Color Temperature Conversion of Uncalibrated Video Signal Based on Color Compensation in PDP-TV

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Abstract

It is often desirable that manufacturers and users can convert the reference white of display into the preferred color temperature by controlling the color temperature that is one of representative color characteristics of a light source. Accordingly, this paper proposes an efficient method of color compensation for displaying the uncalibrated video signal in PDP-TV and is also shown to be successfully coupled with flexible color temperature conversion based on the signal processing technique.

1. 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. Because 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 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 three steps: a step to estimate the correlated color temperature from the input video signal, a step to transform the input video signal to the output video signal of which the color temperature is the user-preferred color temperature, and a final step to compensate color for PDP-TV.

2. Color Temperature Conversion and Color Compensation in PDP-TV

We estimate the correlated color temperature of the uncalibrated video signal by extracting the reference white region. The transfer matrix is then calculated by using the estimated color temperature and the user-preferred color temperature, thereby converting the input video signal to the output video signal. The color compensation is accomplished by using reference white and phosphor chromaticities. The involved steps are summarized in Fig. 1.

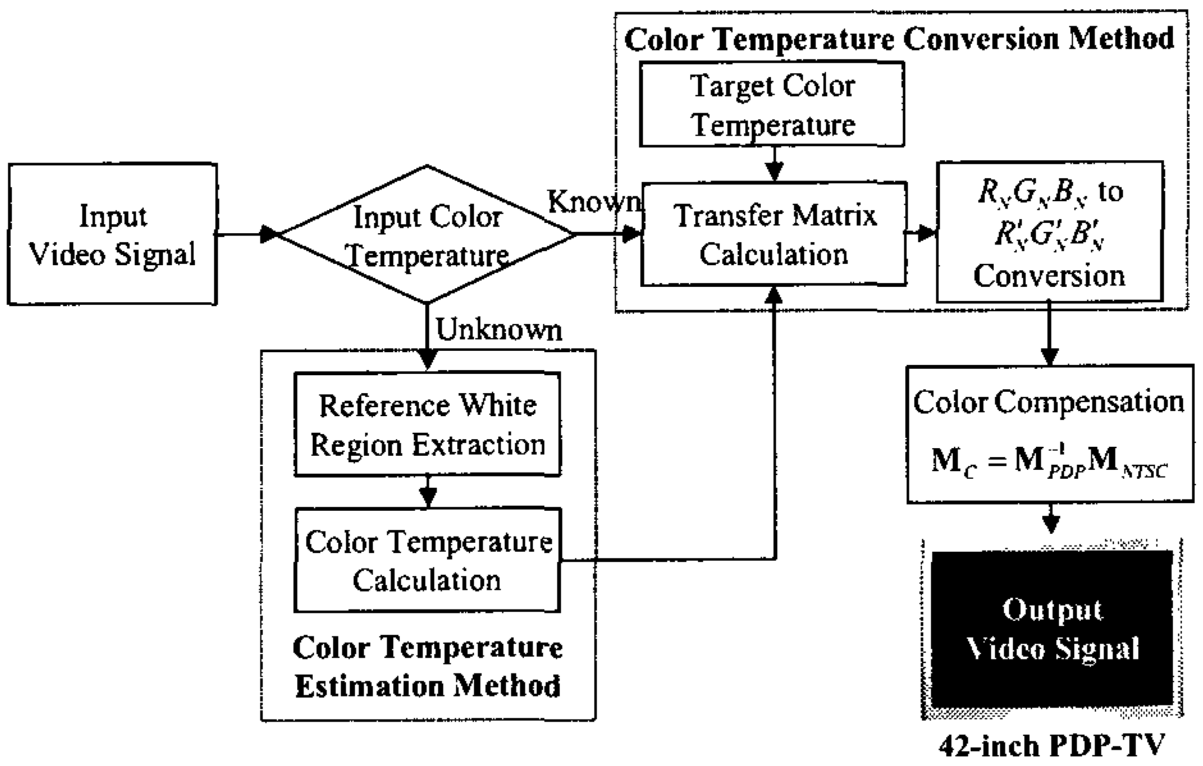


Figure 1 Overall diagram of proposed color temperature conversion method based on color compensation in PDP-TV.

