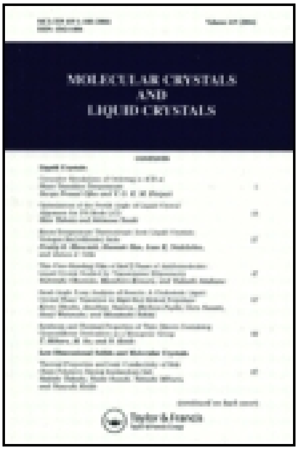

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 31 Jan 2007

To cite this article: Hyun Chul Do, Sung Jin Kang, Sung Il Chien & Heung Sik Tae (2006): Color Correction Method Using Luminance and Chromaticity of Seven Colors in PDP-TV, Molecular Crystals and Liquid Crystals, 459:1, 205/[485]-213/[493]

To link to this article: http://dx.doi.org/10.1080/15421400600930243

Mol. Cryst. Liq. Cryst., Vol. 459, pp. 205/[485]–213/[493], 2006

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400600930243

Color Correction Method Using Luminance and Chromaticity of Seven Colors in PDP-TV

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The displayed colors on PDP-TV screen are not exactly the same as the colors of the transmitted signal from broadcast HDTV because of color reproduction characteristics in PDP-TV. An efficient color correction method is proposed for displaying the digital HDTV-based video signal in PDP-TV by minimizing color reproduction error. It is composed of three correction matrices calculated by using luminance and chromaticity of seven colors. Experimental results show that the average color difference is reduced from 0.0299 to 0.0042 by using the proposed method. The average difference of the proposed method is 0.0021 lower in (u′, v′) chromaticities than that of the conventional method.

Keywords: color correction; color reproduction error; inverse gamma correction; plasma display panel

INTRODUCTION

Plasma display panel televisions (PDP-TVs) are particularly suitable for digital broadcast high definition television (HDTV) because of the large flat panel size (over 42-inch) and excellent image quality [1,2]. However, some image quality aspects still need to be improved. One of those is color reproduction error which is a phenomenon that a PDP-TV cannot display the exact digital HDTV-based video signal

This work was supported by grant No. (R12-2002-055-01003-0) from the Basic Research Program of the Korea Science & Engineering Foundation.

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because of color reproduction characteristics in PDP-TV. The factors which determine color reproduction in PDP-TV include inverse gamma correction [3], cell structure, and inherent emission characteristics of red, green, and blue (RGB) phosphors. Recently, many of PDP-TV manufacturers have changed the display white from the HDTV standard [4] to a more bluish-white by using asymmetrical cells or special color filters. Thus, there is more serious discrepancy for the color reproduction in PDP-TV. In order to correct color reproduction error in CRT, there exist three color correction methods: the four-color matrix method using RGB primaries and a white color [5], the analytic method using region separation in rg-plane [6], and the optimizing method using neural network [7,8]. Two methods except the four-color matrix method have disadvantages of requiring a great deal of measurement data and complex computation.

In this research, a color space is separated into three color regions based on hue: the yellow, the cyan, and the magenta region. The color conversion matrices of PDP-TV and HDTV standard are made independently for three color regions by using luminance and chromaticity of seven colors. An efficient method of correcting color reproduction error based on relationship between the color conversion matrices of PDP-TV and those of HDTV standard is proposed to realize more improved color corrected images in PDP-TV than the four-color matrix method [5].

Color Correction Method

The tristimulus values of the HDTV standard color signals differ from the tristimulus values of color signals measured from the 42-inch PDP-TV due to color reproduction error. The measured tristimulus values from PDP-TV and the calculated tristimulus values from the HDTV standard must be the same for removing such discrepancy in displaying colors. Figure 1 describes the overall block diagram that represents the color correction method using luminance and chromaticity of seven colors in PDP-TV. The inverse gamma correction using $\gamma = 2.2$ is applied to the digital HDTV-based video signal because the correction method compensates the color signals in linear color space. These color signals are transformed to the corrected color signals by the proposed method. Finally, the corrected color signals are displayed in PDP-TV after gamma correction. However, the reproduced color signals are distorted because the gamma value used in inverse gamma procedure in PDP-TV is not exactly 2.2. Thus, gamma correction considering inverse gamma characteristics of plasma TV is applied to the corrected color signals. The inverse gamma characteristics were

