

## 20.1: Perceived Brightness of LED Projector

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### Abstract

It is commonly observed that the LED projectors can provide with more perceived brightness by less stimulus luminance. In this work, the Helmholtz-Kohlrausch effect is applied for studying the enhanced perceived brightness of the LED projector. According to the equations developed by Nayatani's group, the ratio of the enhanced perceived brightness of LED projector is evaluated as 25% to 30% as compared to traditional lamp projector in dark environment. However, in the normal office illumination level, the difference between the LED projector and the lamp projector diminishes.

### 1. Objective and Background

As considering the advantages of compactness, long life, saturated color, low power consumption and short response time[1-2], both the lighting industry and the display industry based on the light emitting diode (LED) lighting technology are developing tremendously fast in the part few years. Recently, it is observed that the perceived brightness of LED projector is higher than that of traditional lamp projector. In other words, an LED projector of relative lower luminance is perceived equal or brighter than a traditional lamp projector of similar luminance.

Delta Electronics, Inc., introduced a full HD LED home theater projector in August 2008 and reached brightness level of 500 ANSI lumens. The birth of this projector in accompany with many other low lumen LED projectors came to the market latter on, made the perceive brightness of LED projectors a subject not only for the interesting of academic research but also a practical and urgent issue for display industry.

The perceive brightness of LED projector is commonly considered as the result of the Helmholtz-Kohlrausch effect (H-K effect) [3-4], which is also called the B/L (perceived brightness/luminance factor) or the L/Y (perceived lightness/luminance factor) ratio effect [5-7]. IEC defined H-K effect as "Change in brightness of perceived color produced by increasing the purity of a color stimulus while keeping its luminance constant within the range of photopic vision." In other words, for any two color stimuli with the same luminance, the perceived brightness induced by the color stimuli of higher purity will be higher than that of lower purity.

Nayatani et al, have developed some numerical equations for the calculation of H-K effect. According to the work of Nayatani's group, either Variable-Achromatic-Color (VAC) method or the Variable-Chromatic-Color (VCC) method is suitable for the study of H-K effect [8-9]. They further concluded that the VCC method is more practical than the VAC, although the previous one is more difficult from experiment point of view. To simplify the process, Nayatani developed equations using the CIELUV formula [10-12] instead of the nonlinear color appearance model [13-14]. Nevertheless, the CIELUV formula gave the same effectiveness as those of the nonlinear color appearance model for the various phenomena from the H-K effect.

In this work, the perceived brightness of the LED projector is evaluated by the VCC method. The result is then compared with that of the traditional lamp projector to get the factor of enhancement on perceptive brightness. The factor of enhancement is further investigated for the case the adapting light is considered.

### 2. Method

The VCC method for luminous colors is adopted to estimate the B/L ratio effect in LED and lamp projectors. The prediction equation for luminous colors is given in Eq. (1) [12].

$$\gamma_{VCC} = \frac{L_{eq}}{L} = 0.4462 \times \{1 + [-0.8660 \cdot q(\theta) + 0.0872 \cdot K_{Br}] \times s_{uv}(u', v') + 0.3086\}^3, \quad (1)$$

where  $L$  is the luminance of one test chromatic light, and  $L_{eq}$  is its equivalent luminance. The equivalent luminance  $L_{eq}$  is the luminance of the reference white light, which matches with the test chromatic light with  $L$  in perceived brightness. The coefficient  $q(\theta)$  is the function for predicting the change of the H-K effect in different hues.

$$q(\theta) = -0.01585 - 0.03017 \cdot \cos \theta - 0.04556 \cdot \cos 2\theta - 0.02667 \cdot \cos 3\theta - 0.00295 \cdot \cos 4\theta + 0.14592 \cdot \sin \theta + 0.05084 \cdot \sin 2\theta - 0.01900 \cdot \sin 3\theta - 0.00764 \cdot \sin 4\theta \quad (2)$$

and  $\theta$  is the hue angle in the CIE 1976  $u'-v'$  chromaticity.

$$\theta = \tan^{-1} \frac{v' - v_c'}{u' - u_c'} \quad (3)$$

where  $u'$  and  $v'$  are test chromatic light, and  $u_c'$  and  $v_c'$  are the reference white light. In addition,  $K_{Br}$  is a coefficient for specifying the adapting-luminance dependency of the H-K effect.

$$K_{Br} = 0.2717 \times \frac{6.469 + 6.362 L_a^{0.4495}}{6.469 + L_a^{0.4495}} \quad (4)$$

