

Color Reproduction Considering the Average Picture Level and Flare Effect in PDP Displays

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Abstract

This paper proposes a method of color reproduction after considering the viewing conditions of PDP displays. Owing to a change of peripheral environments by a temporal and spatial location of observers, the ambient lightings should be considered in the process of color reproduction of displays. A conventional method enhances the contrast and saturation of images by controlling voltage gains in each channel, so that there is a limit to implementing the phenomenon of human adaptation. This method also faces difficulties in reproducing the perceived colors under a variety of viewing conditions. Accordingly, in order to solve this problem, we first characterize the device by considering the average picture level (APL) of PDP displays since the maximum luminance value of a PDP display varies according to the average picture level in order to keep the maximum electric power. In the next step, information about an ambient illuminant is obtained by a sensor and this includes the luminance and correlated color temperature values of ambient lighting. Then, a flare effect is taken into account to exclude the reflected lights in the surface of PDP displays. The chromatic adaptation is finally applied to reproduce colors in PDP displays using the information from the viewing conditions. In the experiments, the images reproduced by the proposed method are visually more similar than those reproduced by a conventional method.

Introduction

Color reproduction in displays is generally carried out in dark rooms in order to maintain any reference conditions. Yet, the conditions by which common observers watch displays vary continuously. At this time, an observer's peripheral environments are affected by inner illumination, daylight, or sunset. Therefore, algorithms that can reproduce colors for each type of ambient illumination in a display are needed. This is because the human visual system changes according to viewing conditions which is called a chromatic adaptation [1, 2].

The curves of a human's LMS cone responses change independently when viewing conditions vary. For example, under an incandescent lamp, the range of the L cone sensitivity is large. In other words, the L cone response for the same stimulus decreases under an incandescent lamp compared to under daylight. Therefore, images have to change in order to consider the variation of the human visual system. Recently, several researchers have studied the goals set by the CIE Technical Committee TC8-04: "To investigate the state of adaptation of the visual system when comparing soft-copy images on self-luminous displays and hard copy images viewed under various ambient lighting conditions [3]."

Kato [4] proposed an adaptation model using the S-LMS space in order to match images between a softcopy versus a softcopy. His method hypothesized that the human visual system is partially adapted to the display's white point and partially to an ambient light. Our proposed method is also similar to Kato's method with respect to using the white point of a display. However, our method considers viewing conditions more adaptively by using a sensor.

The proposed method consists of four steps. First, the PDP display is characterized to convert device-dependent RGB values to a device independence space. At this time, in order to consider the characteristics of a PDP display, sample patches are arranged according to common viewing conditions. Second, a sensor is used to extract the information about a particular viewing condition. Among several sensors, the sensor that can extract the information about color temperature and the luminance of an ambient light is used. Third, a flare effect is calculated to compensate for contrast and saturation by the viewing illuminant. Finally, the image in the PDP TV is reproduced by the chromatic adaptation model using the coefficient determined between the white point of PDP displays and the ambient light obtained by a sensor.

Characterization of PDP Displays Considering Average Picture Level

The process of device characterization is to obtain device-independent values from digital RGB signals or its inverse process. Therefore, we can determine the relation between reference tri-stimulus XYZ values and digital RGB values through device characterization. Potential models, includes GOG, S-curve, and Measurement-based. Among these, the GOG model represents the relation between electric values and light via an exponential curve. This model is accurate for PDP displays and it only needs a few sample patches. Therefore, we characterized PDP devices by the GOG model in this paper. Via the GOG model, input-to-output is represented by the coefficients of a gain, an offset, and a gamma. Luminance for each channel is modeled by red, green, and blue channels as Eq. (1) where d_r , d_g , and d_b are the normalized values for an input. N is the number of bits for a display device. R, G, and B are the normalized values between 0 and 1 for a luminance value. We can obtain a device independent of the XYZ tri-stimulus from the digital value of a display through a matrix operation, after the coefficients of gain, offset, and gamma are determined using training patches for each channel.

