High Fidelity Color Reproduction of Plasma Displays under Ambient Lighting

Oh Seol Kwon, Tae Yong Park, and Yeong Ho Ha, Senior Member, IEEE

Abstract — This paper proposes a method of color reproduction that considers the observer’s viewing conditions and characteristics of a PDP display. In general, ambient lighting requires compensation to provide the same visual perception when the temporal and spatial conditions change. In a conventional method, the image contrast and saturation are enhanced by controlling the voltage gain in each channel to consider the phenomenon of human adaptation. Yet, this method encounters difficulties in reproducing the perceived stimulus under a variety of viewing conditions. Accordingly, this study characterizes a PDP display based on the white point when considering the average picture level of the PDP display as the maximum luminance value of a PDP display varies according to the average picture level. Next, to consider the viewing conditions, information on the ambient lighting is obtained using a sensor. The flare, the reflected ambient lighting, is also eliminated on the surface of the PDP display. Finally, the color values are calculated using a modified chromatic adaptation model. In experiments, images reproduced using the proposed method were visually superior to those reproduced using a conventional method.

Index Terms — Color signal, plasma displays, ambient lightings.

I. INTRODUCTION

Changes in the ambient conditions vary the sensitivities of the human visual system when watching a display [1], resulting in different perceptions under altered viewing conditions despite the same stimulus [2]. Therefore, since a viewer’s peripheral environment can be affected by artificial illumination, daylight, or fading light, algorithms are needed that can reproduce colors on a display under various types of ambient lightings as the viewing conditions are always changing [3].

The LMS cone responses of the HVS change independently when the viewing conditions vary. For example, the range of the L cone sensitivity is larger under an incandescent lamp, meaning that the response of the L cone to the same stimulus decreases under an incandescent lamp compared to that under daylight. As such, images need to be adjusted to take account of such variations in the human visual system. Several researchers have already taken on the challenge of 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 [4].” For example, Kato recently proposed an adaptation model using S-LMS space to match softcopy images based on the hypothesis that the human visual system partially adapts to a display’s white point and partially to the ambient light [5], [6].

In the case of a PDP display, additional factors also need to be considered, such as the white point and flare effect. First, the white point used to transform RGB values to LMS and vice versa should be fixed for every device [7]. Yet, the white point of a PDP display, unlike that of an LCD or CRT display [8], varies dramatically according to the average picture level of the display. While this is effective for reproducing the electrical consumption in PDP displays, it is a disadvantage for accurate color reproduction. Second, PDP displays experience a flare effect due to their glass surface [9]. Thus, viewing under ambient lighting has an adverse affect on the visual system, while the surface of the PDP reflects the ambient lighting.

Accordingly, this paper proposes an algorithm that allows perception of the same stimulus on a PDP display despite changes in viewing conditions. First, the PDP display is characterized by the white point based on the average picture point. A sensor is then used to extract information on the particular viewing conditions including the color temperature and luminance of the ambient light, and this information used to avoid flare by compensating the contrast and saturation. Finally, the image on the PDP display is reproduced using a modified chromatic adaptation model based on the coefficient between the white point of the PDP display and the ambient light determined by the sensor.

II. CHARACTERIZATION BASED ON AVERAGE PICTURE LEVEL

Device characterization seeks to obtain device-independent values from device-dependent values or the inverse process, allowing a relation to be determined between reference tri-stimulus XYZ values and digital RGB values. Potential models include GOG [7], S-curve [8], and Measurement-based [9], which these model represent the relation between electric values and light via an exponential curve. In particular, the GOG...
coefficients using training patches for each channel. Obtained from the display values for the display using a matrix measured in advance in a dark room, where the patch size was few sample patches. In the GOG model, the input-to-output is represented by coefficients for the gain, offset, and gamma. The device-independent input, using Eq. (1), where luminance for each red, green, and blue channel is modeled represented by coefficients for the gain, offset, and gamma. The few sample patches. In the GOG model, the input-to-output is represented by coefficients for the gain, offset, and gamma. The device-independent XYZ tri-stimulus values are then obtained from the display values for the display using a matrix operation, after determining the gain, offset, and gamma coefficients using training patches for each channel.

