Color Reproduction Error Correction for Color Temperature Conversion in PDP-TV

Hyun-Chul Do, Sung-Il Chien, Member, IEEE, Ki-Duck Cho, and Heung-Sik Tae, Member, IEEE

Abstract — *It is often desirable that manufacturers and users can convert the reference white of display into the preferred color temperature that is one of representative color characteristics of a light source. An efficient method of correcting color reproduction error is proposed for displaying the NTSC-based video signal in plasma display panel televisions (PDP-TVs) and is also shown to be successfully coupled with flexible color temperature conversion based on the signal processing technique. As a result, this method can contribute to providing a range of user-preferred color temperature in PDP-TVs.*

Index Terms — color temperature, color temperature conversion, color reproduction error correction, plasma display panel.

I. INTRODUCTION

PLASMA Display Panel (PDP) has exhibited great potential as flat-panel devices for large-area (>42-inch) full-color wall-mounted digital High Definition Televisions (HDTVs) [1]. Recently, the realization of the high-class PDP-TV requires a high quality image and user-preferred color temperature. As for a color temperature, it is well-known that the preferred color temperature depends on ethnic group, age, and personal preference. However, for the high quality digital HDTVs, PDP-TVs cannot provide a range of color temperatures that are satisfactory for most viewers. In spite of various attempts to enhance the color temperature of PDP by using asymmetrical cells [2] or special color filters, recently, more flexible conversion methods have been forwarded using color signal processing techniques [3][4]. They are indeed flexible but cannot be directly applied to PDP-TVs because of color reproduction error due to inherent emission characteristics of PDPs. Therefore, in order to use directly color temperature conversion in PDP-TVs, it is necessary to correct discrepancy for the color reproduction.

The proposed method of this paper is divided into two steps: a step to transform the NTSC-based video signal to the output video signal of which the color temperature is the user-preferred color temperature, and a step to correct color reproduction error for a PDP-TV. The transfer matrix is calculated by using the (u, v) chromaticity values of the color temperature of the NTSC-based video signal and the user-preferred color temperature, thereby converting the NTSC-based video signal to the video signal of user-preferred color temperature. The color reproduction error correction is accomplished by using phosphor and primary chromaticities and the reference whites. The involved steps are summarized in Fig. 1.

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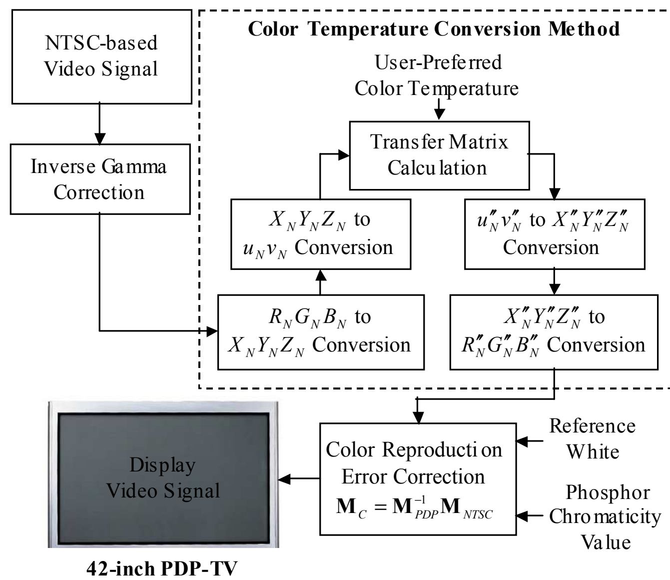

Figure 1. Overall diagram of proposed color reproduction error correction method for color temperature conversion in PDP-TV.

