Image quality evaluation based on Sigmoid function by the modified Color Distribution Index (mCDI)

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ABSTRACT

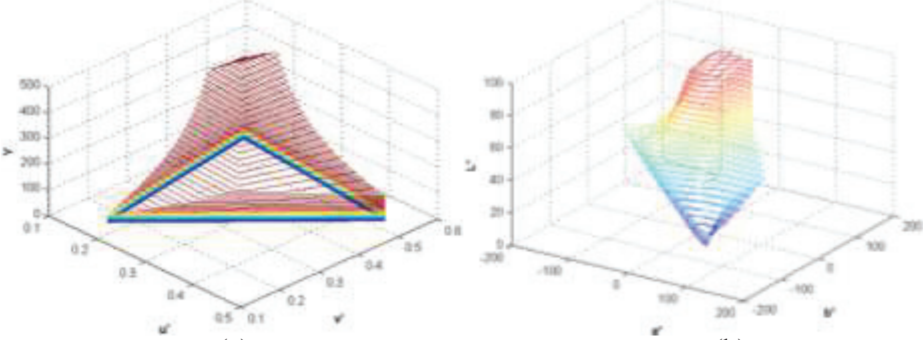
The Color Distribution Index (CDI) proposed by Toshiyuki Fujine and et al., was used to evaluate the color distribution under specific primary colors in displays from the color box divided by the certain determined luminance and color coordination. The image quality evaluates by the physical characteristics, including luminance, gamma correction, color gamut, and bit depth. Image quality strongly depends on the gamma correction resulting in the common function defaulted in display color correction. Gamma correction is one of the standard characteristic, describes the relationship between the input and output luminance. However, the conventional exponential gamma correction could not fulfill the visual adaption of bright and dark image. The Sigmoid function modified the gray level at high and low luminance of the displays and approaching the gradation of human perception may a solution for the difficulty. This paper proposed a modified Color Distribution Index (mCDI) tries to evaluate the image quality when the image under the Sigmoid function correction. The description of color correction by using Sigmoid function increases the values of mCDI and color reproduction quality in different levels of the color gamut volume, also decreases the requirement of bit depth compared with the exponential function of color correction.

KEYWORDS: Sigmoid function, Color correction, modified Color Distribution Index.

INTRODUCTION

The Color Distribution Index (CDI) proposed by Toshiyuki Fujine and et al., considered the physical characteristics of the display to evaluate the color distribution of the display [1]. The CDI employs the Just Noticeable Difference (JND) [2] of luminance and color difference ($\Delta u'v'$) to create the unit cell, and the unit cell (CDI cell) can be regarded as a region approximating the MacAdam ellipse which is built by the CIELUV uniform color space and absolute luminance Y (cd/m^2). Then, the color gamut volume of the display is built and separated into certain CDI cells, according to the definition of luminance and color difference. As a reproducible color point is filled in a CDI cell, the color point can represent the colors which are surrounded by the CDI cell. As all CDI cells of the display in the color gamut volume have one or more color points, the colors inside the color gamut volume can be fully reproduced by the sample display.

The concept of the CDI, containing the human perception (JND of the luminance and color difference) to evaluate the image quality of the display. Unfortunately, the color gamut volume of the CIELUV color space is formed into a pyramid shape and the shape produces the widest gamut at the bottom of the color gamut volume. Owing to the main dominator of the human vision transferring from cones to rods at low luminance condition (under 3 cd/m^2) [2], the gamut of the low luminance condition should be smaller than the gamut of the high luminance condition. In this paper, we propose the new evaluation index called modified Color Distribution Index (mCDI), using the color gamut volume in CIELAB color space, approximate human vision and uniform color space. Also, we propose the description of color correction by Sigmoid function, increases the values of mCDI and color reproduction quality in different levels of the color gamut volume, also decreasing the requirement of bit depth compared with the exponential function of color correction. Figure 1(a) and 1(b) shows the color gamut volume in *u'v'Y* and CIELAB color space, respectively [3].



