Gray Scale CCT Compensation of Mobile Phone LCD

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Abstract: Color reproductions in most LCD are quite different from those of standard CRT (cathode ray tube) monitor display because of the nonlinear characteristic in subtractive color reproduction. Moreover, gray scale CCT (correlated color temperature) reproductions in a typical mobile phone LCD depend on the input RGB levels. A simple LUT (Look-up table) method for constant gray scale CCT and gamma characteristic of mobile phone LCD is presented in this paper. We investigate the mobile phone LCD’s characteristic of compensation of CCT with using the LUT. LCD’s CCT is maintaining about 7500K, which is the target CCT of mobile phone LCD in this paper. Also LCD’s gamma is similar to target gamma.

Key words: CCT compensation, Gamma correction, LUT

1. Introduction

At the present time, the LCD (liquid crystal display) not only emits less radiation and consumers less power, it also takes up less space allowing for a more comfortable work environment. But LCD’s performance of picture quality is still insufficient compared with CRT’s. In general, the CRT has a few variation of CCT (correlated color temperature) with a gray scale and a chromaticity coordinate of the three primary colors with input levels. But for physical, electrical, and optical characterization of liquid crystal and color filter, LCD’s color reproduction has many variations with digital input levels[1]-[3]. Mobile phone LCD display bluish image when digital input level is lower. Namely displayed image goes dimmer, gray scale CCT goes higher. This is Color reproduction characteristic of mobile phone LCD. Okano[4] corrected gray scale CCT with LUT that is only corrected for B data. But only B data is corrected. This makes variation of CCT and coordinates. Namely only B data is reduced. It results in deterioration of luminance characteristics.

In this paper, we investigated characteristics of correlated color temperature and gamma by variation of LCD’s digital input levels. And we proposed new LUT which corrects R, G, B digital input levels for correction of CCT variation by change of gray scale input levels. This LUT has makes smaller deterioration of luminance

Mobile phone LCD applied proposed LUT maintain near target CCT (7500 K) and gamma (1.8). We confirmed that this method reproduce more accurate color than conventional method.

In order to apply to mobile phone hardware without structural modification, we analyzed conventional image processing source code embedded on mobile phone. And we improved conventional image processing part adding new source code that minimizes deterioration of picture quality.

This method applied to exiting mobile phone. That result in more uniform gray scale CCT. Besides we verified nice color that is similar to standard color by decreases of color reproduction error.

2. Characterization of Mobile phone LCD

Video signal processing for mobile phone LCD is shown in Fig 1. Each 8-bit output signals of Y, Cb, and Cr from mobile phone camera are transformed into 8-bit RGB signals respectively. And then this RGB signals are changed to 16-bit signal with removing lower 3-bit of R and B and removing lower 2-bit of G.

To get target display gamma characteristic through compensating nonlinear light transmittance characteristic, mobile phone executes Gray scale control pulse’s position (GCP). Mobile phone LCD in this paper has 64-step GCP. R, G and B of LCD panel has different light transmittance characteristic. So we need three GCP to compensate different light transmittance of R, G and B for right color reproduction on LCD. But most LCD panel has only one GCP. Therefore LCD has more difference between input level and output level. As input level is smaller, CCT of gray scale is higher. In other words, image tone tends to blue and correct color reproduction is impossible.
Absolute temperature of black body that has same chromaticity with some illuminants is defined color temperature of the illuminants. And near color temperature of black body locus is called CCT (correlated color temperature)[4]. Fig. 2 illustrates equal CCT line and reference white point of C, D65, and D75 illuminant on (x, y)-chromaticity coordinates. C and D65 illuminants are standard illuminants that are selected by CIE (Commission Internationale de l'Eclairage). CCT of C illuminant is 6774 K \( (x_w = 0.3101, y_w = 0.3162) \) and CCT D65 illuminant is 6504 K \( (x_w = 0.3127, y_w = 0.3290) \). Reference white for mobile phone LCD is D75 \( (x_w = 0.3037, y_w = 0.3234) \) that is target white value in this paper.