II. COLOR TEMPERATURE CONVERSION

The conventional method of color temperature conversion converts the (R_N, G_N, B_N) contents of the NTSC-based video signal into new ones of which the color temperature will be the user-preferred color temperature. The color temperature transfer matrix should be calculated. Let the initial and final tristimulus values of two color temperatures be (X_i, Y_i, Z_i) and (X_f, Y_f, Z_f), respectively. The relation between these two values are given by

$$[X_f, Y_f, Z_f]^T = \mathbf{M}_{T(x,y)} [X_i, Y_i, Z_i]^T . \tag{1}$$

It is also assumed that the initial and final luminance values remain the same, that is, $Y_f / Y_i = 1$. Then, the (x, y) chromaticity values of the two color temperatures are defined by (x_i, y_i) and (x_f, y_f) values, respectively. The color temperature transfer matrix is given by

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$$\mathbf{M}_{T(x,y)} = \begin{bmatrix} x_f y_i / x_i y_f & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & z_f y_i / z_i y_f \end{bmatrix}, \quad (2)$$

where $z_i = 1 - x_i - y_i$, $z_f = 1 - x_f - y_f$.

and the (u,v) chromaticity coordinates used for the 1960 CIE UCS (u,v) diagram is given by

$$u = \frac{4x}{-2x + 12y + 3} \text{ and } v = \frac{6y}{-2x + 12y + 3} \text{ or} \quad (4)$$

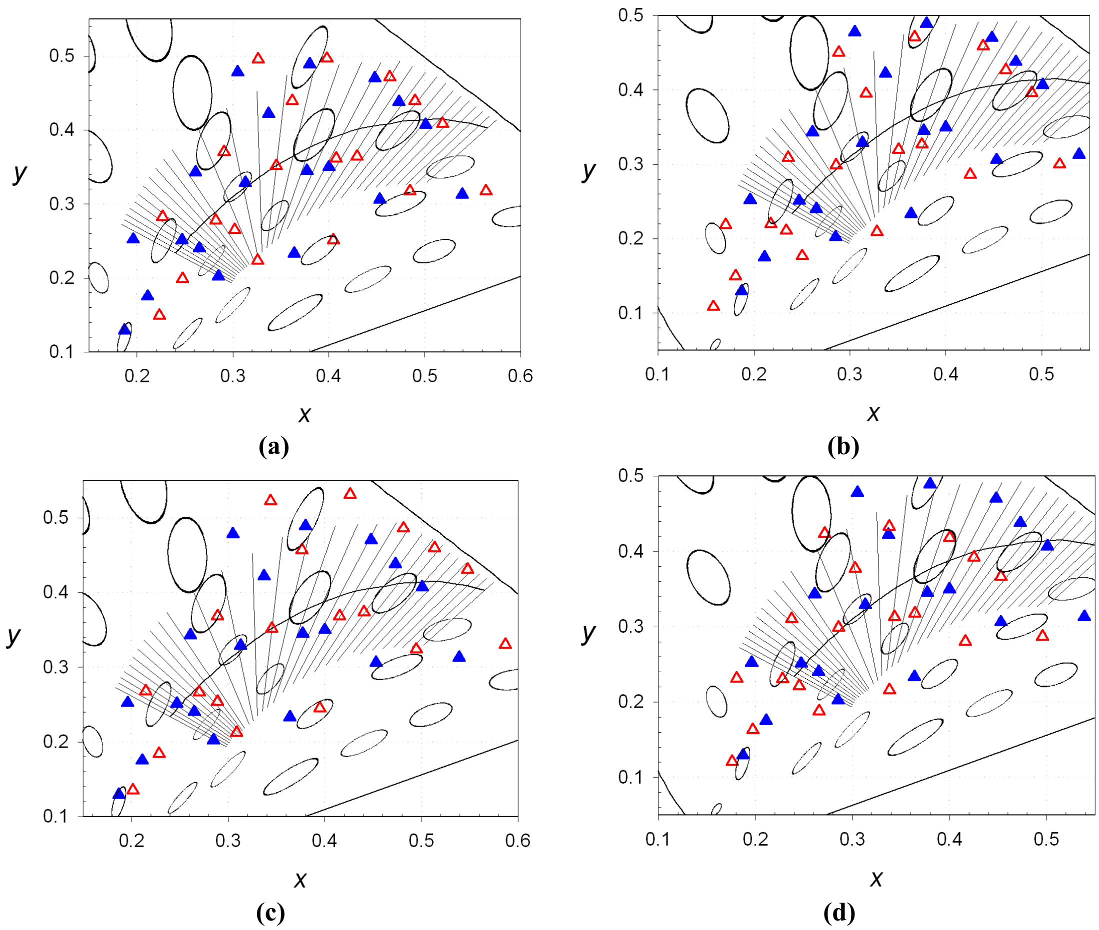

Figure 2. (x, y) **chromaticity coordinates for 24 Macbeth colorchecker colors when two color temperature conversion methods are applied: (a) conversion from D65 to 5000 K and (b) conversion from D65 to 9300 K for the conventional method, (c) conversion from D65 to 5000 K and (d) conversion from D65 to 9300 K for the proposed method. A filled triangle represents an original chromaticity value and an open triangle represents a converted chromaticity value, respectively.**

