# Color Correction for the Mobile Phone Camera

**Eun-Su Kim**[1] **Soo-Wook Jang**[2], **Sung-Hak Lee**[2], **In-Ho Song**[2], **and Kyu-Ik Sohng**[2]

[1]Division of Electronic Engineering, Sunmoon University, Korea

[2]School of Electrical Engineering and Computer Science, Kyungpook National University, Korea

**Abstract -** *The color correction is needed because the spectral sensitivity of the CMOS image sensor (CIS) in each color is neither the same color component for most standard colors nor the appropriate color representation for any output devices. In the conventional method, a color correction is empirically obtained by a large number of iterative experiments, but the result is not so satisfied. In this paper, a new method to obtain the efficient color correction method for CIS digital camera is proposed. The experimental results show that the transfer characteristic of CIS by the proposed method is close to that of the ideal standard camera. In addition, we confirmed that the image quality of CIS mobile phone camera by the proposed color correction method is dramatically enhanced.*

**Keywords:** CMOS image sensor, Digital camera, Color correction, Image Enhancement

## 1 Introduction

In the digital camera system, CMOS image sensors (CISs) are widely used for mobile phone camera. Because it has low price, low power consumption, low size, and easy of mass production [1]. But channel stopper capacity of CIS which has simple RGB color filter is insufficiency. So CIS has different transfer characteristic from ideal image sensor. Therefore color correction is needed in order to be close to transfer characteristic of ideal camera. In the conventional method, a color correction is empirically obtained by a large number of iterative experiments, but the result is not so satisfied.

In this paper, a new method to obtain the efficient color correction matrix of the CIS digital camera for mobile phone is proposed. In experimental results, the transfer characteristic of digital camera by the proposed color correction method is close to that of the ideal standard camera.

## 2 Video Signal Processing for Cameras

Video signal processing for digital camera has gamma correction, color interpolation, and color correction [2]. *RGB* signal that has passed through Gamma correction and color interpolation block is different from transfer characteristic of ideal digital camera because of spectral characteristic of optical system, light source condition, and characteristic of color filter. Therefore, we need color correction to make like ideal transfer characteristic and equal *RGB* output signal for various camera systems. We must derive and analysis the transfer characteristic of camera.

## 3 Color Correction for Enhancement of the Image Quality

It is camera characterization that represents conversional relation the tristimulus *XYZ* and *RGB* output signals of camera[3],[4]. In this paper, we derive transfer characterization of camera using variable polynomial regression with least squares fitting. This method is widely used to derive the camera transfer characterization[3]. Because only *XYZ* values and *RGB* output signal are needed.

The test colors of the proposed method are Macbeth color checker which has 12 colors. The test bed for camera characterization is shown in Fig. 1. And the transfer characteristic matrix $\mathbf{M_c}$ of the test CIS camera is obtained by Eq. (1).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \mathbf{M_c} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{1}$$

where, $[R\ G\ B]^T$ represent *RGB* output signals of the test CIS camera and $[X\ Y\ Z]^T$ represent the tristimulus *XYZ* of the test colors. In this paper, we use the transfer characteristic matrix $\mathbf{M_c}$ that is obtained by using red, green, and blue in test color set. Because of $\mathbf{M_c}$ using red, green, and blue is more effective than transfer characterization matrix using other colors[4].

In ideal case, output *RG*B value ratio must be 1:1:1 when we photograph specific reference white color with white balanced camera under the reference white. However the transfer characteristic matrix $\mathbf{M_c}$ of the test CIS is not satisfied this. Therefore, we added the white correction part to be satisfied output *RGB* value ratio.

The white correction matrix, $\mathbf{K_W}$, that satisfy camera output value is $R$=$G$=$B$=1. Therefore, $\mathbf{K_W}$ can be found by Eq. (2).

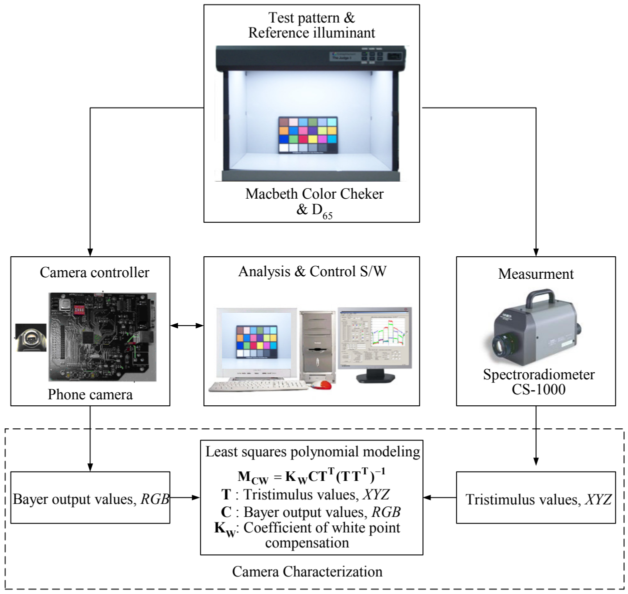



Fig. 1. Schematic diagram of test bed for camera characterization.