An experiment that achieve in this paper executed under following equal condition. Used Spectroradiometer (MINOLTA CS 1000) in darkroom \( (0 \text{ cd/m}^2) \) of room temperature environment, LCD size is \( 176 \times 220 \) pixels. We controlled measurement range of CS-1000 keeping measurement angle and measurement distance. And test image is fully displaying on LCD. To investigate gamma characteristic of LCD, luminance of 32-step gray, red, green and blue JPEG image is measured. The gamma characteristic of mobile phone LCD is shown Fig. 3.
3. Proposed CCT compensation method for mobile phone LCD

Okano[4] adjusted gray scale CCT to target value through lowering the B input digital value. But only B input digital values are changed. This causes deterioration of LCD's luminance characteristics.

In this paper, hence, we propose changing method of R and B input digital values. Also, we proposed LUT that makes fixed CCT for general mobile phone LCD with one GCP. Conventional RGB 5-6-5 bit system has resolution deterioration. Therefore, proposed method uses RGB 6-6-6 bit system by bit stuffing. In order to apply to mobile phone hardware without structural modification, we added color convert function to conventional image processing source code embedded on mobile phone.

Fig. 5 illustrates flowchart of improved video signal processing to reproduce standard color for mobile phone LCD.

In this paper, we proposed CCT correction method without deterioration of picture quality. Simple flowchart of this process is shown Fig. 6. First, we set the reference white value to $D_7$ for mobile phone LCD. Because mobile phone LCD display full white at $D_7$. Also we set the gamma value for mobile phone LCD to 1.8 that is value considered mobile phone camera and human visual gamma. And then measuring the maximum luminance of set value of display reference white, $L_{max}$ and setting luminance value of i-th step based on $L_{max}$ is,

$$L_i = L_{max} \times \left( \frac{m}{64} \right)^{1.8}$$

where 64 is the number of full step and 1.8 is setting value for mobile phone LCD.

And we adjust values of R and B in order to keep CCT of gray scales in range of 7500 K ± 500 K and maximum contrast ratio of LCD. We remain dark range that has wide differences of CCT because human visual system can't perceive color variation as luminance reducing. LUT for CCT compensation is shown in Fig. 7.
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Figure 3. Gamma characterization for mobile phone LCD:
(a) Luminance of R, G, B and White; (b) gamma characteristics.

Fig. 4 illustrates change of chromaticity coordinates of gray scales by change of input digital values, from white (R(255), G(255), B(255)) to black (R(0), G(0), B(0)). As input digital value is smaller, the variation on chromaticity coordinate is bigger.

Figure 4. Locus of gray chromaticity points on (x, y) diagram varying the input digital level.
Figure 5. Flowchart of improved video signal processing to reproduce standard color for mobile phone LCD.

- Display reference white and gamma setting: \( D_w(x_r=0.3037, y_r=0.3234), \gamma = 1.8 \)
- Measurement of maximum luminance of reference white, \( L_{\text{max}} \)
- Calculation of gamma corrected luminance of \( i \)-th gray level, \( L_i \):
  \[ L_i = L_{\text{max}} \cdot \left( \frac{1}{64} \right)^{\gamma} \]
- Control tcl R and B input value
- Adjustment of gamma and CCT in each gray level

Figure 6. Process of gamma and CCT correction all together.

Figure 7. CCT correction LUT for mobile phone LCD.

4. Result of CCT correction for mobile phone LCD

Fig. 8(a) and (b) illustrate before and after applying the proposed LUT. It is shown that chromaticity coordinates of gray scales vary greatly with input digital values in Fig. 8(a). But chromaticity coordinates and CCT of gray scales keep stability in Fig. 8(b). After compensation, we know that the gamma of mobile phone LCD is similar to target gamma value 1.8. If we compensate gamma and CCT correctly, we can find characteristic of color additivity.

Figure 8. Comparison of chromaticity and CCT:
(a) Comparison of chromaticity coordinate variation; (b) comparison of CCT variation.
Figure 9. Result of gamma and CCT correction: (a) Luminance of R, G, B, and white; (b) gamma characteristics of R, G, B, and white; (c) characteristics of color additivity.

5. Conclusions

In this paper, first we analyze characteristics of mobile phone LCD, white and gamma, with display color reproduction theory. And then we propose CCT and gamma compensation by LUT. This method reduces color reproduction errors and CCT variation for varying input digital values that is caused by physical and electro-optical characteristic of mobile phone LCD. Fig. 9 illustrates result of gamma and CCT correction. Experimental results confirmed that the proposed method keeps CCT near target CCT(7500 K) and target gamma (1.8).

References