Now, (R_N, G_N, B_N) values are transformed into (R''_N, G''_N, B''_N) values by

$$[R''_N, G''_N, B''_N]^T = \mathbf{M}_{NTSC}^{-1} \mathbf{M}_{T(x,y)} \mathbf{M}_{NTSC} [R_N, G_N, B_N]^T. \quad (3)$$

Here, $\mathbf{M}_{NTSC}$ is the matrix, which converts (R_N, G_N, B_N) values into (X_N, Y_N, Z_N) values.

The color temperature conversion of the proposed method is accomplished on the uniform color space that is designed to aid in uniformity of the magnitude of the perceived color difference. The relationship between the (x, y) chromaticity coordinates

$$x = \frac{3u}{2u - 8v + 4} \text{ and } y = \frac{2v}{2u - 8v + 4}. \quad (5)$$

The (u,v) chromaticity values of two color temperatures are calculated and defined by (u_i, v_i) and (u_f, v_f) values, respectively. The proposed color temperature transfer matrix $\mathbf{M}_{T(u,v)}$ is given by

$$\mathbf{M}_{T(u,v)} = \begin{bmatrix} u_f / u_i & 0 \\ 0 & v_f / v_i \end{bmatrix}. \quad (6)$$

(u_N, v_N) values are transformed into (u''_N, v''_N) values. Then (x''_N, y''_N) values are obtained by using (5). The tristimulus values (X''_N, Y''_N, Z''_N) are calculated by using (x''_N, y''_N) values and the original luminance value Y_N from

$$X''_N = \frac{x''_N}{y''_N} Y_N,\ Y''_N = Y_N \text{ and } Z''_N = \frac{z''_N}{y''_N} Y_N . \quad (7)$$

The tristimulus values (X''_N, Y''_N, Z''_N) are converted into the (R''_N, G''_N, B''_N) contents of video signal of user-preferred color temperature by using matrix $\mathbf{M}^{-1}_{NTSC}$.

Figure 2 shows the (x, y) coordinates of the 24 Macbeth colorchecker colors when two color temperature conversion methods are used. A filled triangle represents an original chromaticity value and an open triangle represents a converted chromaticity value, respectively. The 25 MacAdam ellipses of equally perceptible color differences are also plotted in Fig. 2. The axes of the plotted ellipses are 10 times of their actual lengths. As the conventional method transforms color temperature from D65 to 5000 K in Fig. 2(a), the variation of the (x, y) coordinates is relatively larger at the smaller size of the ellipses and vice versa. However, by the proposed method in Fig. 2(c), the variation of the (x, y) coordinates is roughly proportional to the size of the ellipses. This result appears to match with human visual perception on color differences at color temperature conversion. When the color temperature rises to 9300 K, similar results can be obtained as shown in Figs. 2(b) and (d). Accordingly, the proposed method can resolve the problem of the conventional method that the image becomes too bluish in case the color temperature is increased.

III. Color Reproduction Error Correction in PDP-TVs

The main reason of color reproduction discrepancy is that the chromaticity values of the NTSC primaries and the reference white (D_{65}) differ from those of PDP phosphors and the PDP reference white, which were actually measured from the 42-inch PDP-TV for our experiment and included in Table I. To overcome such discrepancy in displaying colors, the correction matrix $\mathbf{M}_C$ is proposed. Let (R''_N, G''_N, B''_N) be a color signal for the NTSC standard and (R''_P, G''_P, B''_P) be a color signal for the PDP-TV and let (X''_N, Y''_N, Z''_N) and (X''_P, Y''_P, Z''_P) be their tristimulus values, respectively. The relationships between them are described, respectively, as

$$[X''_N, Y''_N, Z''_N]^T = \mathbf{M}_{NTSC} [R''_N, G''_N, B''_N]^T , \quad (8)$$

$$[X''_P, Y''_P, Z''_P]^T = \mathbf{M}_{PDP} [R''_P, G''_P, B''_P]^T . \quad (9)$$