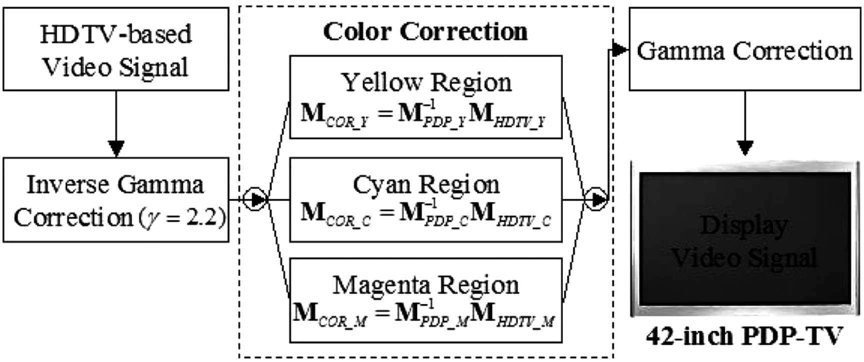

FIGURE 1 Overall diagram of proposed color correction method using luminance and chromaticity of seven colors in PDP-TV.

measured by using Color Analyzer (CA-100) when colors on a 170×96 patch with a zero level background were displayed. The normalized inverse gamma curves are shown in Figure 2.

While the four-color matrix method [5] uses RGB primaries and a white for color correction, the proposed seven-color method partitions the (x, y) chromaticity diagram into three color regions based on hue as shown in Figure 3. Then, the color conversion matrix is made independently for three color regions. It is calculated by using luminance and chromaticity of RGB primaries, white, deep yellow (255, 255, 128), deep cyan (128, 255, 255), and deep magenta (255, 128, 255). However, the color conversion matrix in PDP-TV uses the measured luminance and chromaticity of deep yellow (255, 255, 175), deep cyan (176, 255, 255), and deep magenta (255, 175, 255) due to the inverse gamma characteristics in Figure 2. Let (R_P, G_P, B_P) and (X_P, Y_P, Z_P) be the input RGB values and the tristimulus values of the reproduced colors in PDP-TV, respectively. Then, the color conversion matrices are given by

If $(R_P - B_P) \geq 0$ and $(G_P - B_P) \geq 0$,

$$(X_P \; Y_P \; Z_P)^T = \mathbf{M}_{PDP\_Y}(R_P - B_P \; G_P - B_P \; B_P)^T. \tag{1}$$

If $(G_P - R_P) \geq 0$ and $(B_P - R_P) \geq 0$,

$$(X_P \; Y_P \; Z_P)^T = \mathbf{M}_{PDP\_C}(R_P \; G_P - R_P \; B_P - R_P)^T. \tag{2}$$

If $(R_P - G_P) \geq 0$ and $(B_P - G_P) \geq 0$,

$$(X_P \; Y_P \; Z_P)^T = \mathbf{M}_{PDP\_M}(R_P - G_P \; G_P \; B_P - G_P)^T. \tag{3}$$

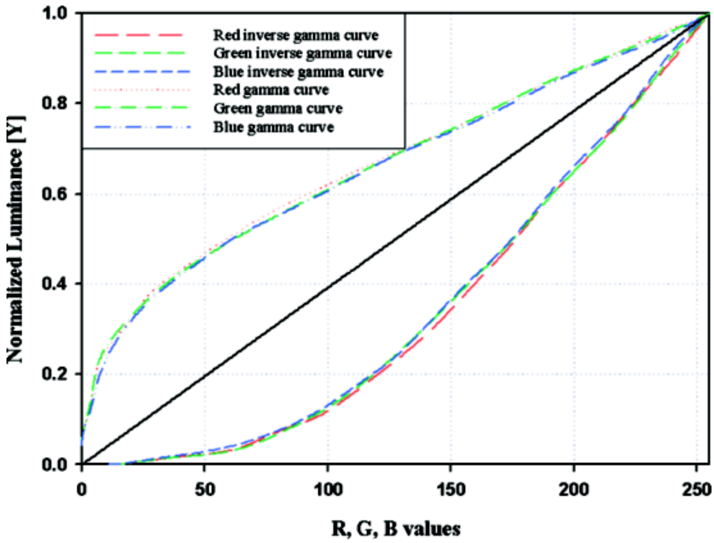

FIGURE 2 Measured inverse gamma curves and corrected gamma curves.

