

A Tone Reproduction of Displayed and Printed Images Predicted by Using CIECAM02

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Abstract

It is known that preferred tone reproduction is affected by color appearance phenomena. Therefore a preferred tone reproduction curve can be obtained if using a color appearance model that can predict color appearance phenomena accurately. Many color appearance models have been proposed, and the latest color appearance model is CIECAM02 that CIE published in 2004. The CIECAM02 model takes into account Stevens effect, but CIECAM97s, the base model of CIECAM02, does not deal with high levels of illumination such as sunlit conditions. Then, we examined whether the CIECAM02 model could give a tone reproduction curve similar to the preferred tone reproduction curve of conventional photography or not. As a result, it was found that the CIECAM02 model could not be used to predict preferred tone reproduction curves. In addition, we measured tone reproduction curves of two typical imaging systems, DSCs (Digital Still Cameras) and displays, and DSCs and printers. Comparison of the obtained curves with those from the CIECAM02 model showed that they considerably differed in shape.

Introduction

There are various image input/output devices, which have their own tone reproduction characteristics. Many studies of tone reproduction have been made and reported since the age of analog photography.^[1] In the literature [1], a preferred tone reproduction curve from subjective evaluation experiment was described. Since a preferred tone reproduction curve is affected by color appearance phenomena, we thought that the preferred tone reproduction curve could be obtained by using a color appearance model that can predict color appearance phenomena accurately. In fact, the tone reproduction curve calculated by Nayatani model was similar to the preferred tone reproduction curve of analog photography.^{[2][3]} Many color appearance models, e.g. Nayatani model, Hunt model and CIECAM97s, were proposed and in 2004, CIECAM02 was published.^[4] Then, color appearance models were almost completed by the appearance of CIECAM02 and trend of research was shifted from color appearance models to image appearance models and noise appearance models. It is thought that Stevens effect, which refers to an increase of contrast with illuminance, has significant effects on preferred tone reproduction curves, and the CIECAM02 model takes into account Stevens effect.^{[5][6]} On the other hand, CIECAM97s that is basis for CIECAM02 does not deal with high levels of illumination.^{[4][7]} Therefore it is not clear whether the CIECAM02 model can predict a preferred tone reproduction curve for an outdoor scene such as sunlit scenes or not. In this study, we attempted to calculate a tone reproduction curve by using the CIECAM02 model, and compared it with the preferred tone reproduction curve obtained in conventional photography. Also the tone reproduction curve predicted by

CIECAM02 was compared with the tone reproduction curves of the representative imaging systems such as digital still camera and display, and digital still camera and printers.

Tone reproduction curve predicted by CIECAM02

In this study, the term “original condition” and “reproduction condition” are referred to as viewing conditions for original colors placed in outdoor scene and reproduced colors observed in a

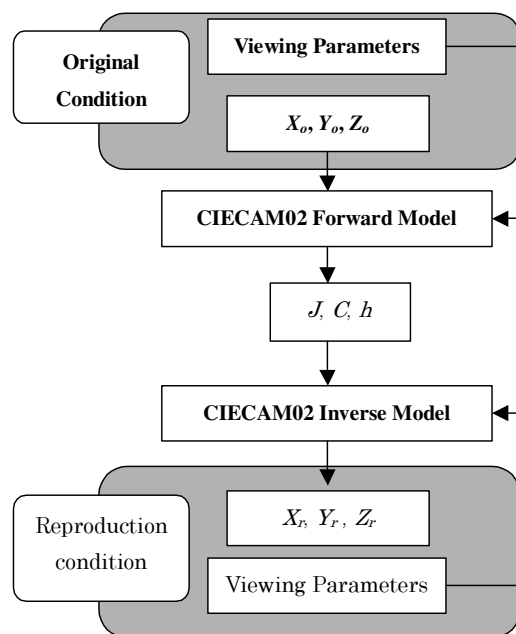


Fig. 1. Flow chart for calculating tone reproduction curve by using CIECAM02

room respectively. Variables of original and reproduction conditions are designated with suffixes “o” and “r” respectively. For calculating tone reproduction curve predicted by CIECAM02, it is necessary to calculate tristimulus values of reproduced colors from those of original colors. For using CIECAM02, it is necessary to assign viewing parameters in both original and reproduction conditions that built up with adapting luminance L_A , surround ratio S_R , tristimulus values of reference white X_W , Y_W and Z_W , and luminance factor of background Y_b . In this study, device whites of original and reproduction conditions were assigned to perfect diffuser under illuminants D_{55} and D_{50} respectively. Values of viewing parameters of original and reproduction conditions are summarized in Table 1.