In this study, to characterize the display, a few patches were measured in advance in a dark room, where the patch size was one-fifth of the height of the display and measurement equipment was located at a distance of 4 times the height of the display, as recommended by the CIE. Even though the same patches were used, the tri-stimulus values for the pixels differed according to the background luminance of the sample patch on the PDP display. This is because PDP displays have the characteristic of an Average Picture Level (APL).

$$\begin{align*}
R &= \left[k_{r,0} \left(\frac{d_r}{2^{N-1}} - 1\right) + k_{r,0} \right]^0, \left[k_{r,0} \left(\frac{d_r}{2^{N-1}} - 1\right) + k_{r,0} \right] \geq 0 \\
&= 0, \left[k_{r,0} \left(\frac{d_r}{2^{N-1}} - 1\right) + k_{r,0} \right] < 0
\end{align*}$$

$$G = \left[k_{g,0} \left(\frac{d_g}{2^{N-1}} - 1\right) + k_{g,0} \right]^0, \left[k_{g,0} \left(\frac{d_g}{2^{N-1}} - 1\right) + k_{g,0} \right] \geq 0 \\
&= 0, \left[k_{g,0} \left(\frac{d_g}{2^{N-1}} - 1\right) + k_{g,0} \right] < 0
$$

$$B = \left[k_{b,0} \left(\frac{d_b}{2^{N-1}} - 1\right) + k_{b,0} \right]^0, \left[k_{b,0} \left(\frac{d_b}{2^{N-1}} - 1\right) + k_{b,0} \right] \geq 0 \\
&= 0, \left[k_{b,0} \left(\frac{d_b}{2^{N-1}} - 1\right) + k_{b,0} \right] < 0$$

Fig. 1. Relation of between sustain number and APL.
III. DETECTION OF VIEWING LIGHTINGS USING SENSORS

The perceived properties change according to the viewing conditions where ambient illumination can be defined by the brightness and chromaticity. Thus, to detect information on the viewing illuminations, three types of sensor were used and their results analyzed. The TSL 2550 sensor detects information on the brightness and chromaticity of a particular illumination using the outputs of two channels. Although this sensor is relatively simple, as it only uses two channels, the results were not satisfactory. The second TSL 230 sensor detects the luminance, hue, and saturation using the three RGB channels. This sensor was more accurate than the TSL 2550 sensor, yet has the disadvantage of being self-lit which means that the lighting from this sensor can affect the information on the viewing conditions. Finally, the TSL 2571 sensor detects the luminance and correlated color temperature information using all three channels. Fig. 3 shows the circuit and sensitivities of the TSL 2571 sensor. This sensor also has the added advantage that it can calculate luminance information from a wide wavelength. The sensor results under several illuminations are shown in Table II. Although the sensor’s ability to detect information on the viewing conditions was generally satisfactory, it did become saturated by a high luminance, such as direct sun light outdoors. Thus, since outdoor experiments did not produce the desired results, Therefore, it was assumed that the display was located indoors.

IV. CONTRAST COMPENSATION FOR FLARE EFFECT

Flare is the ambient light reflected on the surface of a display, which then affects the color stimulus. Flare also decreases the contrast and saturation on a display. In particular, flare has a much higher impact on a PDP monitor than on an LCD or CRT display. Thus, to eliminate this, the flare of the viewing illumination was considered in the process of device characterization [5].

The error was within three in delta E as the color difference space, meaning minimal discrimination between the characterized and original values.

$$\Delta E^*_{ab} = \sqrt{\Delta L^*^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

The error was within three in delta E as the color difference space, meaning minimal discrimination between the characterized and original values.

$$\Delta E^*_{ab} = \sqrt{\Delta L^*^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Fig. 2. Change in maximum values according to background luminance on PDP display.

Fig. 3. TSL 2571 sensor: (a) circuit and (b) sensitivity of each channel.
TABLE III

<table>
<thead>
<tr>
<th>Illuminations</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Rbk</th>
</tr>
</thead>
<tbody>
<tr>
<td>500lx</td>
<td>1.78</td>
<td>1.91</td>
<td>2.63</td>
<td>0.01</td>
</tr>
<tr>
<td>4,000lx</td>
<td>12.76</td>
<td>13.5</td>
<td>14.63</td>
<td>0.01</td>
</tr>
<tr>
<td>9,000lx</td>
<td>29.20</td>
<td>30.4</td>
<td>39.73</td>
<td>0.01</td>
</tr>
<tr>
<td>15,000lx</td>
<td>47.92</td>
<td>49.5</td>
<td>59.7</td>
<td>0.01</td>
</tr>
</tbody>
</table>

where \( R_{bk} \) is the reflectance of the display surface and \( M \) is the luminance of the light sources. To determine the reflectance ratio, the \( XYZ \) tri-stimulus values were measured using \( RGB \) (0,0,0) patches in a dark room and under ambient light. The amount of flare was then calculated by the difference between the two cases, and the reflectance ratio estimated based on the measured data. As a result, the reflectance ratio of the PDP was determined at about 1% as shown in Table III. Thus, to compensate the contrast in the case of a flare effect, the digital values of the PDP display were adjusted as follows:

\[
f(Y) = \{Y/(Y_p + Y_f)\}^r\]

where \( Y \) is the digital value, \( Y_p \) is the dependent value of the considered APL, \( Y_f \) is the dependent value of the flare effect, and \( r \) is the contrast value for the display.