2.1 Color Temperature Conversion of the Uncalibrated Video Signal

In correlated color temperature estimation work, we aim to directly estimate the correlated color temperature from the given uncalibrated video signal and for this, we propose reference white region estimation to calculate the correlated color temperature from the (R,G,B) color domain without changing the R, G, and B values of the uncalibrated video signal into those in the tristimulus (X,Y,Z) domain. In the (R,G,B) coordinates, the neighboring pixels around the maximum peak white point are found and made take part in estimating the white point from an illuminant, which in turn is directly related to discovering the correlated color temperature of the illuminant. The reference white regions are extracted from the input video signal by determining intensity and threshold experimentally [4]. Three (R,G,B) components of the extracted region are averaged to $\overline{R}_{WR},\overline{G}_{WR},\overline{B}_{WR}$. The X, Y, and Z values in CIE 1930 coordinates are obtained by

$$\left[\overline{X}_{WR},\overline{Y}_{WR},\overline{Z}_{WR}\right]^T = \mathbf{M}_{NTSC}\left[\overline{R}_{WR},\overline{G}_{WR},\overline{B}_{WR}\right]^T. \qquad (1)$$

Here, $\mathbf{M}_{NTSC}$ is the matrix which converts (R,G,B) values to the (X,Y,Z) values.

Their normalized tristimulus values, called chromaticity coordinates, (x,y), are calculated by using the (X,Y,Z) primary stimuli as follows:

$$x_s = \frac{\overline{X}_{WR}}{\overline{X}_{WR}+\overline{Y}_{WR}+\overline{Z}_{WR}} \qquad (2)$$
$$y_s = \frac{\overline{Y}_{WR}}{\overline{X}_{WR}+\overline{Y}_{WR}+\overline{Z}_{WR}}$$

The correlated color temperature of uncalibrated video signal is obtained from (x_s,y_s) by applying Robertson's method [5]. In this paper, Robertson's method is changed so that it can be directly used in (x,y) coordinates. If the color temperature of an input video signal is known, this estimation step will be skipped.

In color temperature conversion work, the (R,G,B) contents of the uncalibrated video signal are converted into new ones of which the correlated color temperature will be a user-preferred color temperature. First, 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 is given by

$$\left[X_f,Y_f,Z_f\right]^T = \mathbf{M}_T\left[X_i,Y_i,Z_i\right]^T. \qquad (3)$$

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

$$\mathbf{M}_T = \begin{bmatrix} x_f y_i / x_i y_f & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & z_f y_i / z_i y_f \end{bmatrix}. \qquad (4)$$

Figure 2 shows color temperature conversion that is divided into the two steps. The original (R,G,B) values are transformed into new (R_N,G_N,B_N) values in the color temperature of 6500K.

$$\begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix} = \mathbf{M}_{NTSC}^{-1}\mathbf{M}_{T1}\mathbf{M}_{NTSC}\begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (5)$$

Here, the matrix $\mathbf{M}_{T1}$ can be obtained by using the chromaticity values of the estimated color temperature and the color temperature of 6500K shown in Eq. (4).

