Color Difference Evaluation and Calculation for Digital and Printed Images

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Abstract

The calculation method of color difference in images is still an unsolved issue. A series of experiments and calculations have been done to test the consistency between computing color difference and perceptual one in images. Five ISO SCID images N2, N3, N4, N5 and N7 were used as the test image in the experiments, whose color were altered in lightness, chroma and hue independently or simultaneously to form the test image pairs. Each image pair was of different color difference grade. CIELAB, CIE94, CIEDE2000 and CMC color difference were computed by averaging color difference pixel by pixel for digital images and by averaging color difference of 256 typical color patches extracted from each image for printed images. The digital test images were displayed on an EIZO CG19 LCD and the printed test image pairs were viewed in a D50 light booth. The experimental results showed that the lightness, chroma and hue difference behaved differently when plotted the perceptual color difference against computed ones. This implied that the color difference formulae should be optimized and different weighting factors should be added to different visual attributes. The color difference formulae can be optimized by the slope of fitting lines of C/L*. The optimized CIELAB(1.5:1), CIE94(3:1), CIEDE2000(2.3:1) and CMC(3.4:1) for digital images and CIELAB(1.58:1), CIEDE2000(1.75:1) and CMC(1.84:1) or CIELAB(2.44:1.54:1), CIEDE2000(2.76:1.58:1) and CMC(2.74:1.49:1) when hue is considered for printed images by experiment data performed much better than the original formulae.*

Key words: Color difference, image evaluation, color difference formula, formula optimization

INTRODUCTION

Color image is a kind of information in daily life and used more and more widely in nowadays. An image may be appeared different in color sensation when it rendered on different media, so it is a very important work to evaluate color difference in images under different viewing conditions and media. Because an image is a non-uniform or complex color sample which made by many pixels with different color values, its color sensation is induced by all the pixels and can not be measured directly by spectrometer. Therefore, how to calculate color difference in images is a very important and practical issue. CIE TC08 was founded to solve the problems involved in evaluating image color difference and has finished its work with a technical report CIE 199-2011 [1], some remarkable works have been conducted by many researchers in this area.

EXPERIMENTS

Two psychophysical experiments, referred to Experiment I and Experiment II, were conducted in this research to evaluate color difference magnitude in images for digital and printed images.

Experiment I

Five CMYK/SCID ISO 400 images [2] N2, N3, N4, N5 and N7 (Figure 1) were used as test images in the experiment. The colors in images were altered in lightness and chroma attributes separately or simultaneously, the linear and exponent transformation functions and different coefficients were used to make serious color difference grades[3,4]. As the results, the test image pairs were made up by 8 color difference grades for C* and L* modified respectively and 4 grades for C* and L* modified simultaneously and its corresponding original, so in total 20 pairs of images were prepared for each of 5 original images.

The color difference of image pairs were computed pixel by pixel and represented by the mean difference of all pixels. Equation (1) is the calculation for mean CIELAB difference.

$$\Delta E = \frac{\sum_{0\le i\le M}\sum_{0\le j\le N}[(L^*_{1ij}-L^*_{2ij})^2+(a^*_{1ij}-a^*_{2ij})^2+(b^*_{1ij}-b^*_{2ij})^2]^{1/2}}{M\times N} \quad (1)$$

Where the subscript “1” and “2” denote the modified and original images, *i* and *j* are the row and column number of pixels, *M* and *N* are the width and height of image. The calculations for other color-difference formulae are similar.

The test image pairs were displayed on a colorimetric calibrated EIZO CG19 LED monitor in a random order under normal office environment (luminance level of 300~500 lx, about 5300K color temperature). The resolution of monitor was set to 1280×1024 and the observation distance was about 450 mm. The images were 448×560 or 560×448 pixels so that the displayed image size was 130×165 mm2 or 165×130 mm2 and about 27 pixels per viewing angle[5]. Each modified image paired with original and separated about 10 mm between them to form a pair of test images.

12 observers (6 male, 6 female with average age of 26.4) with normal color vision took part in the experiment, each image pair was assessed three times by every observer. All 300 assessments (5 images×20 grades×3 replications) were arranged in a random order and divided to 10 sessions for each observer, the duration of each session was approximately limited within 15 minutes. A total of 3600 judgments were obtained. In the experiment observers were asked to judge image color difference (ΔV) by 5 categories as listed in Table 1. A decimal value was encouraged if the difference sensation was considered between any two levels, such as ΔV=2.8,

 

N2 N5

 

N3 N4

N7

Figure 1. *Five ISO SCID images used in the experiments*

Figure 2 *An example of the printed test image pair (N7) with its 256 typical color patches*

and if the difference was considered to be greater than level 4, a number greater than 4 was also valid, such as ΔV=5.5.