Hence the matrices $\mathbf{M}_{PDP\_Y}$, $\mathbf{M}_{PDP\_C}$, and $\mathbf{M}_{PDP\_M}$ are obtained by using the measured values in PDP-TV as follows: Let the luminance

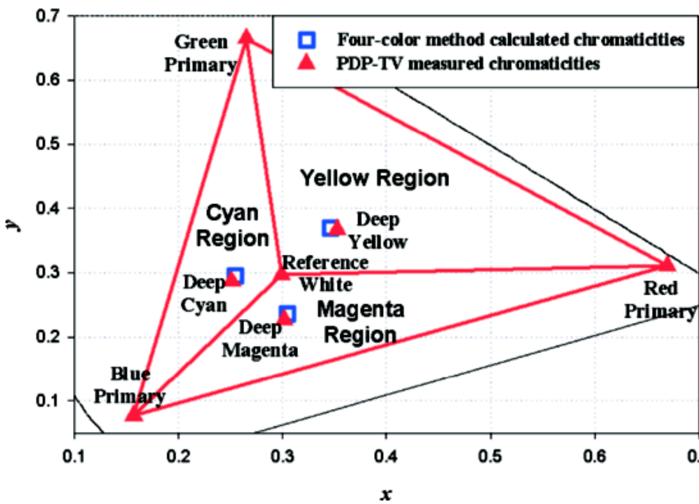

FIGURE 3 (x, y) chromaticity diagram with three color regions.

and the (x, y) chromaticities of deep yellow, deep cyan, and deep magenta be respectively Y_{dy} and (x_{dy}, y_{dy}, z_{dy}), Y_{dc} and (x_{dc}, y_{dc}, z_{dc}), and Y_{dm} and (x_{dm}, y_{dm}, z_{dm}). Let the y_w value be the luminance of white and the (x_r, y_r, z_r), (x_g, y_g, z_g), (x_b, y_b, z_b), and (x_w, y_w, z_w) values be the (x, y) chromaticity of red, green, blue, and white, respectively. Then, the matrix $\mathbf{M}_{PDP\_Y}$ becomes

$$\mathbf{M}_{PDP\_Y} = \begin{pmatrix} x_r & x_g & x_w \\ y_r & y_g & y_w \\ z_r & z_g & z_w \end{pmatrix} \begin{pmatrix} C_r & 0 & 0 \\ 0 & C_g & 0 \\ 0 & 0 & C_b \end{pmatrix},$$

$$\begin{pmatrix} C_r \\ C_g \\ C_x \end{pmatrix} = \frac{2Y_{dy}}{Y_w y_{dy}} \begin{pmatrix} x_r & x_g & x_w \\ y_r & y_g & y_w \\ z_r & z_g & z_w \end{pmatrix}^{-1} \begin{pmatrix} x_{dy} \\ y_{dy} \\ z_{dy} \end{pmatrix}, \quad C_b = \frac{1}{y_w}. \tag{4}$$

The matrix $\mathbf{M}_{PDP\_C}$ becomes

$$\mathbf{M}_{PDP\_C} = \begin{pmatrix} x_w & x_g & x_b \\ y_w & y_g & y_b \\ z_w & z_g & z_b \end{pmatrix} \begin{pmatrix} C_r & 0 & 0 \\ 0 & C_g & 0 \\ 0 & 0 & C_b \end{pmatrix},$$

$$\begin{pmatrix} C_x \\ C_g \\ C_b \end{pmatrix} = \frac{2Y_{dc}}{Y_w y_{dc}} \begin{pmatrix} x_w & x_g & x_b \\ y_w & y_g & y_b \\ z_w & z_g & z_b \end{pmatrix}^{-1} \begin{pmatrix} x_{dc} \\ y_{dc} \\ z_{dc} \end{pmatrix}, \quad C_r = \frac{1}{y_w}. \tag{5}$$

The matrix $\mathbf{M}_{PDP\_M}$ becomes

$$\mathbf{M}_{PDP\_M} = \begin{pmatrix} x_r & x_w & x_b \\ y_r & y_w & y_b \\ z_r & z_w & z_b \end{pmatrix} \begin{pmatrix} C_r & 0 & 0 \\ 0 & C_g & 0 \\ 0 & 0 & C_b \end{pmatrix},$$

$$\begin{pmatrix} C_r \\ C_x \\ C_b \end{pmatrix} = \frac{2Y_{dm}}{Y_w y_{dm}} \begin{pmatrix} x_r & x_w & x_b \\ y_r & y_w & y_b \\ z_r & z_w & z_b \end{pmatrix}^{-1} \begin{pmatrix} x_{dm} \\ y_{dm} \\ z_{dm} \end{pmatrix}, \quad C_g = \frac{1}{y_w}. \tag{6}$$

Here, the intermediate C_x value is not used.