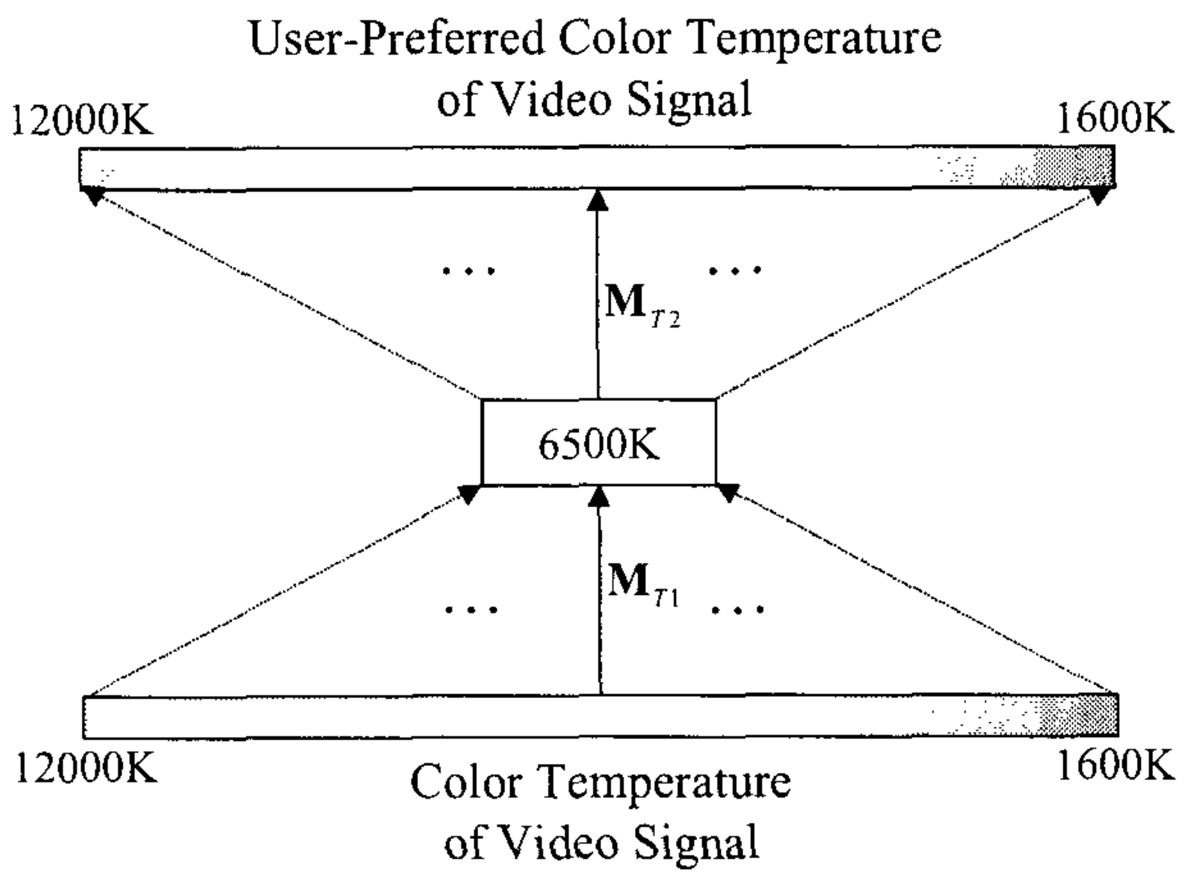


Figure 2 Color temperature conversion method based on color compensation in PDP-TV.

The (R_N,G_N,B_N) values are compensated for color by matrix $\mathbf{M}_C$. The compensated color values are transformed into (R'_P,G'_P,B'_P) values in the user-preferred color temperature.

$$\begin{bmatrix}R'_P\\G'_P\\B'_P\end{bmatrix} = \mathbf{M}_{NTSC}^{-1}\mathbf{M}_{T2}\mathbf{M}_{NTSC}\mathbf{M}_C\begin{bmatrix}R_N\\G_N\\B_N\end{bmatrix} \qquad (6)$$

2.2 Color Compensation in PDP-TV

In the color compensation work, 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 1. To overcome such discrepancy in displaying colors, the compensation 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

$$[X_N, Y_N, Z_N]^T = \mathbf{M}_{NTSC}[R_N, G_N, B_N]^T, \qquad (7)$$

$$[X_P, Y_P, Z_P]^T = \mathbf{M}_{PDP}\,[R_P, G_P, B_P]^T. \qquad (8)$$

Here, **M** matrix can be obtained by using phosphor and primary chromaticities and the reference whites [6].

Table 1 Primary and phosphor chromaticities for standard NTSC and PDP-TV and their reference whites