TABLE 1 COLOUR-DIFFERENCE CATEGORIES FOR VISUAL EVALUATION EXPERIMENT

Colour perception	Category
no difference	0
just perceptible difference	1
weak difference, which is ensured to exist	2
a little obvious difference, which is acceptable	3
Obvious difference, which is not acceptable	4

Experiment II

Experiment II was designed almost the same as Experiment I but with the printed test image pairs. The difficult for the printed test image pairs is that the color difference of each test image pair can not be calculated as the digital one. Two different methods have been tested. One was that all test images were digitalized by a colorimetric characterized scanner and then calculated by Equation (1), but its results was not satisfied. Another method was to extract some typical color samples from each image, then combined them with images as a part of test image and modified and printed them with test images together, as shown in Figure 2 [6]. The color difference of an image pair was computed also by Equation (1) but $M \times N$ was equal to 256. The 256 typical color samples were extracted as indexed color by Photoshop software and measured by X-Rite EyeOne spectrometer. The experimental results showed that the second method was superior to the first one so the second method was adopted by the Experiment II. Each original image was altered in lightness, chroma and hue with the same transform functions as Experiment I but with different factors. Lightness was altered both in lighter and darker directions in 30 grades for each image, chroma altered in desaturation direction in 15 grades, and hue altered in 10 grades by about 1 degree shift of hue angle for each step, 55 color difference grades for each image and 275 test image in total.

The printed test image pairs were viewed under a D50 light booth with the illumination level about 930 lx in a dark room. The test images were viewed within 600 mm distance and in 45/0 viewing condition. 12 observers took part in the experiment and each test pair was assessed two times, so 6600 assessments were obtained in the experiment.

RESULTS AND DISCUSSIONS

Results of Experiment I

Figure 3 shows the results of Experiment I. The abscissa is the calculated color difference by CIELAB(1:1) formulae, and the ordinate is the perceptual difference. The experimental data for each image are plotted by different dot shape and the lines are the best fitted linear equations. Table 2 lists the coefficients of the fitted lines of all four color-difference formulae. From Figure 3 and Table 2 it can be seen that the perceptual color difference is roughly proportional to the calculated difference with reasonable high Pearson's correlation coefficients (R), although the dots are somewhat scattered. This is means that the perceptual and calculated color differences have a kind of relevance relation, the color-difference formulae which derived from uniform color samples can be also used to represent the color difference of images approximately.

Table 2 The coefficients of the fitted lines and their correlation factors in Figure3

	CIELAB(1:1)			CIEDE2000(1:1)			CIE94(1:1)			CMC(1:1)		
	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R
N2	0.37	1.17	0.86	0.37	1.68	0.70	0.27	1.92	0.60	0.23	1.93	0.61
N3	0.36	1.02	0.92	0.39	1.61	0.74	0.27	1.88	0.65	0.19	2.01	0.61
N4	0.30	2.19	0.86	0.37	2.19	0.88	0.28	2.34	0.82	0.30	2.21	0.88
N5	0.29	1.90	0.71	0.37	2.04	0.67	0.22	2.30	0.55	0.34	1.96	0.70
N7	0.37	1.34	0.93	0.39	1.98	0.75	0.28	2.23	0.65	0.22	2.33	0.62
Mean	0.34	1.52	0.85	0.38	1.90	0.75	0.26	2.13	0.65	0.26	2.09	0.69

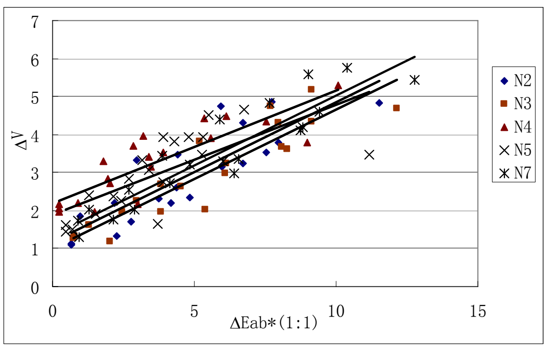

Figure 3 *Experimental results plotted against CIELAB(1:1) color difference*

Optimizing the color-difference formulae

In order to investigate the reason why the dots scattered differently with different formulae, the experiment data were fitted according to lightness and modifications. It was found that the fitted lines for only lightness and only chroma modifications are separated from each other, indicating that the trends of lightness and chroma sensation are very different to the calculated differences. The ratio of slopes of fitted lines for lightness and chroma (C*/L*) was use as the parameter kL of color-difference formulae, the result being 1.50, 2.29, 3.04 and 3.38 for CIELAB, CIEDE2000, CIE94 and CMC, respectively, shown in Table 3.

Figure 4 shows the results of experiment I with the optimized color-difference formulae. The coordinates are of the same meaning as Figure 3 but the abscissa is the calculated color difference with optimized color-difference formula. Compare Figure 4 to Figure 3, the improvement of performance of optimized color-difference formulae can be seen obviously, the data dots are less scattered and the fitted lines for each image are almost parallel. The optimized results for other color-difference formulae have similar results and can be seen in Table 3.