$$\begin{bmatrix} R=1 \\ G=1 \\ B=1 \end{bmatrix} = \mathbf{K_W M_c} \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix}_{D_{65}} \tag{2}$$

where, $X_W$, $Y_W$, and $Z_W$ are tristimulus of reference white $D_{65}$. Therefore, white-corrected transfer characteristic matrix $\mathbf{M_{cW}}$ is expressed in Eq. (3).

$$\begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix} = \mathbf{K_W M_c} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \mathbf{M_{cW}} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{3}$$

## 3.1 Set the standard camera as a target

We must set the ideal standard camera to enhance image quality by color correcting. We choose sRGB(ITU-R BT. 709, standard internet color system)[5],[6] as the standard camera considering object of output images of digital camera.

## 3.2 The proposed color correction method

Color correction makes the transfer characterization of camera like that of ideal standard camera and enhance performance of color reproduction and chroma[7].

The proposed color correction procedure is shown in Fig. 2. First, the transfer characterization of the ideal standard camera can be represented in Eq. (4).

$$\mathbf{S_s} = \mathbf{M_s} \cdot \mathbf{T} \tag{4}$$

where, $\mathbf{S_s}$ is output *RGB* values of the standard camera, $\mathbf{T}$ is the tristimulus *XYZ* of the object, and $\mathbf{M_s}$ is transfer characteristic matrix of the standard camera.

Second, the transfer characterization of the test CIS camera in Eq.(2) can be described by Eq. (5).

$$\mathbf{S_c} = \mathbf{M_{cW}} \cdot \mathbf{T} \tag{5}$$

where, $\mathbf{S_c}$ is the output *RGB* values of the test camera and $\mathbf{M_{cW}}$ is white-corrected transfer characteristic matrix of the test camera.

Third, in order to achieved the perfect color correction, Eq.(5) must be same with Eq.(4) about *XYZ* values of the original object. However, because $\mathbf{M_{cW}}$ is different from $\mathbf{M_s}$, the output *RGB* values of test CIS camera can be equal to those of standard camera if it is satisfied as follows.

$$\begin{aligned} \mathbf{S_{cc}} &= \mathbf{M_{cc}} \cdot \mathbf{S_c} \\ &= \mathbf{M_{cc}} \cdot \mathbf{M_{cW}} \cdot \mathbf{T} \end{aligned} \tag{6}$$

where, $\mathbf{S_{cc}}$ is the output *RGB* values of color corrected test CIS camera and $\mathbf{M_{cc}}$ represents color correction matrix.

Finally, the proposed color correction matrix is expressed in Eqs. (7) through (9).

$$\mathbf{S_s} = \mathbf{S_{cc}} \tag{7}$$

$$\mathbf{M_s} = \mathbf{M_{cc}} \cdot \mathbf{M_{cW}} \tag{8}$$

$$\mathbf{M_{cc}} = \mathbf{M_s} \cdot \mathbf{M_{cW}^{-1}} \tag{9}$$

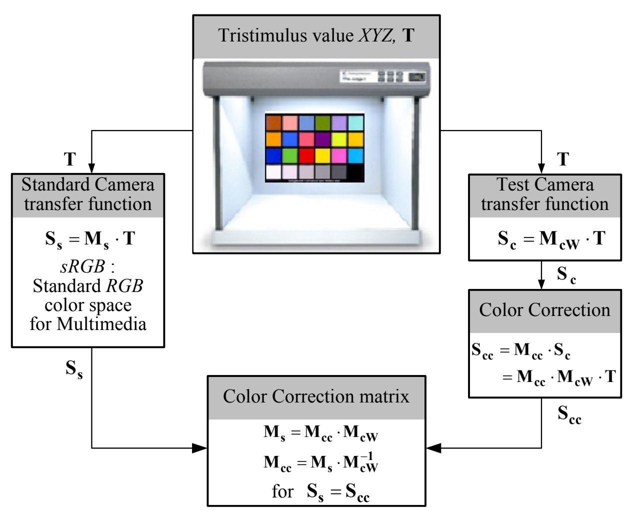



Fig. 2. Block diagram of color correction for image enhancement.

# 4 Experiments and Results

We evaluate the performance of the proposed color correction method. Table 1 shows output *RGB* values between the corrected colors by the proposed method and the uncorrected colors about the test color samples. And hue and saturation for the test color samples in HSV color space[2] are represented in Fig. 3. Color difference between before color correction and after in HSV color coordinates is shown in Table 2. Here, we confirmed that color difference of the proposed method is reduced about 85.5 % from 0.5136 to 0.2130.