Next, consider the interrelated color conversion matrices of the HDTV-based video signal. Let (R_H, G_H, B_H) and (X_H, Y_H, Z_H) be the inverse gamma corrected RGB values and the calculated tristimulus values of the HDTV-based video signal. Then, the relationship

(R_H, G_H, B_H) and (X_H, Y_H, Z_H) can be specified by the color conversion matrices.

If $(R_H - B_H) \geq 0$ and $(G_H - B_H) \geq 0$,

$$(X_H\ Y_H\ Z_H)^T = \mathbf{M}_{HDTV\_Y}(R_H - B_H\ G_H - B_H\ B_H)^T. \tag{7}$$

Here, the matrix $\mathbf{M}_{HDTV\_Y}$ is calculated by using Eq. (4) with red, green, white, and deep yellow of HDTV standard.

If $(G_H - R_H) \geq 0$ and $(B_H - R_H) \geq 0$,

$$(X_H\ Y_H\ Z_H)^T = \mathbf{M}_{HDTV\_C}(R_H\ G_H - R_H\ B_H - R_H)^T. \tag{8}$$

Here, the matrix $\mathbf{M}_{HDTV\_C}$ is calculated by using Eq. (5) with green, blue, white, and deep cyan of HDTV standard.

If $(R_H - G_H) \geq 0$ and $(B_H - G_H) \geq 0$,

$$(X_H\ Y_H\ Z_H)^T = \mathbf{M}_{HDTV\_M}(R_H - G_H\ G_H\ B_H - G_H)^T. \tag{9}$$

Here, the matrix M_{HDTV_M} is calculated by using Eq. (6) with red, blue, white, and deep magenta of HDTV standard.

Finally, the proposed color correction matrices are computed by using the color conversion matrices of the separated color region. The measured tristimulus values (X_p, Y_p, Z_p) from PDP-TV and the calculated tristimulus values (X_H, Y_H, Z_H) from the HDTV standard must be the same for removing color discrepancy. Therefore, the resultant color correction matrices are given by

If $(R_H - B_H) \geq 0$ and $(G_H - B_H) \geq 0$,

$$\mathbf{M}_{COR\_Y} = \mathbf{M}_{PDP\_Y}^{-1}\mathbf{M}_{HDTV\_Y}. \tag{10}$$

If $(G_H - R_H) \geq 0$ and $(B_H - R_H) \geq 0$,

$$\mathbf{M}_{COR\_C} = \mathbf{M}_{PDP\_C}^{-1}\mathbf{M}_{HDTV\_C}. \tag{11}$$

If $(R_H - G_H) \geq 0$ and $(B_H - G_H) \geq 0$,

$$\mathbf{M}_{COR\_M} = \mathbf{M}_{PDP\_M}^{-1}\mathbf{M}_{HDTV\_M}. \tag{12}$$

EXPERIMENTAL RESULTS

The performance of the color correction methods is evaluated by using the color difference $(\Delta u'v')$ [9] between the original (u', v') chromaticities and the (u', v') chromaticities measured from PDP-TV. According to this criterion, the proposed method was compared to the conventional four-color matrix method [5] to confirm the effectiveness of the proposed method.

