Research on revising the weight functions and parameters of CIEDE2000 color- difference formula *

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Abstract

*For revising the weight functions S_L,S_C of CIEDE2000 color-difference formula to calculate medium color difference in accord with visual perception. By the color patches of medium lightness and chroma of Munsell color system, experiments were carried with 34 pairs for lightness and 25 pairs for chroma altering of 5R、5Y、5G、5B separately, and then get a serial of new weight functions. Using the new weight functions to calculate the color patches of Munsell color system and a psychophysical experiment was designed with 27 pairs of color patch. It is validated that when calculating medium color difference, in terms of the uniform and linear relativity with visual perception the revised color difference formula is superior to CIEL*a*b* and CIEDE2000 color difference formula, it can be used for evaluating color reproduction.*

1 Introduction

CIE1976 $L^*a^*b^*$ color-difference formula is commonly used in the course of evaluating color difference in color reproduction. But in practice, CIE1976 $L^*a^*b^*$ space is still not uniform, the samples in different color center with the same color difference can arise different visual perception. Various advanced color-difference formulae such as CMC, CIE94, and the latest CIEDE2000 have been proposed. CIEDE2000 outperformed others and was recommended by the CIE in 2001[1].

CIEDE 2000[2,3] is suitable for calculating small color difference, but in industrial application, for requirement or the instability of the device, it is need to deal with many medium color difference patches and is not appropriate to use CIEDE2000 yet, as the viewing condition is not accord with the CIE regulated. The calculation will not accord with visual perception.

We revise the S_L and S_C weight functions in different color regions with Munsell color samples for calculating medium color difference, and validate the S_L and S_C weight functions with designed color samples, compared with visual estimation.

2 CIEDE2000 Formula

The expression of CIEDE 2000 is[2]:

$$\Delta E_{00}=\sqrt{\left(\frac{\Delta L'}{K_LS_L}\right)^2+\left(\frac{\Delta C'_{ab}}{K_CS_C}\right)^2+\left(\frac{\Delta H'_{ab}}{K_HS_H}\right)^2+R_T\left(\frac{\Delta C'_{ab}}{K_CS_C}\right)\left(\frac{\Delta H'_{ab}}{K_HS_H}\right)} \quad (1)$$

The viewing condition is regulated as: D65 stimulation, 1000lx, above 4°visual angle, uniform color patches, the value of CIE $L^*a^*b^*$ among 0-5, the background is set as CIE gray L^*=50. In equation (1), S_L, S_C and S_H are weight functions, which defined the axis of the ellipse, and are allowed to adjust in different region in CIE LAB space to revise the uniform of the color space.

$$S_L=1+\frac{0.015\times\left(\overline{L'}-50\right)^2}{\sqrt{20+\left(\overline{L'}-50\right)^2}},\quad S_C=1+0.045\times\overline{C^*_{ab}},$$

the $\overline{L'}$ and $\overline{C^*_{ab}}$ were the mean of lightness and chroma of two color patches and the K_L, K_C, K_H are the parameters for taking into parametric effects. For CIE given viewing condition, $K_L=K_C=K_H=1$, and is allowed to adjust the value of them when the condition is not agree with the given.

3 Revise the Weight Functions

Munsell color system[4,5] is the system with the same color-difference for adjoining color patches based on many psychophysical experiments, and the samples were arranged with hue, chroma and lightness altering respectively. The color-difference is beyond 5(CIE $L^*a^*b^*$), belonging to medium color-difference. So, it can be used to revise the S_L and S_C weight functions in different color region of CIEDE 2000 color-difference formula.

3.1Revise S_L

Select the samples of 5R、5Y、5G、5B with the same chroma C^*_{ab} (about equal to 50) and different lightness.

The procedures as :

1) Calculating the color-difference in different color regions with CIEDE2000, as: $\triangle E_{00R}$=8.706, $\triangle E_{00Y}$ =8.266, $\triangle E_{00G}$ =8.179, $\triangle E_{00B}$=8.762, the mean of them is 8.478;

2) Given $S_L=\Delta L'/8.478$, calculating the S_L with different hue respectively when only altering lightness. For the samples from Munsell color system with the same V number and have the same lightness, so we can just select the same S_L weight function for 5R、5Y、5G、5B. the simulative equation of S_L and $\overline{L'}$ (the mean lightness of adjoining color patches) can be:

$$S_L=1.0033+0.0145\overline{L'}-3\times10^{-5}\overline{L'}^2+2\times10^{-6}\overline{L'}^3$$

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（R^2＝0.9874）　　(2)

3.2 Revise S_C

Select the samples of 5R、5Y、5G、5B with the same lightness (V/=5) and different chroma.