To characterize the display, some patches are measured in advance. Equipment for measuring is generally located at a distance of 4 times the height of the display. As well, the size of

$$\begin{aligned}
R &= \begin{cases} \left[k_{g,r} \left(\frac{d_r}{2^N - 1} \right) + k_{o,r} \right]^{Y_r}, & \left[k_{g,r} \left(\frac{d_r}{2^N - 1} \right) + k_{o,r} \right] \geq 0 \\ 0, & \left[k_{g,r} \left(\frac{d_r}{2^N - 1} \right) + k_{o,r} \right] < 0 \end{cases} \\
G &= \begin{cases} \left[k_{g,g} \left(\frac{d_g}{2^N - 1} \right) + k_{o,g} \right]^{Y_g}, & \left[k_{g,g} \left(\frac{d_g}{2^N - 1} \right) + k_{o,g} \right] \geq 0 \\ 0, & \left[k_{g,g} \left(\frac{d_g}{2^N - 1} \right) + k_{o,g} \right] < 0 \end{cases} \\
B &= \begin{cases} \left[k_{g,b} \left(\frac{d_b}{2^N - 1} \right) + k_{o,b} \right]^{Y_b}, & \left[k_{g,b} \left(\frac{d_b}{2^N - 1} \right) + k_{o,b} \right] \geq 0 \\ 0, & \left[k_{g,b} \left(\frac{d_b}{2^N - 1} \right) + k_{o,b} \right] < 0 \end{cases} \\
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} &= \begin{bmatrix} X_{r,\max} & X_{g,\max} & X_{b,\max} \\ Y_{r,\max} & Y_{g,\max} & Y_{b,\max} \\ Z_{r,\max} & Z_{g,\max} & Z_{b,\max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}
\end{aligned} \tag{1}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{r,\max} & X_{g,\max} & X_{b,\max} \\ Y_{r,\max} & Y_{g,\max} & Y_{b,\max} \\ Z_{r,\max} & Z_{g,\max} & Z_{b,\max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{2}$$

the patches is one-fifth for the height of a display in a dark room such as for a reference of CIE. At this time, although the same patches are used, the pixel values are different according to the background luminance of the sample patch in a PDP display. This is because one characteristic of a PDP display is Average Picture Level (APL).

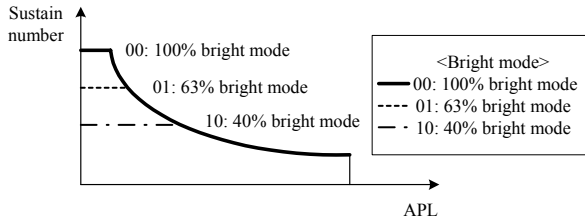


Figure 1. The relation between a sustain number and the APL in bright mode.

APL is related to the maximum power delivered to the PDP display. Fig. 1 shows the relation of between a sustain number and the APL. Luminance values at 100% bright mode, for example, are higher than those at 40% bright mode in cases of a low level of APL. Based on these data, we investigated the transition of the luminance of a white patch, according to the intensity of a background in PDP displays. The change of maximum values according to the luminance of a background is shown in Fig. 2.

While the maximum value of a display's luminance represents 300cd/m² when the luminance of a background is (0, 0, 0), the value of a display's luminance decreases to 100cd/m² when the luminance of a background is (255, 255, 255). In this paper, in order to maintain an average picture level in PDP displays, the characterization of a PDP display is carried out after a mean value set of a display's luminance is determined. The parameters can be calculated by using the GOG model in Table 1.

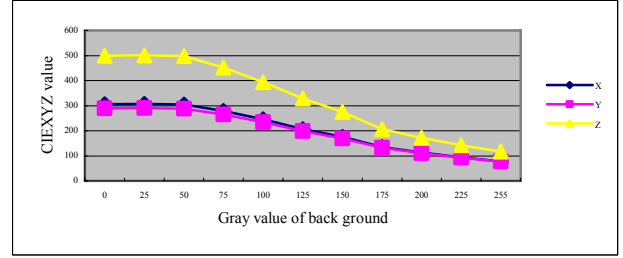


Figure 2. The change of maximum values according to the background luminance in PDP displays.

Table 1. The results of the characterization of displays.

Channel s	PDP 1			PDP 2		
	k_g	k_o	gamma	k_g	k_o	gamma
R	1.0258	-0.0258	2.1306	1.0031	-0.0031	2.4264
G	1.0215	-0.0215	2.1346	1.0639	-0.0639	2.1322
B	0.9743	0.0257	2.5397	1.0316	-0.0316	2.4398

At this time, in order to evaluate accuracy, we calculate the characterization error for 64 test patches using four steps in each RGB. Prior to calculating the error, RGB values were transformed to L*a*b* space as follows:

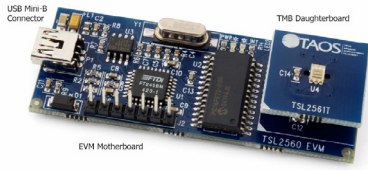
$$\begin{aligned}
L^* &= 116 \left(\frac{Y}{Y_n} \right)^{1/3} - 16 \\
a^* &= 500 \left[\left(\frac{X}{X_n} \right)^{1/3} - \left(\frac{Y}{Y_n} \right)^{1/3} \right] \\
b^* &= 200 \left[\left(\frac{Y}{Y_n} \right)^{1/3} - \left(\frac{Z}{Z_n} \right)^{1/3} \right]
\end{aligned} \tag{3}$$

The error was within three in delta E as the color difference space. It means that there was little discrimination between characterized and original values.

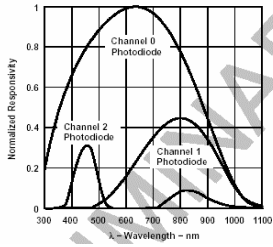
$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{1/2} \tag{4}$$

Extraction of Information About Viewing Conditions Using a Sensor

The perceived properties change according to viewing conditions. At this time, the environment consists of ambient illumination, which is defined by brightness and chromaticity. In order to extract information for viewing illumination, three types of sensors were used and the results were analyzed. The TSL 2550 sensor can extract information regarding brightness and chromaticity for an illumination using the outputs of two channels. This sensor is relatively simple as it only uses two channels, but the results are not satisfactory. The second TSL 230 sensor represents luminance, hue, and saturation by using RGB channels. This sensor is more accurate than a TSL 2550 sensor, but it has the disadvantage of self-lighting. It means that the lighting from this sensor can affect the information of the viewing conditions.



(a)



(b)

Figure 3. TSL 2571 sensor; (a) circuit (b) sensitivities of each channel

Finally, the TSL 2571 sensor can extract luminance and correlated color temperature information by using three channels. Fig. 3 shows the circuit and sensitivities of TSL 2571 sensor. This sensor has an advantage in that it can calculate luminance information from a wide wavelength. Table 2 shows the results for several illuminations.

The sensor's ability to extract information is generally satisfactory. In the case of it being close to illumination, however, the ability of the sensor is poor because it is saturated by high luminance. Accordingly, if the experiment is carried out outdoors, we can not obtain the results that we want. Therefore, we assume that the display is located indoors.

Table 2. Comparison of results between a sensor and a CS-1000 Radiometer.

Illuminations	CS-1000		TSL 2571 sensor	
	LUX	CCT	LUX	CCT
A(Booth)	690	2688K	620	3040K
D5500(Booth)	571	5681K	520	5600K
D6200(Booth)	872	6200K	940	6000K
D6500(Indoor)	138	6400K	109	6450K

Color Reproduction Based on Flare Effect and Chromatic Adaptation

Flare phenomena are the reflections of ambient light from the surface of a display, which then reduce the color gamut. A flare has a much higher impact on a PDP monitor than on a LCD and CRT display. To accomplish this, we calculated the flare effect on the viewing illumination in a characterization process [5].

$$\begin{aligned}
 \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ExternalFlare}} &= R_{bk} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ExternalFlare}} \\
 &= R_{bk} \cdot \frac{M}{\pi} \cdot \frac{1}{y_{\text{Ambient}}} \cdot \begin{bmatrix} x_{\text{Ambient}} \\ y_{\text{Ambient}} \\ 1 - x_{\text{Ambient}} - y_{\text{Ambient}} \end{bmatrix} \quad (5)
 \end{aligned}$$

where R_{bk} is the reflectance of a display surface and M is the luminance of light sources. The flare of ambient light is produced by a decrease in the contrast and saturation in the display. Usually, the CRT reflection ratio is 3 to 5%, while the LCD reflection ratio is 0.5 to 2% based on the experimental results in Table 3. First, XYZ tri-stimulus values to obtain the reflection ratio are measured using RGB(0,0,0) patches in both a dark room and under ambient light. The amount of flare is calculated by the difference value, where the reflection ratio is estimated by equation (5) using measured data.

Table 3. Measured data and reflection ratio according to viewing conditions

Illuminations	X	Y	Z	R_{bk}
500lux	1.78	1.91	2.63	0.01
4,000lux	12.76	13.5	14.63	0.01
9,000lux	29.20	30.4	39.73	0.01
15,000lux	47.92	49.5	59.7	0.01

We can determine digital values of a PDP display to compensate for the contrast while considering the flare effect as follows:

$$f(Y) = \{Y / (Y_p + Y_{ill})\}^r \quad (6)$$

where Y is the digital value and Y_p is the dependent value of the considered APL, Y_{ill} is the dependent value of the flare effect, and r is the contrast value of the display.