$L_a$  is adapting luminance, and  $K_{Br}$  is normalized to unity at  $L_a = 63.66 \text{ cd/m}^2$ . And  $s_{uv}(u', v')$  is the metric saturation of the test chromatic light with  $u'$  and  $v'$ :

$$s_{uv}(u', v') = 13 \times \sqrt{(u' - u_c')^2 + (v' - v_c')^2}, \quad (5)$$

As assessing and realizing brightness matches between any two chromatic colors, two luminous colors  $(x_1, y_1, L_1)$  and  $(x_2, y_2, L_2)$  are considered under the same adapting luminance  $L_a$ . Furthermore the equivalent lightness values can be given by  $L_{eq}^{(1)} = \gamma_{VCC}^{(1)} L_1$  and  $L_{eq}^{(2)} = \gamma_{VCC}^{(2)} L_2$ . If  $L_{eq}^{(1)} > L_{eq}^{(2)}$ , color  $(x_1, y_1)$  is brighter than color  $(x_2, y_2)$ . It is allowed to increase  $L_2$  to the metric lightness  $L_2^{(corrected)}$ , which

$$L_2^{(corrected)} = \frac{\gamma_{VCC}^{(1)}}{\gamma_{VCC}^{(2)}} \cdot L_1 \quad (6)$$

such that the perceived brightness matching holds between color  $(x_1, y_1, L_1)$  and the corrected color  $(x_2, y_2, L_2^{(corrected)})$ .

Two Delta DLP projectors were used in the experiment, one with lamp and the other with RGB LEDs as the light sources. These projectors are adjusted with a Minolta CL-200 photometer to the same brightness level and white point.

### 3. Results

Considering the white light is made of red, green, and blue primaries in both LED and the traditional lamp projectors, the corresponding  $\gamma_{VCC}$ 's and  $L_{eq}$ 's of each primary are characterized and evaluated in Table 1 respectively. The stimulus luminance from the lamp projector ( $242\text{lm/m}^2$ ) is a little more than from the LED projector ( $236\text{lm/m}^2$ ). As applying the VCC equation, the perceived brightness is estimated  $363\text{lm/m}^2$  for the LED projector and  $302\text{lm/m}^2$  for the lamp projector under the dark environment ( $L_a=0$ ). The B/L ratios are 1.54 ( $=363/236$ ) and 1.25 ( $=302/242$ ), respectively. The LED projector is of higher perceptive brightness than the lamp projector. It matches well to the observation by human eyes. The white color on the screen illuminated by the LED projector does look brighter than the one by the lamp projector.

The adapting light  $L_a$  is another key factor to the perceived brightness. When  $L_a$  is dim, the perceived brightness increases as  $L_a$  gets higher. However, when  $L_a$  gets over a threshold level, around 20-30 Nits in this case, the perceived brightness decrease dramatically as  $L_a$  gets even brighter (Fig. 1a). For each  $L_a$  level, the perceived brightness of the lamp projector has been corrected to be equal to the same as that of the LED projector with the help of Eq. (6). Fig. 1b shows the enhancement ratio of the perceptive brightness of LED projector with respect to lamp projector.

In environment dimmed for home theater projector, LED projector gives 25% to 30% enhancement on the perceptive brightness.

Table 1 Characteristics of the LED and the lamp projector.

		LED ( $236\text{lm/m}^2$ )		
		R	G	B
Y		60.000	165.000	11.000
Chromaticity Coordinates	x	0.705	0.200	0.145
	y	0.292	0.731	0.040
White Point	$x_n$	0.325		
	$y_n$	0.327		
		Lamp ( $242\text{lm/m}^2$ )		
		R	G	B
Y		54.000	164.000	24.000
Chromaticity Coordinates	x	0.640	0.308	0.150
	y	0.329	0.591	0.065
White Point	$x_n$	0.304		
	$y_n$	0.305		

Table 2  $\gamma_{VCC}$  and  $L_{eq}$  of LED and lamp projectors in dark surrounding,  $L_a=0$ .

	LED			Lamp		
	R	G	B	R	G	B
$\gamma_{VCC}$	2.560	1.050	3.302	1.706	0.892	2.663
$L_{eq}$	153	173	36	92	146	63
	363			302		
B/L	1.540			1.249		

Fig. 1: (a)  $L_{eq}$  vs. the level of the adapting light  $L_a$ . The solid line denotes the case for the LED projector, and the dash line for the lamp projector. (b) Ratio of  $L_{eq}$  in the LED to the lamp projector.

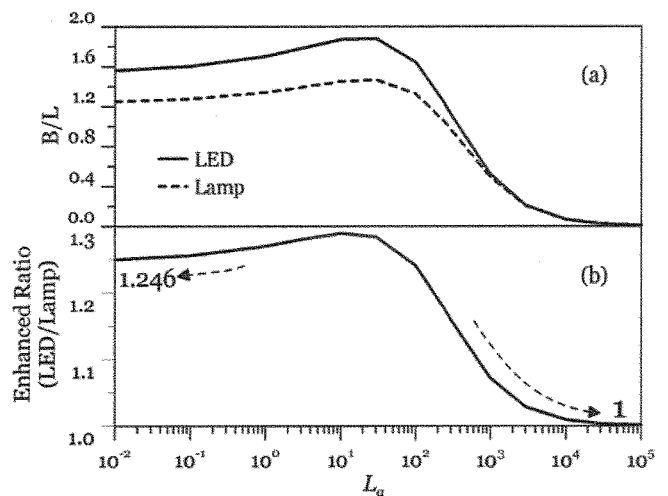


Fig. 1: (a) B/L ratio vs. the level of the adapting light  $L_a$ . The solid line denotes the case for the LED projector, and the dash line for the lamp projector. (b) Enhanced ratio of B/L in the LED to the lamp projector.