(a) (b)

Figure 1: Color gamut volume in u'v'Y and CIELAB color space.

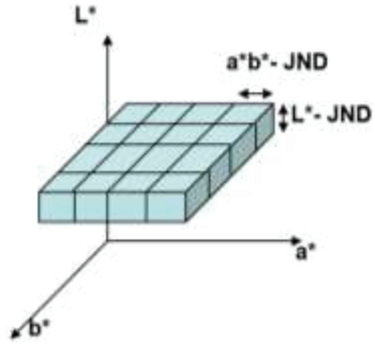


Figure 2: concept of mCDI cells.

The basic concept of mCDI is the same as the CDI. Figure 2 shows the concept of mCDI cells in CIELAB color space. The color gamut volume of the display is separated into certain mCDI cells, according to the JND of luminance and color difference. In mCDI, the height of the mCDI cells ΔL is defined as the JND luminance ratio of the sample luminance L as $\Delta L/L$=0.01. According to the research of Shen and Berns [4], the color difference of human visual was described. The maximum width of the mCDI cells is defined as 0.4.

Image quality evaluation is used to judge the quality of digital image. It divides into subjective and objective method. And also divides into Full-reference (FR) methods and No-reference (NR) methods. Mean Square Error (MSE) and Peak signal-to-noise ratio (PSNR) are common used to evaluate the distortion of the image [5].Structural SIMilarity (SSIM) Index is the method considered human visual perception [6]. In this paper, mCDI is used to evaluate the quality of image. The mCDI is a No-reference method. It evaluates by the physical characteristics of the image. Such as color correction, color gamut, bit depth, and etc..

GAMMA THEORY

Color correction is used to modulate the intensity or tri-stimulus values of gray level in display or sensing device. Gamma correction is one of the common characteristic in color correction, describes the relationship in exponential function as equation (1). Where L_{output} and L_{input} denote the output and input values of intensity, respectively. γ denotes the exponential parameter of input intensity. All of the intensity are normalized in the range of 0~1 by the constant of A.

$$L_{output} = AL_{input}{}^{\gamma} \tag{1}$$

In order to enhance the image quality in the low and high luminance level. Sigmoid gamma function is proposed as equation (2).

$$S(y) = \frac{x}{1+e^{(A+C_1g+C_2g^{r_1}+C_3g^{r_2})}} \quad \text{and} \quad g = \frac{t}{2^n-1} \tag{2}$$

Where x and y denote the input and output values of intensity, respectively. t denotes the gray level of the display. r_1 and r_2 denote the exponents of the power function; n denotes the bit depth of the display. A, C_1, C_2 and C_3 denotes the parameters for the Sigmoid function. The Sigmoid function is adjusted by the intensity of four sampled gray level of the sample display. The parameters A, C_1, C_2 and C_3 are solved by substituting the corresponding light intensity of gray level of the display into Sigmoid function. Figure 3 shows the curves of gamma function and Sigmoid function.

EXPERIMENTAL

The simulation of mCDI takes the standard of color gamut BT. 709 as the gamut characteristic, and takes the other physical characteristics as parameter. The physical characteristics of display are referred to Table 1. Four modulation of color correction will be chosen as gamma 1 and 2.2, Sigmoid function 1 and 2. The width of mCDI cell is 0.4. The four curves of color correction are shown in Figure 3. The modulation of Sigmoid function 1 and 2 will distribute more descriptions of gray level at high and low luminance.