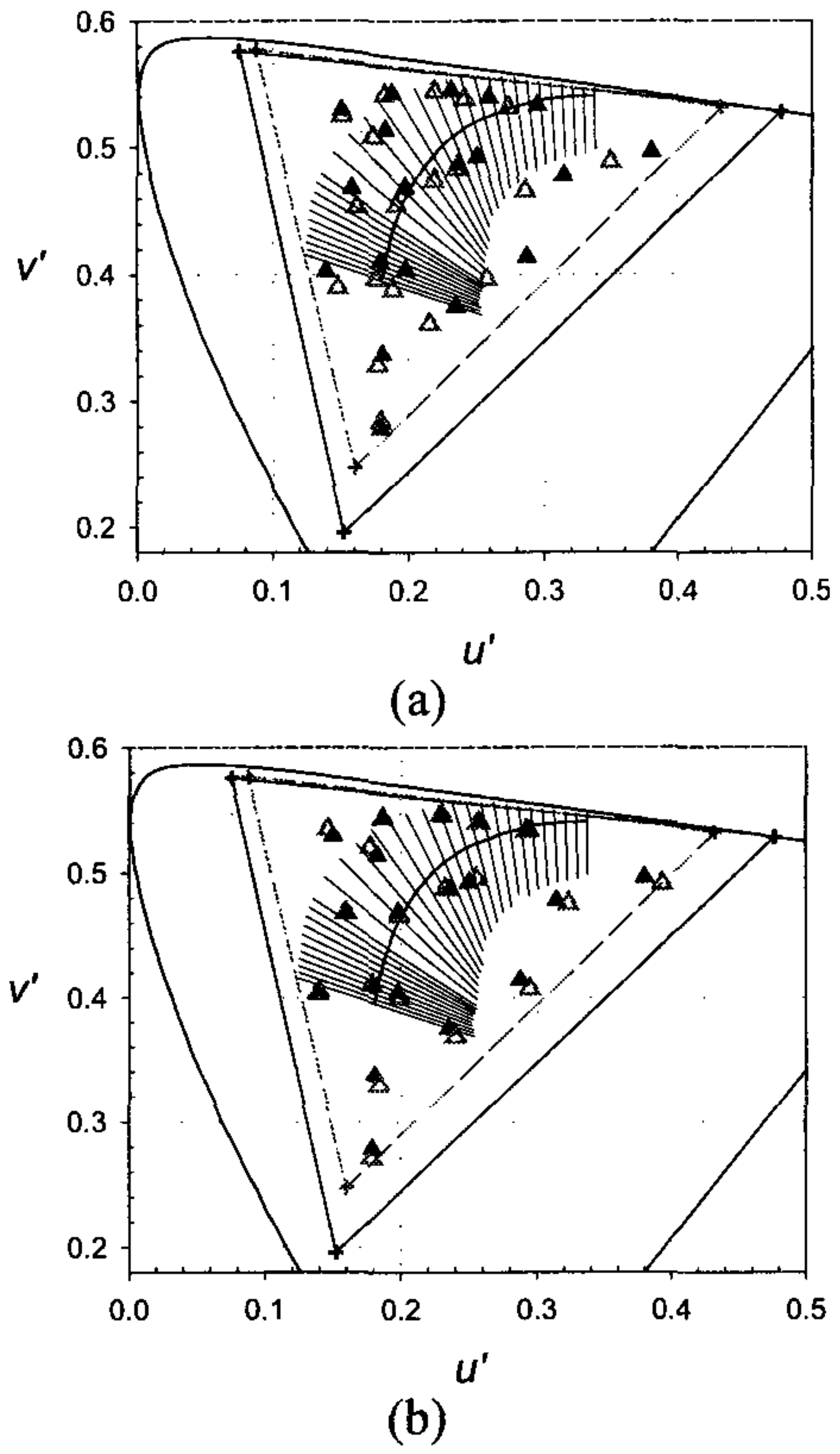
	NTSC				PDP			
	R Prim-ary	G Prim-ary	B Prim-ary	Refe-rence white (D_{65})	R Phos-phor	G Phos-phor	B Phos-phor	Refe-rence white
x	0.67	0.21	0.14	0.313	0.64	0.24	0.16	0.293
y	0.33	0.71	0.08	0.329	0.35	0.70	0.11	0.309

Since the two tristimulus values in Eqs. (7) and (8) must be the same for removing color discrepancy, the resultant converting equation with matrix $\mathbf{M}_C$ is given by

$$[R_P, G_P, B_P]^T = \mathbf{M}_C[R_N, G_N, B_N]^T, \quad \text{where } \mathbf{M}_C = \mathbf{M}_{PDP}^{-1}\mathbf{M}_{NTSC}. \qquad (9)$$

3. Experiment Results

Macbeth colorchecker colors before and after color compensation are put on the (u', v') coordinates as in Fig. 3 (a) and (b), respectively. A filled triangle represents an original chromaticity value and an open triangle represents a chromaticity value which 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 color compensation. Numerically speaking, the average error in $\Delta u'v'$ was 0.017 before color compensation and 0.005 after color compensation. Macbeth colorchecker images are included in Fig. 3 for visual inspection. The images in Fig. 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.