Next, chromatic adaptation is the phenomenon as to how we perceive different colors as being the same, due to changes in the visual characteristics of the viewing conditions. This effect can develop from XYZ to LMS values in order to consider the human visual system. Several researchers have suggested many kinds of chromatic adaptation models. In the early 90's, Hunt-Pointer-Esteves (HPE) transformation and Thornton's optimal primaries were used. Recently, Luo et al.'s results were superior, so we used the BFD (Bradford) transform in the following:

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.8951 & 0.2664 & -0.1614 \\ -0.7502 & 1.7135 & 0.0367 \\ 0.0389 & -0.0685 & 1.0296 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (7)$$

Incomplete adaptation is then carried out in order to compensate for the white point of a human visual system in the self-luminous displays. Even in a dark room, the human visual system does not adapt totally to self-luminous displays. Incomplete adaptation was originally proposed by Luo et al. Later, Kato modified the equation as follows:

$$C'_{n(PDP)} = \frac{C_{(PDP)}}{D + C_{n(PDP)}(1 - D)} \quad (8)$$

where C is the LMS cone response; S consists of the exponential form. The model was simplified so that it could be applied to the real time processing in the future. When D increases, the human visual system adapts more to displays. After an incomplete adaptation, we applied a mixed adaptation when considering the

viewing conditions. Also, Kato hypothesized that the human visual system could be adapted around the middle point, between a display's white point and an ambient light's white point.

$$C_{n(PDP)}^n = R_{adp} \cdot C_{n(PDP)}' + (1 - R_{adp}) \cdot C_{(Ambient)}' \quad (9)$$

After applying incomplete adaptation and mixed adaptation, a perceived value in the human visual system can be obtained. This method is different from hardcopy images that are applied with the simple von Kries model.

$$C_{n(PDP)} = C_{(PDP)} / C_{n(PDP)}^n \quad (10)$$

The forward process is completed. Gamut mapping is needed if experiments are between hardcopy and softcopy images, but we have no need for gamut mapping in this experiment. Therefore, we can calculate the display's values through inverse processing.

Experimental Results

In order to perform the experiments, we used the standard recommended by the CIE. All experiments featured the DN-50PX40M (50-inch PDP) by LG Electronics. Fig. 4 shows the specification of the experiment, including the viewing conditions of the observer. The surround and center region for the observer were covered with N9 of the Munsell Color Book to avoid interaction for each viewing illumination. First, in order to determine the adaptation ratio, we used the SMH (simultaneous haploscopic) method whereby one eye was toward one viewing condition and the other eye was focused on a second viewing condition. Nine observers could select one value in 0.1 increments from 0 to 1 iteratively.

We could also observe the adaptation ratio according to the size of an image. K. Xiao et al. [6] investigated the change of color appearance due to dissimilar sizes (degree of 4, 10, and 17). They concluded that perception increases according to the sample size for lightness and chroma except hue. However, our result was similar for the adaptation ratio due to the limited sample size for a display. Table 4 shows the adaptation ratio when the sample size was changed. Even though there was a variation for each test image, relatively, it was not large. So, we determined about 0.7 as a ratio of adaptation. Last, we compared CIECAM02 with the proposed method.

Table 4. Adaptation ratio according to the size of the test image.

Adaptation ratios	Test image 1			Test image 2			Test image 3		
	17°	10°	4°	17°	10°	4°	17°	10°	4°
1	0	1	0	0	0	0	0	0	0
0.9	3	0	1	0	0	1	2	0	0
0.8	3	5	3	3	2	2	3	3	2
0.7	2	2	3	2	1	1	2	3	4
0.6	1	1	2	1	4	4	2	3	2
0.5	0	0	0	3	2	1	0	0	1
Mean	0.78	0.78	0.73	0.66	0.63	0.68	0.76	0.70	0.68
Total	0.71								

At this time, an average intensity, chroma, and contrast for seven images were used as measures as shown in Fig. 5. The results showed that it was difficult to determine what method was superior. However, our aim was to design a PDP display considering an ambient illumination and specially, we could obtain good results for an average intensity and contrast.