Here, matrix $\mathbf{M}$ is written as the product of phosphor or primary chromaticity coordinate matrix and a tristimulus constant matrix and detailed elsewhere [5]. Since the two tristimulus values in (8) and (9) must be the same for removing color discrepancy, the resultant converting equation with matrix $\mathbf{M}_C$ is given by

$$[R''_P, G''_P, B''_P]^T = \mathbf{M}_C [R''_N, G''_N, B''_N]^T , \quad (10)$$

where $\mathbf{M}_C = \mathbf{M}^{-1}_{PDP} \mathbf{M}_{NTSC}$.

The Macbeth colorchecker colors before and after error correction are put on the (u', v') coordinates as in Figs. 3(a) and (b), respectively. A filled triangle represents an original chromaticity value and an open triangle represents a chromaticity value that was measured directly from the PDP-TV screen by using Color Analyzer CA-100. The solid line represents the color gamut of the NTSC system, while the broken line represents that of the PDP-TV. As can be seen in Fig. 3, the reproduction error has been decreased considerably after error correction. Numerically speaking, the average error in $\Delta u'v'$ was 0.017 before error correction and 0.005 after error correction. The Macbeth colorchecker images are included in Fig. 4 for visual inspection. The images in Figs. 4(b) and (c) were actually captured from the screen of the PDP-TV. It can be easily seen that the patches of Fig. 4(c) look more similar in color to those of Fig. 4(a) than those of Fig. 4(b) do.

TABLE I
PRIMARY AND PHOSPHOR CHROMATICITIES FOR STANDARD NTSC AND PDP-TV AND THEIR REFERENCE WHITES

	NTSC				PDP			
	R Primary	G Primary	B Primary	Reference white (D_{65})	R Phosphor	G Phosphor	B Phosphor	Reference white
x	0.67	0.21	0.14	0.313	0.64	0.24	0.16	0.293
y	0.33	0.71	0.08	0.329	0.35	0.70	0.11	0.309

IV. Experiment Results and Discussion

Figure 5 and 6 show the results of the color temperature conversion of NTSC-based image containing various color contents. Figure 5(a) is an original image of 6500 K and Figs.

5(b) and (c) are result images after being converted to higher color temperature (15 000 K) for the conventional and the proposed method, respectively.