(a)

(b)

Figure 3 (u', v') chromaticities for 24 Macbeth colorchecker colors measured on 42-inch PDP-TV: (a) before color compensation and (b) after color compensation

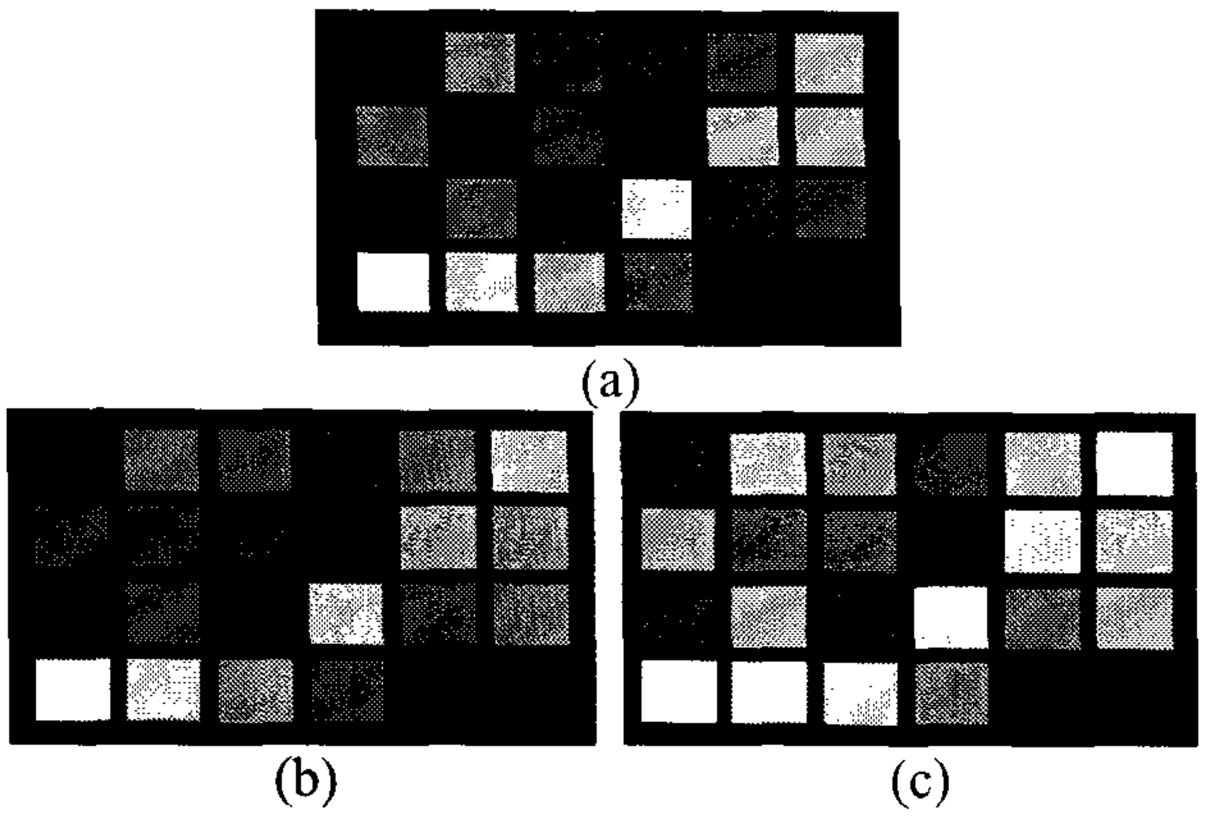

(a)
(b) (c)