Conclusions

This paper proposed a method of color reproduction after considering the viewing condition in PDP displays. The proposed method analyzes a variation of the maximum luminance according to the average picture level. The PDP display is characterized under conditions considering the average picture level. Next, the information about viewing lights is obtained using a sensor. To exclude a reflected light from viewing lights on the surface of a PDP display, the flare effect is considered using the information about illuminants. Last, the chromatic adaptation is applied to reproduce colors based on the human visual system.

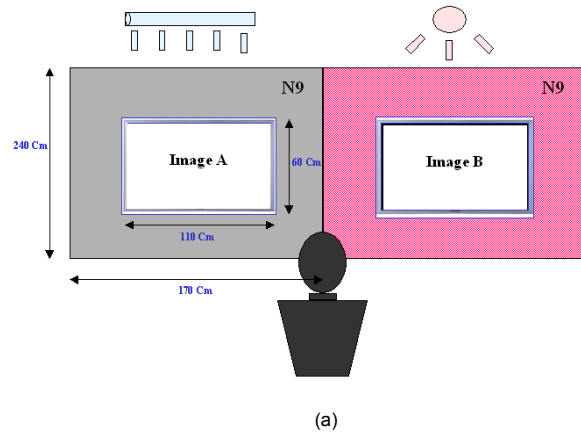
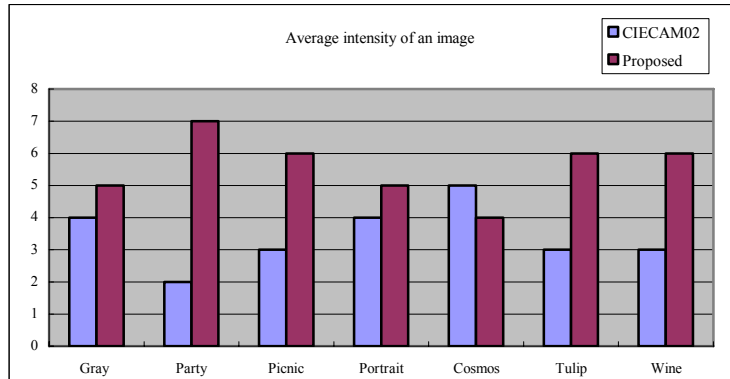
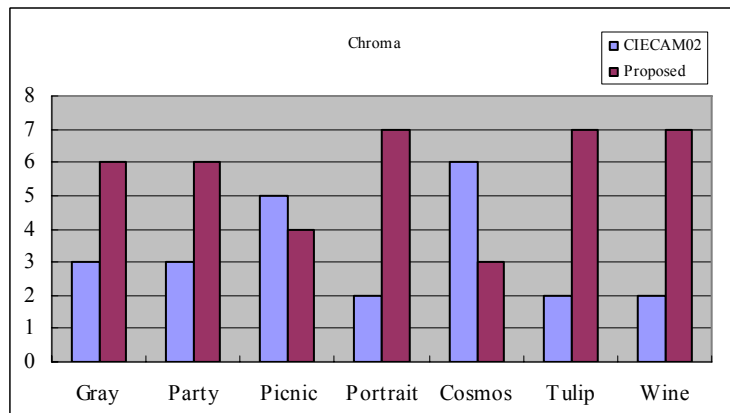


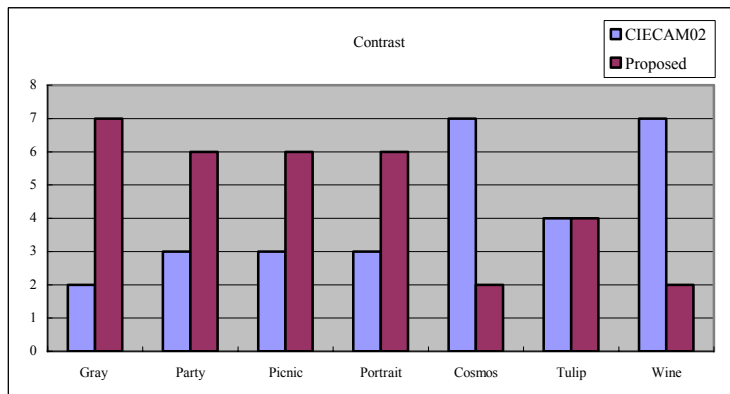
Figure 4. Experimental setup; (a) specifications and (b) test situation.



(a)



(b)



(c)

Figure 5. Comparison of between the proposed method and CIECAM02; (a) average intensity, (b) chroma, and (c) contrast

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