The procedures as :

1) Calculating the color-difference in different color regions with CIEDE2000, as :$\triangle E_{00R}$=3.340, $\triangle E_{00Y}$ =4.830, $\triangle E_{00G}$=3.007, $\triangle E_{00B}$=3.598，the mean of them is 3.710;

2) Given $S_C=\Delta C'/3.710$, calculating the S_C with different hue respectively when only altering chroma. We can get the S_C weight function of 5R、5Y、5G、5B, the simulative equation of S_C and $\overline{C'}$ (the mean chroma of adjoining color patches) can be:

$$S_{CR}=6.46-0.2079\overline{C'}+0.0035\overline{C'}^2-2\times10^{-5}\overline{C'}^3$$

（R^2＝0.9187）　　(3.1)

$$S_{CY}=2.2194+0.1502\overline{C'}-0.0039\overline{C'}^2+3\times10^{-5}\overline{C'}^3$$

（R^2＝0.9252）　　(3.2)

$$S_{CG}=4.0255-0.018\overline{C'}-4\times10^{-5}\overline{C'}^2+9\times10^{-7}\overline{C'}^3$$

（R^2＝0.7811）　　(3.3)

$$S_{CB}=4.0569-0.1003\overline{C'}+0.0017\overline{C'}^2-9\times10^{-6}\overline{C'}^3$$

（R^2＝0.8476）　　(3.4)

4 validate the weight function

4.1 validate with Munsell color system

4.1.1 validate S_L

From equation (2), we can get the revised S_L , and then calculate the revised $\triangle E_{00}$ instead of the original S_L, that is $\triangle E_{00}^*$ hereinafter for short.

Table1 Mean color difference and standard deviation of altering lightness

△E σ/△E	R	G	Y	B
$\triangle E^*_{ab}$	11.36	10.15	10.36	10.38
	0.163	0.031	0.043	0.025
$\triangle E_{00}$	8.71	8.27	8.18	8.76
	0.118	0.169	0.159	0.114
$\triangle E_{00}^*$	8.75	8.11	8.18	8.38
	0.104	0.049	0.048	0.023

For the samples of the same chroma and hue, the smaller σ/△E for the adjoining lightness is, the superior performance of the color–difference is. And we can see the hue of R and B $\triangle E_{00}^*$ gives the best performance, and the hue of Y and G, $\triangle E^*_{ab}$ is just superior to $\triangle E_{00}^*$, in all regions, $\triangle E_{00}^*$ outperforms $\triangle E_{00}$. and for R、Y、G and B, the standard deviation of $\triangle E_{00}^*$ 0.29 superior to $\triangle E_{00}$ 0.31 and $\triangle E^*_{ab}$ 0.54. That is to say the revised color-difference $\triangle E_{00}^*$ gives best performance when calculating medium color-difference with different lightness.

4.1.2 validate S_C

From equation (3.1-3.4), we can get the revised S_C and then calculate the revised $\triangle E_{00}^*$ instead of the original S_C.

Table2 Mean color difference and standard deviation of altering chroma

	R	G	Y	B
$\triangle E^*_{ab}$	9.33	11.18	15.72	8.75
	0.071	0.089	0.232	0.049
$\triangle E_{00}$	3.4	3.00	5.09	3.60
	0.538	0.567	0.303	0.383
$\triangle E_{00}^*$	4.13	3.73	3.63	3.90
	0.126	0.080	0.033	0.056

For the samples of the same lightness and hue, we can see the hue of Y and G $\triangle E_{00}^*$ gives the best performance, and the hue of R and B $\triangle E^*_{ab}$ gives the best performance, and for R、Y、G and B, the standard deviation of $\triangle E_{00}^*$ 0.22 superior to $\triangle E_{00}$ 0.91 and $\triangle E^*_{ab}$ 3.16. That is to say the revised color-difference $\triangle E_{00}^*$ gives best performance when calculating medium color-difference with different chroma.