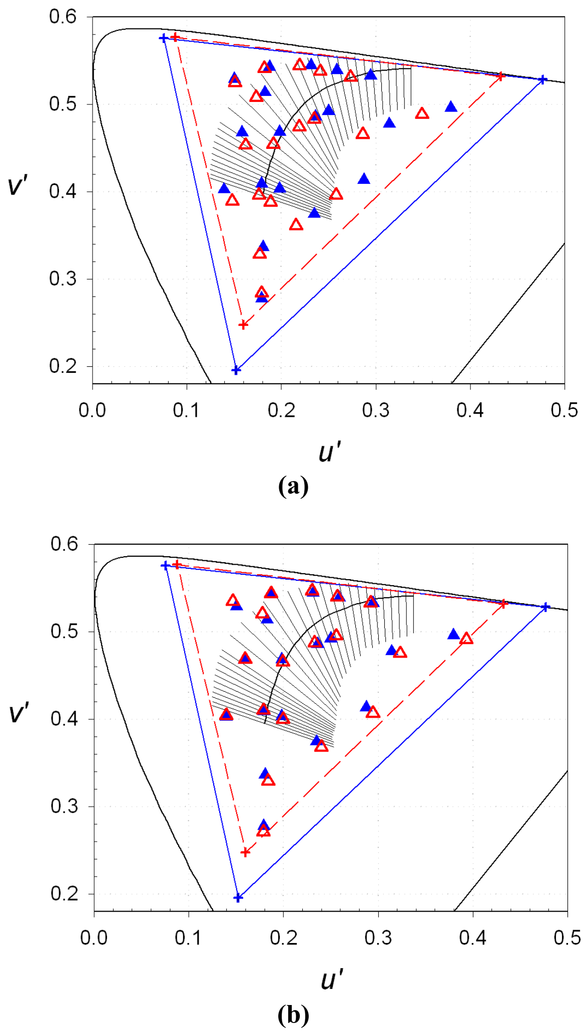

Figure 3. (u', v') **chromaticity coordinates for 24 Macbeth colorchecker colors: (a) before error correction and (b) after error correction. A filled triangle represents an original chromaticity value and an open triangle represent a chromaticity value that was measured directly from the PDP-TV screen by using Color Analyzer CA-100.**

The result image for the conventional method on (x, y) chromaticity coordinate is more bluish than one for the proposed method on (u, v) chromaticity coordinate, as is expected from the previous analysis on Macbeth colorchecker colors. Figure 6(a) is an original image of 6500 K and Figs. 6(b) and (c) are result images after being converted to lower color temperature (5000 K) for the conventional and the proposed method, respectively. Figure 6(b) differs from Fig. 6(c) in that the result image for the proposed method looks more yellowish than one for the conventional method.

Figure 7 shows a sample example of color temperature conversion experiment. Converted images whose color temperatures range from 4000 K to 11 000 K are actually acquired from the PDP-TV screen. It is also found from the careful evaluations that the conversion error becomes smaller with color reproduction error correction. The proposed method of correcting color reproduction error can reproduce color signals faithfully without introducing variation in sharpness and luminance of images.

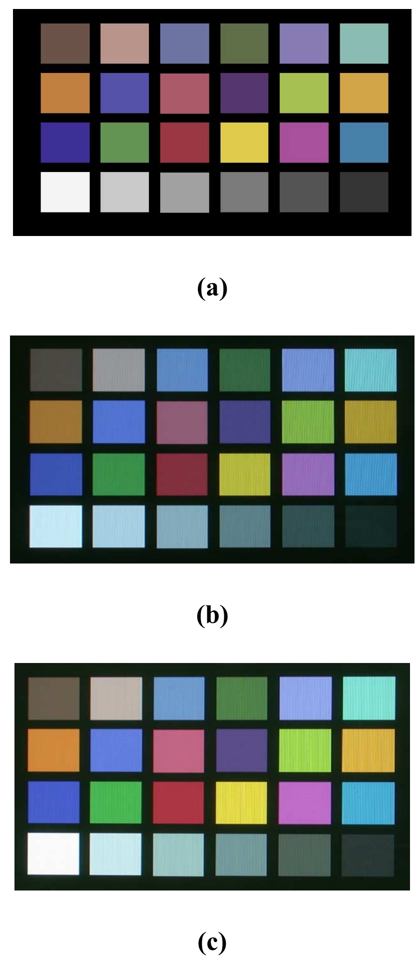

Figure 4. (a) Original Macbeth colorchecker colors, (b) colorchecker images directly captured from PDP-TV screen before error correction, and (c) colorchecker images directly captured from PDP-TV screen after error correction.

(a)

(b) **(c)**

Figure 5. Results from color temperature conversion experiments: (a) original image (6500 K), (b) converted image with higher color temperature (15 000 K) for conventional method, (d) converted image with higher color temperature (15 000 K) for proposed method.

(a)

(b) **(c)**

Figure 6. Results from color temperature conversion experiments: (a) original image (6500 K), (b) converted image with lower color temperature (5000 K) for conventional method, (d) converted image with lower color temperature (5000 K) for proposed method.

(a)

(b) **(c)**

(d) **(e)**

Figure 7. Results from color temperature conversion experiments: (a) original image (6500 K), (b) converted image (4000 K), (c) converted image (5000 K), (d) converted image (9300 K) and (e) converted image (11 000 K). These images are captured from PDP-TV screens.

V. Conclusion

An efficient method of correcting color reproduction error is proposed to be used for color temperature conversion based on the signal processing technique in PDP-TV. The color temperature conversion is accomplished in the uniform color space to match with human visual sensitivity. The matrix of correcting color reproduction error is calculated by using phosphor and primary chromaticities and the reference whites. The proposed method can control a range of color temperatures and can reproduce color signals more faithfully.

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