### 4. Conclusion

With the aid of the Helmholtz-Kohlrausch effect and the VCC method, the enhanced perceived brightness of the LED projector has been explored. The perceived brightness to stimulus luminance in LED projectors is about 1.540, while in the traditional lamp projectors it is 1.249. The enhancement ratio is around 25% to 30% to LED projector. If the adapting light goes brighter and above the normal illuminating levels, the enhancement is getting diminished.

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## 6. References

- [1] G. Harbers, M. Keuper, and S. Paolini, High Power LED Illuminators for Data and Video Projectors, Proc. IDW02, Vol.9, pp.501-504(2002).
- [2] G. Harber, S. Paolini, and M. Keuper, "Performance of high-power LED illuminators in projection displays," in SID Microdisplay 2002 Digest of Papers, pp. 22-25(2002).
- [3] G. Wyszecki and W. S. Stiles, Color Science, 2nd Edition, Wiley, New York, pp.410-419(1982).
- [4] Mark D. Fairchild, Color Appearance Models, Addison Wesley Longman, pp.141-143(1998).
- [5] Miyoshi Ayama and Mitsuo Ikeda, Brightness-to-Luminance Ratio of Colored Light in the Entire Chromaticity Diagram, Color Research and Application, Vol.23, No.5, pp.274-287(1998).
- [6] Eiichiro Toriumi, Sosuke Morii, Miyosi Ayama and Takeshi Kumagai, Brightness-to-Luminance Ratio of Colored Lights in Various Environments, The Illumination Engineering Institute of Japan, Vol.24, No.2, pp.28-39(2000).
- [7] Yoshinobu Nayatani and Hiroaki Sobagaki, Causes of Individual Differences on Brightness/Luminance (B/L) Ratios, The Illumination Engineering Institute of Japan, Vol.27, No.3, pp.30-34(2003).
- [8] Yoshinobu Nayatani, Hiroaki Sobagaki, and Kenjiro Hashimoto, Existence of Two Kinds of Representation on the Helmholtz-Kohlrausch Effect, Part 1: Their Experimental Confirmation, Color Research and Application, Vol.19, No.4, pp.246-261(1994).
- [9] Yoshinobu Nayatani, Hiroaki Sobagaki, and Kenjiro Hashimoto, Existence of Two Kinds of Representation on the Helmholtz-Kohlrausch Effect, Part 2: The Models, Color Research and Application, Vol.19, No.4, pp.262-272(1994).
- [10] Yoshinobu Nayatani and Motohiro Nakajima, Prediction of the Helmholtz-Kohlrausch Effect Using the CIELUV Formula, Color Research and Application, Vol.21, No.4, pp.252-268(1996).
- [11] Yoshinobu Nayatani and Motohiro Nakajima, Prediction of the Helmholtz-Kohlrausch Effect (VCC Method) Using the Swedish NCS System, Color Research and Application, Vol.21, No.4, pp.269-276(1996).
- [12] Yoshinobu Nayatani, Simple Estimation Methods for the Helmholtz-Kohlrausch Effect, Color Research and Application, Vol.22, No.6, pp.385-401(1997).
- [13] Yoshinobu Nayatani, Kenjiro Hashimoto, and Hiroaki Sobagaki, A Nonlinear Color-Appearance Model Using Estevez-Hunt-Pointer Primaries, Color Research and Application, Vol.12, pp.231-242(1987).
- [14] Yoshinobu Nayatani, Kotaro Takahama, Hiroaki Sobagaki, and Kenjiro Hashimoto, Color-Appearance Model and Chromatic-Adaptation Transform, Color Research and Application, Vol.15, pp.210-221(1990).
- [15] Selig Hecht, Charles Haig, and Aurin M. Chase, The Influence of Light Adaptation on Subsequent Dark Adaptation of the Eye, The Journal of General Physiology, Vol.20, pp.831-850(1937).
- [16] Selig Hecht, James C. Peskin, and Marjorie Patt, Intensity Discrimination in the Human Eye II. The Relation Between  $\Delta I/I$  and Intensity for Different Parts of the Spectrum, The Journal of General Physiology, Vol.22, pp.7-19(1938).
- [17] [http://www.xrite.com/custom\\_page.aspx?PageID=77](http://www.xrite.com/custom_page.aspx?PageID=77).