4.2 Validate with the Devised Samples

4.2.1 Experimental Samples

in order to investigate the consistency of visual perception and the revised $\triangle E_{00}^*$,we designed red, yellow, green and blue four color centers, and output color print after color management, then measure the colorimetric of L^*, a^*,and b^* ,as table 3 showed:

For altering the lightness and chroma of the above 4 color centers, we select a and k two parameters in the compiled the software another testtiff for adjustment[6,7,8], as figure 1 showed:

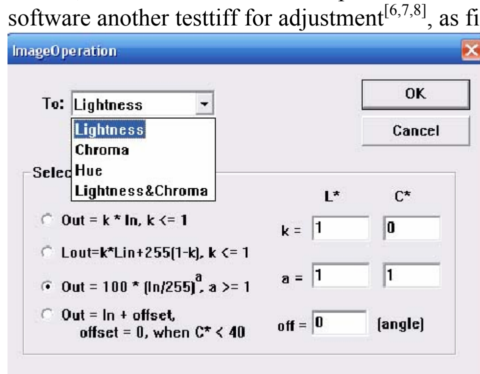

Fig1 the mode of transferring lightness and chroma

With the modification of tiff image of $L^*a^*b^*$ mode, and saved as a new tiff file. Choose the exponential alterative mode, and with every mode of 0.8, 1.0and 1.2 levels. With the lightness alteration, chroma alteration, lightness and chroma alteration, we get 9 pairs testing samples of every color center. Then output the original and alterative samples.

4.2.2 Visual Experiment

26 observers were asked to participate in the experiment, 15 males and 11 females, aged from 21-55 years old, all have the normal visual perception and have no similar visual experiment before.

1) observation condition: Gretag Macbeth The Judge II standard booth with Day mode and gray background, a pair of the standard and the testing samples were set of the center of the booth.

2) experimental method[7]: design the gray scale as the grade of visual estimation, the visual color-difference $\triangle V$ ranged from 0-6.

3) experimental results: with twice estimation of the 9 pairs samples of 26 observers, we can gain 468 estimative results. Consider the average of 52 estimative results of every pair samples as the visual color-difference $\triangle V$.

4.2.3 Calculate with the Revised CIEDE2000 color-difference

Measure the 9 pairs color samples of every color center with X-Rite 530 spectrophotometer of the mode of D65 and 2° field, and calculate the color-difference of every color-difference formulae, and compared them with visual estimation. For the value of $\triangle E^*_{ab}$ of yellow samples less than 5, belonging to small color-difference. So, we deal with the experimental data of red, green and blue center finally. Consider the lightness and chroma of output samples will alter with the standard, when designed alter lightness and chroma separatively. So, we replace the S_L、S_C weighting function of the original when calculating with the revised CIEDE2000 color-difference. As table3 showed, is compared with standard sample, the visual perception, $\triangle E_{00}$, $\triangle E_{00}^*$.

The visual estimation $\triangle V$, color-difference $\triangle E_{00}$ and the revised $\triangle E_{00}^*$ of the 27 experimental pairs of samples are plotted in figure 2.

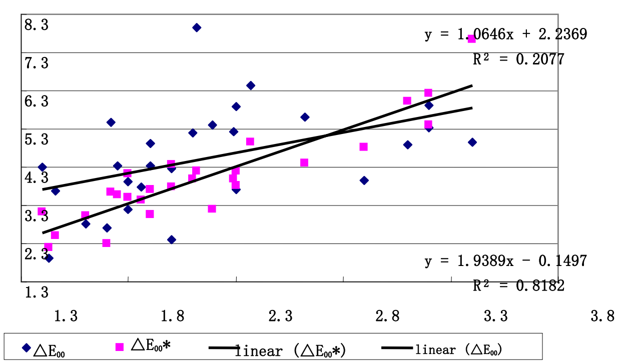

Fig2 Correlation of estimate $\triangle V$、 $\triangle E_{00}$ and $\triangle E_{00}^*$

As figure 2 showed, the above, the linear correlation coefficient of $\triangle V$ and $\triangle E_{00}$ is 0.21, while the bottom, the linear correlation coefficient of $\triangle V$ and $\triangle E_{00}^*$ is 0.82, superior to $\triangle E_{00}$ obviously. That is to say, for estimating medium color-difference, given $\triangle V$, we can use $\triangle E_{00}^* = 1.9389\triangle V - 0.1497$ calculate the corresponding color-difference, which is precise to the original formular.