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

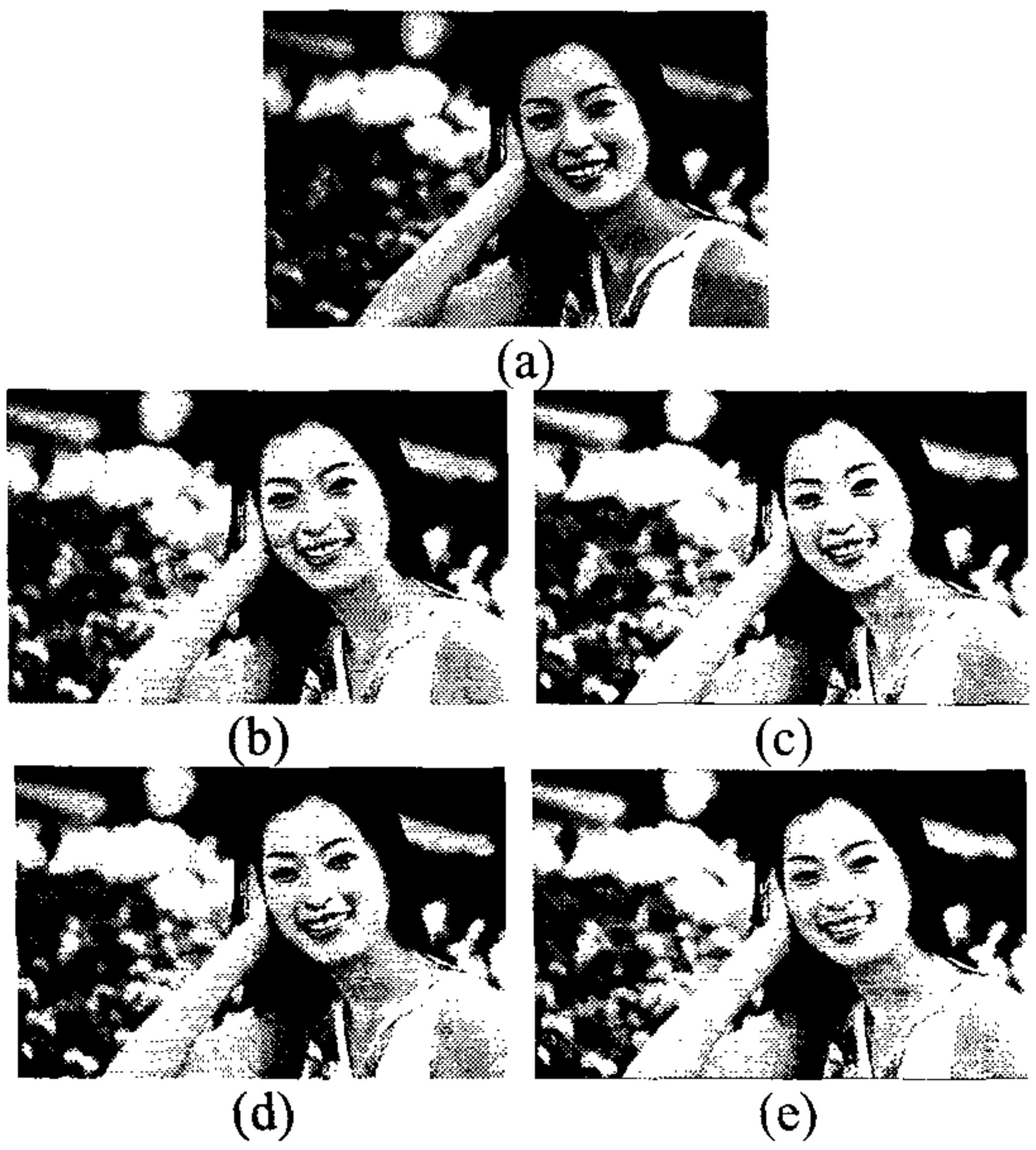

(a)
(b) (c)
(d) (e)

Figure 5 Results from color temperature conversion experiments: (a) original image (6810K), (b) converted image (4000K) captured from PDP-TV screen, (c) converted image (5000K), (d) converted image (9300K) and (e) converted image (11000K)

Figure 5 shows a sample example of color temperature conversion experiment. Converted images whose color temperatures range from 4000K to 11000K are actually acquired from the PDP-TV screen. It is found from the careful evaluations that the conversion error becomes smaller with color reproduction error correction.

4. Conclusion

An efficient method of correcting color reproduction error is proposed to use directly color temperature conversion based on the signal processing technique in PDP-TV. The conversion has been performed by product of conversion and compensation matrices. The proposed method can provide a range of color temperatures that are satisfactory for most viewers and can exactly reproduce color signals.

5. Acknowledgement

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6. References

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