Table 1. Viewing parameters of original and reproduction conditions

	Original condition	Reproduction condition
Illuminant	D_{55}	D_{50}
X_W	95.68	96.42
Y_W	100.00	100.00
Z_W	92.14	82.49
L_A	4000cd/m ²	20cd/m ²
S_R	1.0	1.0
Y_b	0.2	0.2

Values of lightness J , chroma C and hue h were calculated from tristimulus values of grays X_o , Y_o , and Z_o and viewing parameters in original condition by using CIECAM02 forward model. Then tristimulus values X_r , Y_r , and Z_r were calculated from the values of J , C and h and reproduction condition by using CIECAM02 inverse model. The calculated tristimulus values X_r , Y_r , and Z_r meant the values in reproduction condition were the same appearance as tristimulus values X_o , Y_o and Z_o in original condition. Then tristimulus values Y were transformed to lightness L^* . Finally, reproduced lightness L_r^* were plotted to original lightness L_o^* , and a tone reproduction curve was drawn. The tone reproduction curve predicted by CIECAM02 is shown in Fig. 2 with the preferred tone reproduction curve of Reference [1]. In this

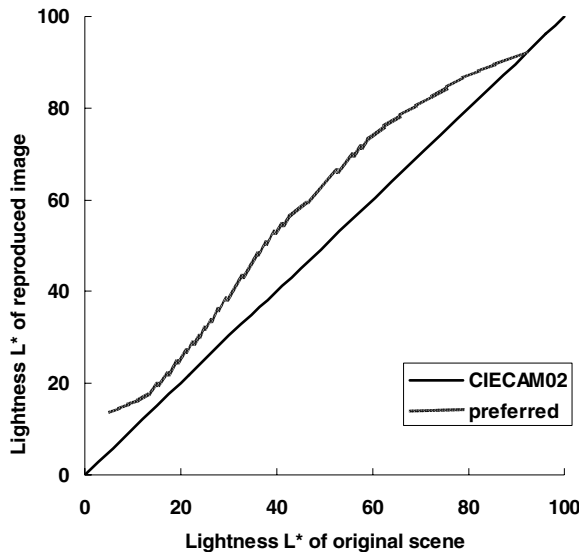


Fig. 2 Tone reproduction curve predicted by CIECAM02 and the preferred tone reproduction curve

study, tone reproduction curves are shown in lightness, not in density. The tone reproduction curve predicted by CIECAM02 is linear, and dissimilar to the S-shaped preferred tone reproduction curve. Cause of it is CIECAM02 built on the basic structure and

form of CIECAM97s. CIECAM97s was designed for simplicity and usability, while comprehensive model CIECAM97c was supposed to be designed for all conditions. However CIECAM97c was not finished up. High luminance condition

Comparison with tone reproduction curves of current imaging systems

Tone reproduction curves of current imaging systems were measured and compared with the tone reproduction curve predicted by CIECAM02. At first, the chart, Gretag Macbeth Color Checker DC, was illuminated by an illuminant of simulated D_{55} , and tristimulus values X_o , Y_o , and Z_o of twelve gray patches on the chart were measured with Topcon Spectroradiometer SR-3. The illuminant was consisted with tungsten lamps and conversion filters for color temperature, the color temperature of the illuminant was about 5100K. [8] Tristimulus values of device white in original condition X_{no} , Y_{no} , and Z_{no} were assigned those of perfect diffuser under the simulated D_{55} . On the other hand, tristimulus values of device white of each display in reproduction condition X_{nr} , Y_{nr} and Z_{nr} were measured with SR-3. Viewing parameters of original and reproduction conditions are summarized in Table 2.

Table 2. Tristimulus values of device white and color temperature of original and reproduction conditions

	Original condition	Reproduction condition		
		CRT	LCD	Printers
Illuminant				D_{50}
X_n	106.29	96.68	98.92	96.42
Y_n	100.00	100.00	100.00	100.00
Z_n	105.33	108.21	105.19	82.49
Color temperature	5100	5800	6300	5000

The chart was taken with four DSCs under original condition. DSCs 1 and 3 are digital single-lens reflex cameras, DSCs 2 and 4 are compact DSCs. Four images were displayed on two monitors, CRT and LCD, and printed by two inkjet printers. Tristimulus values, X_r , Y_r , and Z_r , of the gray patches in the displayed and printed images were measured with SR-3 or Gretag Macbeth Spectro Eye. Tristimulus values Y in each condition were converted to L^* values. Then tone reproduction curves were plotted. The tone reproduction curves of the imaging systems are shown in Figs. 3 and 4 with the tone reproduction curve predicted by CIECAM02 and the preferred tone reproduction curve. Tone reproduction curves of imaging systems were S-shaped, and shape of them are similar to the preferred tone reproduction curve. The tone reproduction curves of all imaging systems are lower than the preferred tone reproduction curve. Lightness of reproduced image of tone reproduction curves of displays is higher than those of printers at high lightness region in Fig. 3. This is caused by different Y_n which is a denominator of the equation calculating L^* . Measured values of Y of device white are used as Y_n of displays, but hypothetical value of Y of perfect diffuser as Y_n of printers. Shapes of the tone reproduction curves by CIECAM02 and of the

current imaging systems are different, but positions of those curves are near.