Table3 compared with standard sample, the visual perception, $\triangle E_{00}$ and $\triangle E_{00}^*$

Mode of transferring	R（47.43，57.56，18）			G（57.14，－58.88，29.62）		
	△V	△E00	△E00*	△V	△E00	△E00*
a＝1.2	2.37	6.44	4.95	2.19	5.41	3.18
k＝1.2	1.75	4.35	3.56	2.3	5.89	3.83
a＝k＝1.2	1.8	3.92	4.13	1.6	2.81	3.02
a=1.0	1.86	3.78	3.44	1.8	3.2	3.5
k=1.0	1.46	3.68	2.5	2.1	5.21	4
a=k=1.0	2	2.41	3.8	1.9	4.32	3.7
a＝0.8	1.72	5.48	3.66	1.4	4.31	3.14
k＝0.8	2	4.25	4.36	1.7	2.7	2.30
a＝k＝0.8	1.43	1.93	2.20	1.9	4.91	3.05
	B（40.09，5.03，－42.67）					
	△V	△E00	△E00*			
a＝1.2	2.29	5.23	2.07			
k＝1.2	3.2	5.93	3.6			
a＝k＝1.2	2.9	3.96	2.86			
a=1.0	2.3	3.73	1.93			
k=1.0	2.62	5.6	2.73			
a=k=1.0	3.1	4.89	2.93			
a＝0.8	2.12	7.96	2.43			
k＝0.8	3.2	5.33	3.6			
a＝k＝0.8	3.4	4.95	3.81			

Given $K_H=1$, the revised coefficient K_L、K_C of formula(1) would be:$K_L=2.02$，$K_C=2.60$. using the new K_L、K_C, the color-difference of $\triangle E_{00}^*$ just as table 4 showed:

Using the revised coefficient K_L、K_C, the $\triangle E_{00}^{**}$(2.02:2.6:1) is close to the visual color-difference, and the linear relativity is 0.8466, excelled to $\triangle E_{00}^*$ formula, as figure 3 showed:

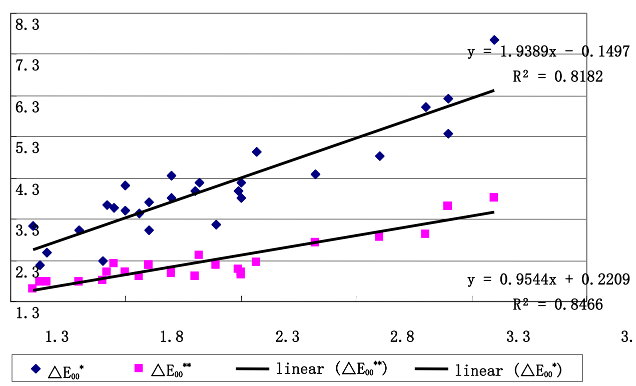

Fig3 Correlation of estimate $\triangle V$、$\triangle E_{00}^*$ and $\triangle E_{00}^{**}$

Table4 compared with standard sample, the visual perception,$\triangle E_{00}^*$,$\triangle E_{00}^{**}$(2.02:2.6:1)

Mode of transferring	R（47.43，57.56，18）			G（57.14，－58.88，29.62）		
	△V	△E00*	△E00**	△V	△E00*	△E00**

a＝1.2	2.37	4.95	2.26	2.19	3.18	2.2
k＝1.2	1.75	3.56	2.23	2.3	3.83	2.03
a＝k＝1.2	1.8	4.13	2.02	1.6	3.02	1.76
a=1.0	1.86	3.44	1.92	1.8	3.5	2.02
k=1.0	1.46	2.5	1.78	2.1	4	1.91
a=k=1.0	2	3.8	1.98	1.9	3.7	2.17
a＝0.8	1.72	3.66	2.02	1.4	3.14	1.62
k＝0.8	2	4.36	2.05	1.7	2.30	1.82
a＝k＝0.8	1.43	2.20	1.76	1.9	3.05	2.2
	B（40.09，5.03，－42.67）					
	△V	$\triangle E_{00^*}$	$\triangle E_{00}^{**}$			
a＝1.2	2.29	3.99	2.07			
k＝1.2	3.2	5.39	3.6			
a＝k＝1.2	2.9	4.82	2.86			
a=1.0	2.3	4.2	1.93			
k=1.0	2.62	4.4	2.73			
a=k=1.0	3.1	6.02	2.93			
a＝0.8	2.12	4.19	2.43			
k＝0.8	3.2	6.22	3.6			
a＝k＝0.8	3.4	7.66	3.81			

5 Conclusion

The medium lightness and chroma color patches of the Munsell color system were choosed for revising the weighting function of CIEDE2000 color- difference formula, the method is simple and intelligible. The medium lightness and chroma color patches of the Munsell color system and the experimental designed patches were calculated, validating that the uniformity and the relativity with the visual estimate of the revised color-difference formula have been amended greatly, and the color-difference can be calculated according to the visual estimation with the linear simulated equation. The revised formula have preferable application for the samples which $\triangle E^*_{ab}$ above 5.

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