Results of Experiment II

The experimental results of Experiment II are very similar to Experiment I though they came from printed images. The results show the correlation between perceptual and calculated color difference but also show the different trends of lightness, chroma and hue. The same optimized method was applied to the Experiment II's data set and the obtained *k*s are listed in Table 4. The last row in Table 4 lists the optimized *k*s calculated by the slope ratio. For example, the slope ratios for CIELAB(1:1:1) are h*:C*:L*=1:0.65:0.41, this means that the slope of h* fitted line is 1.54 times larger than that of C* fitted line and 2.44 times larger than that of L* fitted line. In order to make fitted lines of three visual attributes have the same slope, the slope of C* fitted line should time 1.54 and L* fitted line time 2.44. Figure 5 shows the optimize results and optimized factors are listed in Table 5.

Compare Table 5 with Table 4, the optimized color-difference formulae perform better than the original format, because the correlation factors are increased. The slopes of chroma and lightness are also increased and much closer than before optimized.

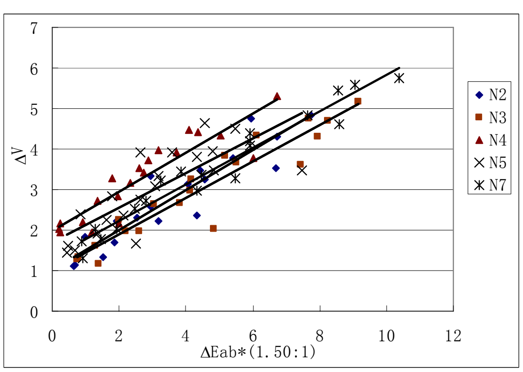

Figure 4 *The performance of CIELAB(1.50:1)*

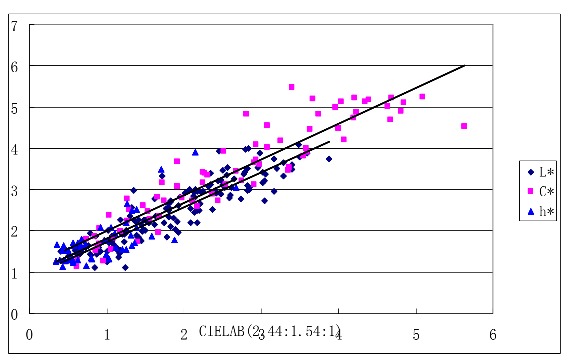

Figure 5 *The performance of CIELAB(2.44:1.54:1)*

Table 3 The coefficients of the lightness and chroma fitted lines and their correlation factors												
	CIELAB(1.50:1)			CIEDE2000(2.29:1)			CIE94(3.04:1)			CMC(3.38:1)		
	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R
C*	0.44	1.56	0.94	0.86	1.51	0.96	0.90	1.53	0.96	0.83	1.43	0.96
L*	0.43	1.48	0.85	0.83	1.46	0.87	0.88	1.47	0.85	0.81	1.63	0.82
C*/L*	1.50			2.29			3.04			3.38		

Conclusions

The property of color difference in images is discussed in the paper. The perceptual color difference is roughly proportional to the calculated one even though the color-difference formulae were developed by homogeneous color samples. But the trends of lightness and chroma sensation are very different to the calculated differences. A method to optimize color-difference formulae is proposed by the paper, by which the weighting factors *k*s can be calculated by the ratio of fitted lines of lightness, chroma and hue attributes simply.

Acknowledgments

This research is supported by National Natural Science Foundation of China (contract grant number: 61078048, 61040066), Beijing Municipal Education Commission of China (Science and Technology Project KM201210015001).

Table 4 Calculating k_L, k_C and k_H from slope ratio of fitted lines									
	CIELAB(1:1:1)			CIEDE2000(1:1:1)			CMC(1:1:1)		
	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R
h*	0.86	0.95	0.76	1.16	0.96	0.73	1.06	0.94	0.76
C*	0.56	1.28	0.85	0.73	1.46	0.80	0.71	1.35	0.82
L*	0.35	1.10	0.91	0.42	1.13	0.91	0.39	1.09	0.91
h*:C*:L*	1:0.65/0.41			1:0.63/0.36			1:0.67/0.36		
k_L:k_C:k_H	2.44:1.54:1			2.76:1.58:1			2.74:1.49:1		

Table 5 The coefficients of the fitted lines and their correlation factors after optimized

	CIELAB(2.44:1.54:1)			CIEDE2000(2.76:1.58:1)			CMC(2.74:1.49:1)		
	Slope	Intercept	R	Slope	Intercept	R	Slope	Intercept	R
h*	0.86	0.95	0.76	1.16	0.96	0.73	1.06	0.94	0.76
C*	0.87	1.13	0.93	0.63	1.26	0.93	0.94	1.42	0.90
L*	0.85	0.89	0.91	1.06	0.65	0.91	1.06	0.90	0.92

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Author Biography

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