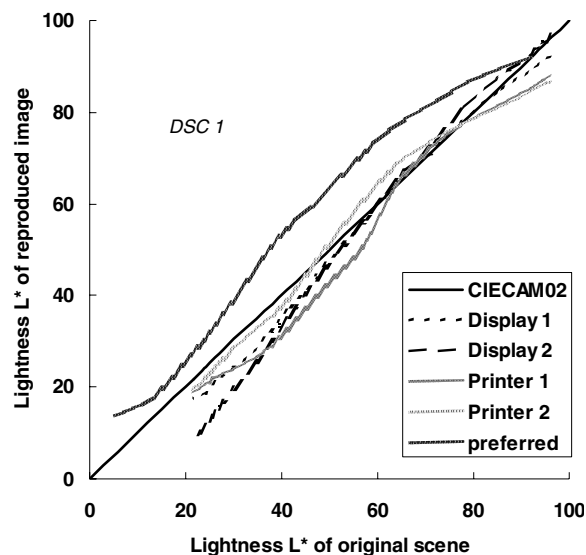


Fig. 3 Tone reproduction curve predicted by CIECAM02, those of current imaging systems, and the preferred tone reproduction curve

Summary

We calculated tone reproduction curve by using CIECAM02. But, the tone reproduction curve was different from the preferred tone reproduction curve contrary to our expectation. We suppose that high luminance condition such as sunlit condition is not supported in CIECAM02. The tone reproduction curve by CIECAM02 is different in shape, but is near in position to those of current imaging systems. The tone reproduction curves obtained by the current imaging systems are lower than the preferred tone reproduction curve. We are interested in the difference between the curves.

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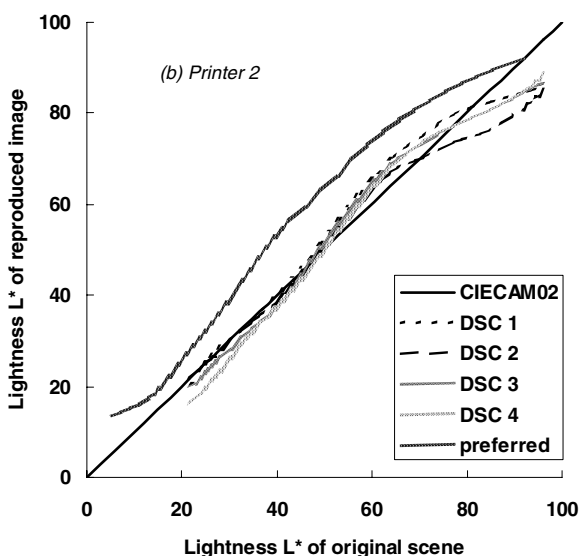
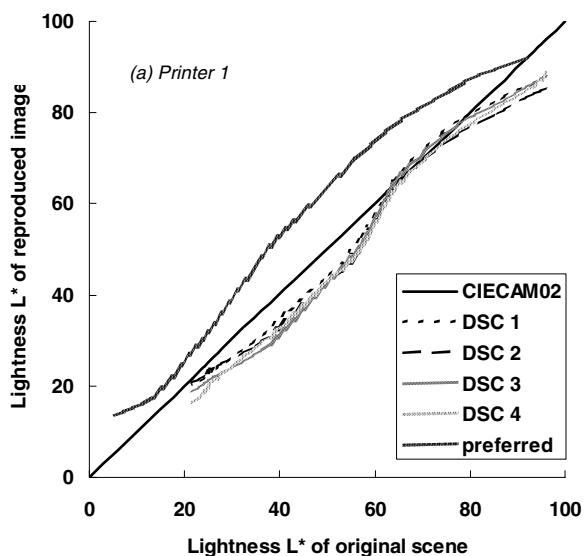


Fig. 4 Tone reproduction curve predicted by CIECAM02, those of imaging systems, and the preferred tone reproduction curve

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Author Biography

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