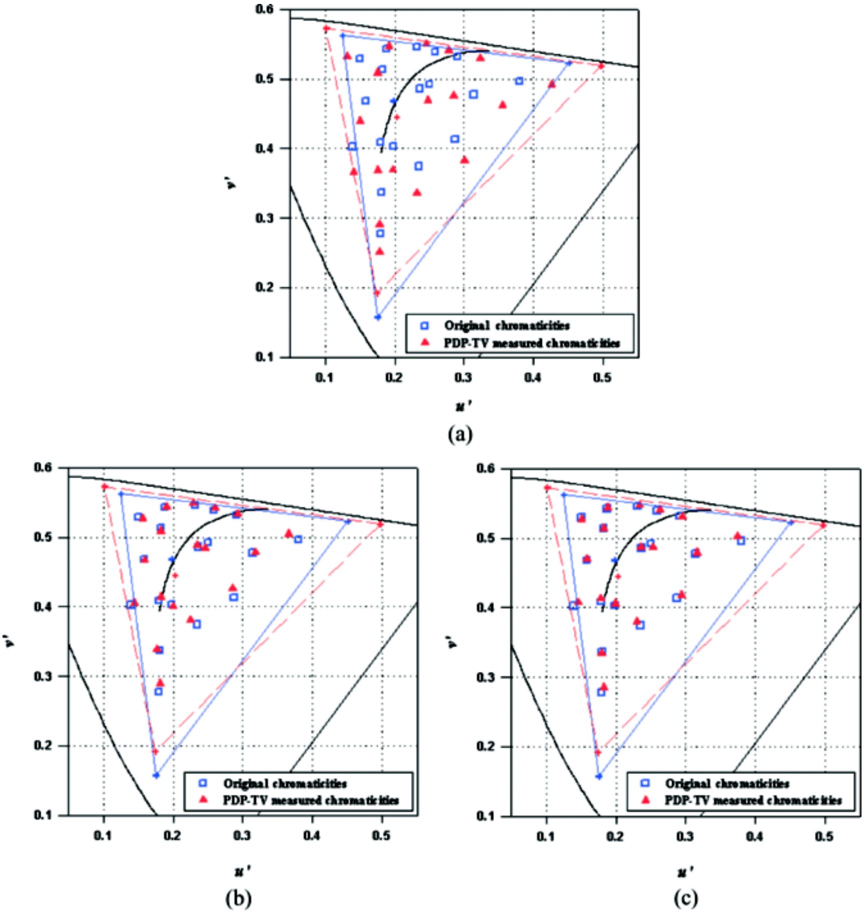

FIGURE 4 (u', v') chromticities for Macbeth colorchecker colors measured on 42-inch PDP-TV: (a) before color correction, (b) after color correction using four-color matrix method, and (c) after color correction using the proposed method.

The RGB primaries, the reference white, and Macbeth colorchecker colors used as testing colors are put on the (u', v') chromaticity coordinates as shown in Figure 4 to evaluate the accuracy of color reproduction in 42-inch PDP-TV. Here, small boxes represent the original (u', v') chromaticities, while small triangles represent the (u', v') chromaticities measured directly from the PDP-TV screen by using CA-100. The solid line represents the color gamut of the HDTV, while the broken line represents that of the PDP-TV. Figure 4(a) shows the

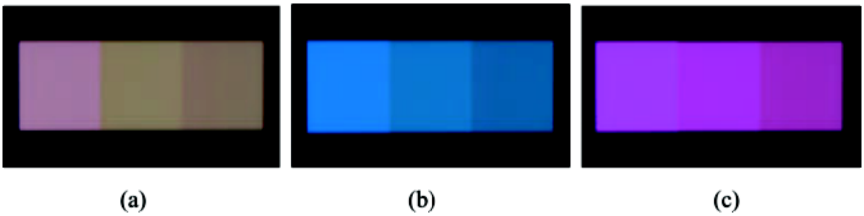

FIGURE 5 Result images captured from 42-inch PDP-TV screen: (a) light skin patch, (b) blue sky patch, and (c) magenta patch.

(u', v') chromaticities before the color correction. Figure 4(b) and 4(c) show the (u', v') chromaticities after the color correction using the four-color matrix method and the proposed method, respectively. As shown in Figure 4, the reproduction error has been decreased the most when the proposed color correction method is used. Numerically speaking, the average color difference before color correction is 0.0299. The average color differences after color correction using the four-color matrix method and the proposed method are 0.0063 and 0.0042, respectively. For a while, two adjacent color patches can usually be distinguished with a $\Delta u'v' \geq 0.004$, but for separated color patches, a shift of $\Delta u'v' \geq 0.04$ is often required to notice a color change [10]. Accordingly, when the proposed color correction method in PDP-TV is applied, the color difference of the reproduced colors is rarely cognized by the human visual system.

Figure 5 shows a sample example of color correction experiment. The result images which are composed of light skin, blue sky, and magenta patch are actually acquired from PDP-TV screen. Each patch is made of three images: the left is the image before color correction, the middle is the result after color correction using four-color matrix method, and the right is the result after color correction using proposed method.

CONCLUSIONS

This paper has proposed the efficient color correction method, which is constructed independently for three color regions by using luminance and chromaticity of seven colors. For Macbeth colorchecker colors the proposed method shows about 33% lower average color difference than the conventional method. The average color difference (0.0042) of the proposed method for PDP-TV is quite close to the threshold called the maximum undistinguishable difference (0.004) above which a human eye is able to recognize two adjacent color patches as the same color.

Thus, the proposed method can reproduce the digital HDTV-based color signals more faithfully.

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