Table 1. Parameters of physical characteristics

Characteristics	Parameters			
Luminance of white point (Y_w)	450 cd/m^2			
Contrast ratio	3000:1			
Bit depth of tri-primary colors	8 bits			
Color gamut	BT. 709	Red: x=0.64 y=0.33	Green: x=0.3 y=0.6	Blue: x=0.15 y=0.06

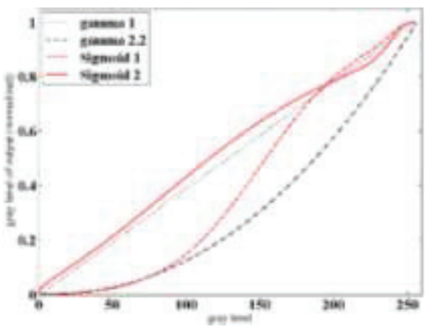


Figure 3: The gamma and Sigmoid functions for simulation.

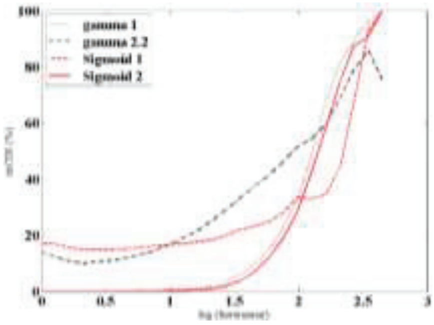
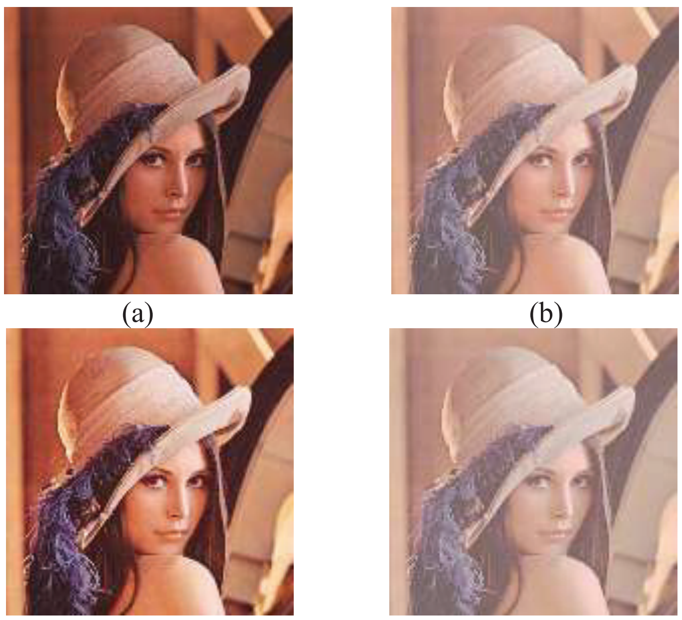


Figure 4: The mCDI result of simulation.

RESULTS AND DISCUSSION

The mCDI result of the four color correction function are shown as Figure 4. The mCDI values enhanced as the output intensity of Sigmoid 1 lower than the curve of gamma 1 in low interval of gray level. The mCDI values of Sigmoid 2 in the same interval approach to 0. Since the color points of low luminance transferred by curves over



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

Figure 5: Color correction of sample image 1 (a) gamma 2.2, (b) gamma 1, (c) Sigmoid 1, (d) Sigmoid 2.

Figure 6: Color correction of sample image 2 (a) gamma 2.2, (b) gamma 1, (c) Sigmoid 1, (d) Sigmoid 2.

gamma 1 are divided into higher luminance part of color volume. The mCDI values of Sigmoid 1 and 2 achieved to 100% in high interval of gray level. The gray level of mCDI value achieved to 100% will decrease as the enhancement of bit depth. The sample images of the four color correction are shown as Figure 5 and 6. Since more gray level description at high and low intensity by Sigmoid function, the intensity of sample images by Sigmoid function will increased. The images can be adjusted to the real color points by modulating the Sigmoid function.

CONCLUSION

In this paper, the No-reference of image quality evaluation method by the modified Color Distribution Index (mCDI) was proposed, under Sigmoid and gamma function of color correction. The description of color correction by using Sigmoid function increases the values of mCDI and color reproduction quality in the color gamut volume, also decreases the requirement of bit depth compared with the exponential function of color correction.

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