V. MODIFIED CHROMATIC ADAPTATION

Chromatic adaptation is the ability of the human visual system to adjust to changes in the viewing conditions. This effect can be calculated by a transformation of the \( XYZ \) values into \( LMS \) values. Various chromatic adaptation models have already been suggested [1], [10], [11]. In the early 90’s, the Hunt-Pointer-Esteves (HPE) transformation and Thornton’s optimal primaries were introduced, and more recently Luo et al produced superior results. However, this study used the following BFD (Bradford) transform as a simple and comprehensive model based on pointing out what features are added to the simple model [1].

\[
\begin{bmatrix}
L \\
M \\
S
\end{bmatrix} = \begin{bmatrix}
0.8951 & 0.2664 & -0.1614 \\
-0.7502 & 1.7135 & 0.0367 \\
0.0389 & -0.0685 & 1.0296
\end{bmatrix} \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

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

\[
C'_{n(PDP)} = \frac{C_{(PDP)}}{D + C_{n(PDP)}(1-D)}
\]

where \( C \) is the \( LMS \) cone response and \( S \) consists of the exponential form. This model was also simplified so that it could be applied to real-time processing. When \( D \) increases, the human visual system adapts more to the display. Thus, after an incomplete adaptation, a mixed adaptation is applied when considering the viewing conditions. Kato also hypothesized that the human visual system adapts around the middle point between the display’s white point and the ambient light’s white point.

\[
C'_{n(PDP)} = R_{adp} \cdot C_{n(PDP)} + (1 - R_{adp}) \cdot C_{(Ambient)}
\]

Therefore, after applying an incomplete adaptation and mixed adaptation, the value perceived by the human visual system can be obtained. This method is different from the hardcopy images that are applied with the von Kries model.

\[
C_{n(PDP)} = C_{(PDP)}/C_{n(PDP)}
\]

The forward process is then complete. A flowchart of the proposed algorithm is shown in Fig. 4. Gamut mapping is needed if the experiments are between hardcopy and softcopy images, yet no gamut mapping was needed in the present experiments. Finally, the display’s values were calculated through inverse processing.

Fig. 4. Flowchart of the proposed algorithm.

VI. EXPERIMENTAL RESULTS

The experiments were performed using the standards recommended by the CIE. All the experiments featured a DN-50PX40M (50-inch PDP) developed by LG Electronics. Fig. 5 shows the specifications of the experiment, including the viewing conditions of the observer. The surrounding and center observation regions were covered with N9 from the Munsell Color Book to avoid interaction between each viewing illumination. Plus the SMH method (simultaneous
haplosopic) was used to determine the adaptation ratio, where one eye was focused on one viewing condition, while the other eye focused on a second viewing condition [12]. Nine observers were asked to select one value in 0.1 increments from 0 to 1 iteratively, and seven images were used in the experiments, as shown in Fig. 6.

The adaptation ratio was also observed according to the size of the image. K. Xiao et al. [13] previously investigated changes in color appearance according to size (degrees of 4, 10, and 17), and concluded that perception increased according to the sample size for lightness and chroma, within exception of hue. The present results also showed a similar change in the adaptation ratio. However, the variation for the test images was not large, as the change in the sample size on the display was limited. Thus, the ratio of adaptation was determined as 0.7. Finally, CIECAM02 was compared with the proposed method. CIECAM02 was implemented using C++ based on available references. The full model, including partial adaptation, was developed and the results confirmed using existing implementations [14].

Fig. 7 shows one of the images used in the experiments. The critical difference with the proposed method was setting a different white luminance in the characterization process. The adaptation ratio was then found experimentally based on considering the flare characteristics of the PDP display. The average intensity, chroma, and contrast for the seven images were used as the measures, as shown in Fig. 8. Although the results did not show a real difficult between the two methods, the current goal was to design a PDP display that considered the ambient illumination, and good results were achieved as regards the average intensity and contrast.

VII. CONCLUSIONS

Reproducing color on a display while considering the human visual system requires various considerations including maintaining the stability of the in a display’s white point and obtaining information of on the viewing conditions. In the case of a PDP display, the white point changes according to the APL and extra equipment is needed to detect the viewing conditions. Therefore, this paper proposed a method of color reproduction that is able to consider the viewing conditions.
based on the APL in a PDP display. As such, the change in the maximum luminance is analyzed according to the APL and the PDP display then characterized using an adaptive luminance for each APL. Meanwhile, a sensor is used to exclude reflected viewing light on the surface of the PDP display where this flare effect is considered based on the luminance and chromaticity obtained from the sensor. Finally, a modified chromatic adaptation is applied to reproduce the colors based on the human visual system. Experiments confirmed that the proposed method can reproduce color considering the viewing lighting based on the characteristics of the PDP display.

REFERENCES