The transfer characteristic matrix that is obtained by using output *RGB* values of each camera about the test color samples is shown in Table 3. And, we represented the camera transfer characterization that is obtained through the transfer characteristic matrix of each camera and CIE color matching functions(CMFs) in Fig. 4. Here, we confirmed that the transfer characterization by the proposed method is close to that of the ideal standard camera than the uncorrected test camera.

The transfer characteristic difference can be expressed in Eq. (10).

$$\Delta rgb(\lambda) = \sum \sqrt{(\Delta \bar{r}(\lambda))^2 + (\Delta \bar{g}(\lambda))^2 + (\Delta \bar{b}(\lambda))^2} \quad (10)$$

In Fig. 4, transfer characteristic difference between color corrected camera by the proposed method and standard camera is 3.272. It is 17.096 before correction. Therefore, we confirmed that the transfer characterization of the CIS digital camera by the proposed method is close to that of the ideal standard camera. Also, we confirmed that the image quality of CIS digital camera using the proposed method is improved.

Table 1. Camera *RGB* output value for the test colors.

| Test colors | Ideal target colors | | | Uncorrected colors | | | Corrected colors | | |
|---|---|---|---|---|---|---|---|---|---|
| | *R* | *G* | *B* | *R* | *G* | *B* | *R* | *G* | *B* |
| Blue | 10 | 11 | 76 | 42 | 51 | 77 | 18 | 33 | 107 |
| Green | 16 | 79 | 14 | 75 | 97 | 76 | 51 | 115 | 41 |
| Red | 114 | 8 | 12 | 108 | 61 | 53 | 172 | 31 | 43 |
| Yellow | 202 | 146 | 3 | 205 | 179 | 111 | 254 | 200 | 8 |
| Magenta | 127 | 22 | 73 | 119 | 83 | 96 | 171 | 45 | 119 |
| Cyan | 0 | 58 | 85 | 63 | 86 | 108 | 24 | 79 | 135 |

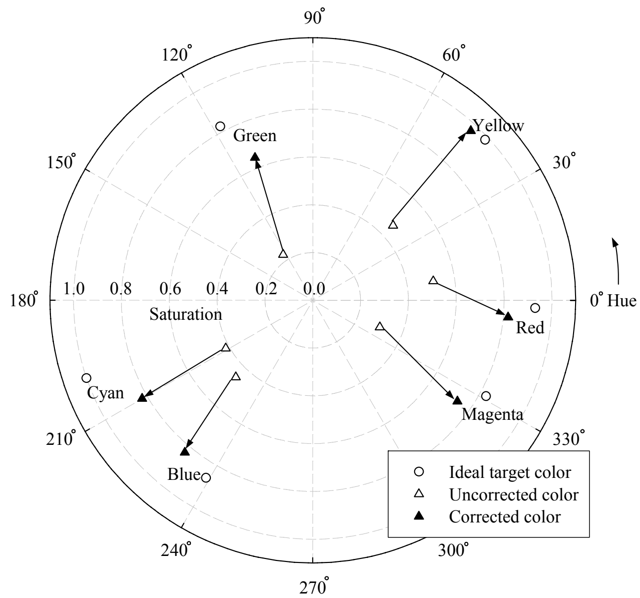


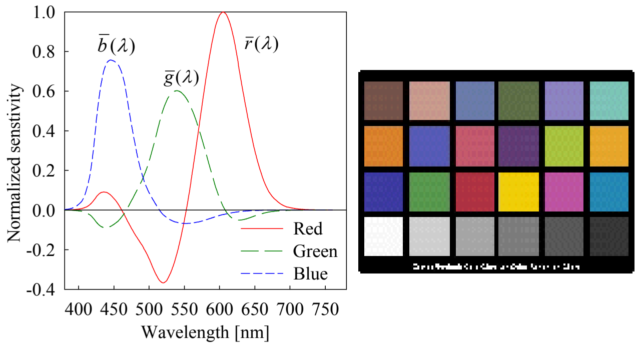

Fig. 3. Hue and saturation for sample patch in HSV color space.

Table 2. Color differences of sample patch in the HSV color space.

