change the color wheel, we just keep the original RGB-primary of one DLP unchanged and mount the new color filter in front of the lamp of the other DLP without color wheel. So that, with images superimposed on the screen, an additive mixture of 4-primary colors is obtained.



(a)



(b)

Figure 3 A double-DLP system

(a) photo of the double-DLP system

(b) the diagram of the system

2.2 Filter Design

The analysis of the color gamut in CIELUV color space is very complicated and for convenience, we use the volume of the polyhedron to approximate the gamut. As to the original three-primary gamut, it approximates to the volume of the polyhedron, whose five vertices are the three primaries, as well as the white and black point of the projector (Figure 4). Using vector mixed product, it's easy to get the volume of original gamut.

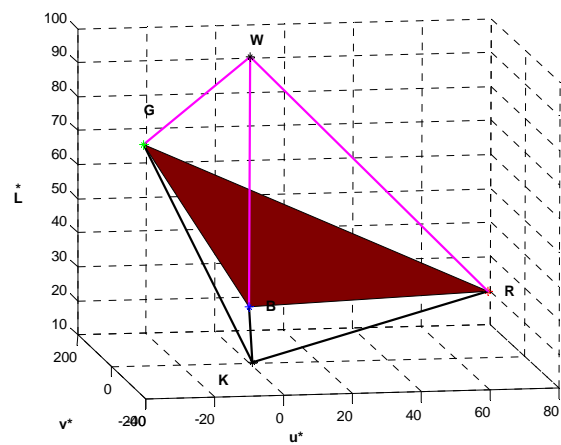


Figure 4 Color solid in CIELUV color space

eq.(1) shows the volume of tetrahedron RGBW—V1:

$$V1 = \left| (\vec{RG} \times \vec{RB}) \cdot \vec{RW} \right| \times \frac{1}{6} \dots\dots\dots(1)$$

eq.(2) shows the volume of tetrahedron RGBK—V2:

$$V2 = \left| (\vec{RG} \times \vec{RB}) \cdot \vec{RK} \right| \times \frac{1}{6} \dots\dots\dots(2)$$

And eq.(3) shows the total volume of the polyhedron—V:

$$V = V1 + V2 \dots\dots\dots(3)$$

Then before calculating the expanded volume, we first do some judgments to ensure the response of a filter suitable for our new system. Above all, the response must fall outside the existing color gamut. Also it is important that the response should have a different hue-angle with any of the existing primaries so as to be a supplement rather than a replacement.^[7] Also we can see that, all suitable colors clearly fall into three different parts corresponding to the different sides of the original color solid (Figure 5). And since colors from one part will not affect the gamut of any of the other two parts, expanded volumes can be calculated independently for the three parts. So use the same algorithm, we get the expanded volume (V) contributed by additional primaries. And comparing these expanded volumes, we obtain the optimal filters respectively belonging to these three parts for our system. The values of expanded volume are listed in Table.1.

3. Acknowledgments

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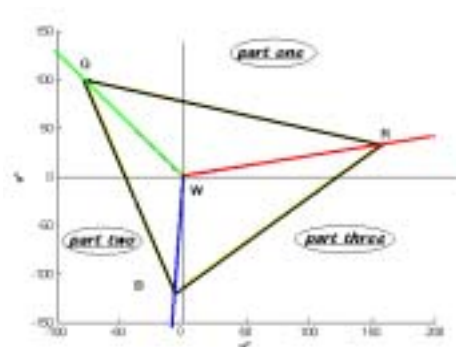


Figure 5 three parts in color space

4. Result

Utilizing volume of the gamut in CIELUV color space, we can evaluate the performance of colors as additional primaries of the existing display system. The color filters for a 4-primary double-DLP system are designed and optimized.

And we notice clearly both from the theory and the experiments (as shown in Figure 6) that, the designed filters do contribute a lot to the gamut of original display system and the images are more colorful displayed in our new 4-primary system (However, because of the limitation of the digital camera, the effect is not so obviously).

Table 1 coordinates and relative volume expansion

	R	G	B	W	K	Y	C	M
L*	29.17	72.28	31.34	100	0.75	91.986	55.61	43.05
U*	69.28	-27.82	-5.24	0	0	26.05	-63.80	-121.95
V*	2.91	58.98	-101.97	0	10.39	88.79	-21.30	32.61
V/V	Reference volume(V)					0.413	0.531	0.458

(Y—yellow in part one, C—cyan in part two, M—magenta in part three)

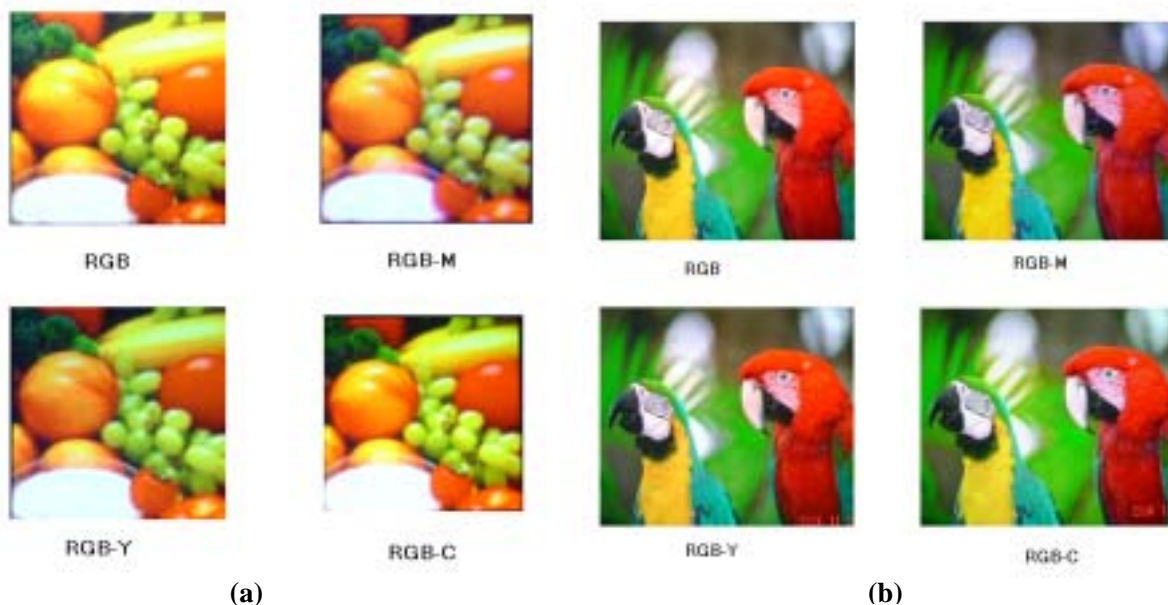


Figure 6 simulation results: (a) fruit; (b) parrots

5. References

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