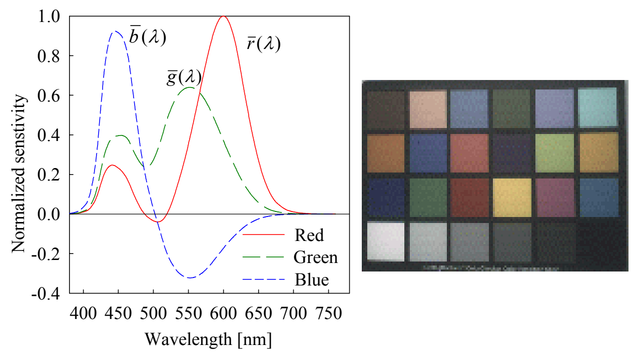
| Test colors | Uncorrected camera | Corrected camera |
|---|---|---|
| | $\Delta E_{HSV}$ | $\Delta E_{HSV}$ |
| Blue | 0.4159 | 0.1295 |
| Green | 0.6003 | 0.2289 |
| Red | 0.4223 | 0.2528 |
| Yellow | 0.5267 | 0.2049 |
| Magenta | 0.5256 | 0.1953 |
| Cyan | 0.5910 | 0.2665 |
| Average error | 0.5136 | 0.2130 |
| Relative color difference [%] | | 85.5 |

Table 3. Ideal target, uncorrected, and corrected camera transfer matrices.

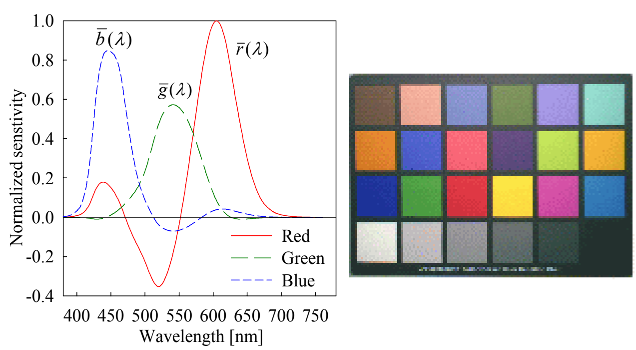
| Camera | Transfer matrix |
|---|---|
| Ideal target camera | $\begin{bmatrix} +3.2300 & -1.5322 & -0.4969 \\ -0.9701 & +1.8777 & +0.0416 \\ +0.0557 & -0.2042 & +1.0579 \end{bmatrix}$ |
| Uncorrected camera | $\begin{bmatrix} +1.5873 & -0.1199 & -0.0874 \\ -0.0693 & +1.0626 & +0.3501 \\ +0.0698 & -0.5589 & +0.8311 \end{bmatrix}$ |
| Corrected camera | $\begin{bmatrix} +3.2062 & -1.4921 & -0.3630 \\ -0.7308 & +1.7240 & +0.1173 \\ +0.2451 & -0.2843 & +1.1494 \end{bmatrix}$ |




(a)




(b) $\Delta\overline{rgb}(\lambda) = 17.096$




(c) $\Delta\overline{rgb}(\lambda) = 3.272$

Fig. 4. Comparison of the transfer characterization and output images : (a) Ideal target standard camera, (b) uncorrected test camera, (c) corrected test camera.

# 5 Conclusions

In this paper, we propose a new method to obtain the efficient color correction matrix for digital camera using CIS is proposed. We derived transfer characteristic of only white balanced camera and made color correction. We applied proposed method to test camera.

In result, we obtained that the transfer characteristic of digital camera by the proposed method is close to that of the ideal camera. Comparison of chromaticity coordinates of output image is as follows. Color difference is reduced by 85.5% from 0.5136 to 0.2130. Also, we can find that Transfer characteristic of corrected camera is close to that of ideal camera and commercial digital camera. Finally, the proposed method is more simple and rapid applicable than previous methods that is obtained through many trial experiment. And proposed method is closer to transfer characteristic of ideal camera than previous methods.

# 6 References

[1] J. C. Russ, *The Image Processing Handbook*, 4th Edition, CRC Press, pp. 8-18, 2002.

[2] Yun Ho Jung, Jae Seok Kim, Bong Soo Hur and Moon Gi Kang, "Design of real-time enhancement preprocessor for CMOS image sensor," *IEEE Trans. on Consumer Electronics*, Vol.46, No 1,pp.68-75, Feb. 2000

[3] G. Hong, M. R. Luo, and P. A. Rhodes, "A study of digital camera colorimetric characterization based on polynomial modeling," *J. of Color Res. and Appl.*, vol. 26, no. 1, pp. 76-84, Feb. 2001.

[4] E.-S. Kim, S.-H. Lee, S.-W. Jang, and K.-I. Sohng, "Adaptive Colorimetric Characterization of Camera for the Variation of White Balance," *IEICE Trans. Electron*, vol. E88-C, no.11, pp.2086-2089, 2005.

[5] ITU-R, *Parameter values for the HDTV standards for production and international programme exchange*, ITU-R BT.709-3, 1998.

[6] S. Susstrunk, R. Bückley, and S.Swen, "Standard RGB color spaces," *Proc. IS&T/SID 7th Color Imaging Conference*, pp.127-134, 1999.

[7] L. J. D'Luna and K. A. Parulski, "A systems approach to custom VLSI for a digital color imaging system," *IEEE J. of Solid-State Circuits*, vol. 26,no. 5, pp. 727-737,May 1991.