Research of the Weighing Coefficient and Acceptability Threshold of Three Different Color-Difference Formulas

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Abstract: The purpose of this research was to improve the uniformity of color-difference equations. Twenty observers performed a pass-fail color tolerance experiment for 17 color centers and approximately 259 color samples, which have different chromatic. We measured CIELab color values of all colors. Multiple linear regression equation can be used to calculate the best weighting coefficient of CIE94、CMC and CIE2000. We got the acceptable threshold of each color center with cumulative frequency statistics method. The improved results of color-difference formulas about the same color and the same color of different saturation were compared.

Keywords: Color difference; CIE94; CMC; CIE2000; Weighting

1. Introduction

The size of color-difference is one of the most important quality control parameters of the packaging product, but the color-difference evaluation have some errors, especially when measure some special colors. Equations such as CMC、CIE94 and CIE2000 are now in common use to set instrumental tolerances for industrial color control. Because the inhomogeneity of the color space and the color-difference formula, results in the calculating color-difference doesn't match with visual perception[1]. So these formulas need to be amended.

Quantitative representation of different color perception is called color difference. The sensitivity of human eyes for different color perception is diverse. For example, The blue area of the CIE 1931chromaticity diagram, color-difference is identified since a slight change of chromaticity coordinates[2]. While in the green area, about ten times the size of the chromaticity coordinates, eyes can identify color-difference. In a chromaticity diagram, equal distance and eye visual judgment is inconsistent. In order to improve the correlation between geometric distance and visual judgment in color space, the CIE recommended some guiding principles to research color-difference formulas[3,4].

2. Experimental

The first,CIE recommended 17 color centers, which includes 8 high chroma centers、8 low chroma centers and gray; The second, proposed some variable parameters, such as sample size, sample interval, color-difference size, brightness size and observation time etc. We choosed 17 color centers, 20which were recommended in the first. Each color center was reference and had some samples, the color-difference between these samples and their reference was big. Twenty observers performed a pass-fail color experiment for these color centers and their samples. The result of visual experiment was used to get the best l:c to optimize these color-difference formulas.

2.1. Sample preparation

In this case, we had selected 17 color centers, their hue were Red, Orange, Yellow, Yellow-green, Green, Bule-green, Bule, Purple and Gray. Each color center included 12 ~ 20 color samples, the number of these samples is 259. The size of each sample is 2.5cm square and sample interval was 2mm.

Table 1. The value of CIE Lab

Color	*L*	*a*	*b*
H red	39.90	46.43	40.63
H orange	57.77	27.60	68.07
H yellow	75.80	-10.73	84.23
H yellow-green	53.63	-29.93	47.77
H green	45.23	-38.87	11.73
H bule-green	40.60	-25.47	-25.60
H bule	26.77	-4.73	-42.53
H purple	42.63	15.40	-26.47
gray	59.23	-4.33	-8.03
L red	37.00	32.17	31.87
L orange	56.37	9.53	18.33
L yellow	76.17	-5.27	39.80
L yellow-green	57.30	-11.43	13.17
L green	42.87	-34.80	-3.83
L bule-green	39.23	-19.37	-18.67
L bule	25.17	0.67	-33.93
L purple	38.97	7.53	-19.17

(H:high chroma; L: low chroma.)

1） *Sample measurements[5]*

All samples were measured using X-Rite Eye One spectrophotometer, which 45°/0° geometry. CIE1964 Standard Observer and CIE Standard Illuminant D65 were used to compute tristimulus and CIELAB coordinates. The CIE L, a, b, C data for reference colors are shown in Table 1.

2) *Distribution of color centers and samples*

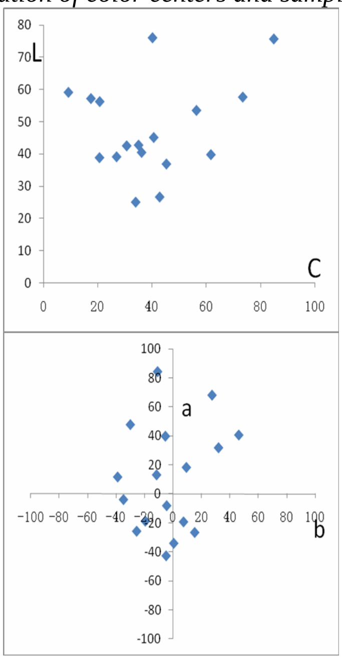

Figure 1. Distrbution of color centers.

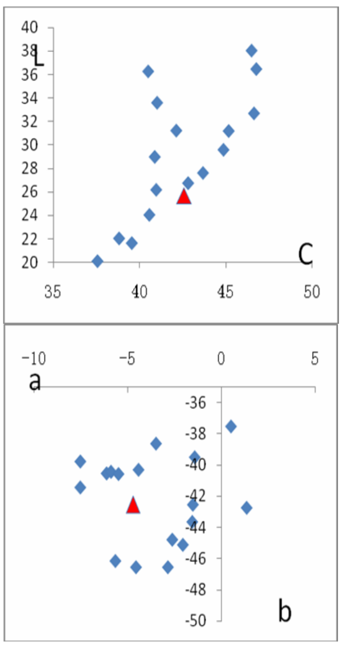

Fig.2 Distrbution of sample color center

(high chroma blue, ▲: reference color)

2.2. Visual evaluation

There are 10 female and 10 male, ranged from 22 to 27 years, total 20 observers performed the experiment. The vision of observer was normal, the ratio of observers between experienced and inexperienced in color judgment was 13:7.

a) *Vision test*. All observers passed the test which with greater precision including the Farnsworth-Munsell 100 hue test and the Nagel anomaloscope.

b) *Observe condition*. All observers viewed samples in viewing cabinet with 1937 lux, D65 standard lighting source, 45°/ 0°geometric conditions.The viewing cabinet has a grey background, reference color and sample color were put in the central position.

c) *Method* [6]. A six category was selected: 0. Not perceptible; 1. Barely perceptible; 2. Perceptible but acceptable; 3. Barelyacceptable; 4. Just unacceptable; 5. Unacceptable.

d) *Result*. Each pair of reference color and sample color had a rejection rate f, i.e. the number of reject decisions devided by 20. The rejection rate f was converted into the visual scale by using the logit function as follow:

$$\Delta V = \ln\frac{f}{1-f} + 6 \qquad (1)$$

where ΔV shows the visual scale and f represents the frequency of rejection. When the vaule of frequency is 0 or 1, both of them are not used. Because color difference are never negative, the visual data should be trans ferred to all positive values, so an constant 6 is added, but this value can be any number.

3. Data processing

In this case, using multiple linear regression method which was proposed by Bern[7] , processed the visual evaluation data and the practical measurement data of the 17 color centers, in order to determine the optimization weighing parameters of the lightness, saturation and hue of the color-difference formulas. The regression function as follow:

$$(\Delta V)_i^2 = \beta_l\left(\frac{\Delta L^*}{S_l}\right)_i^2 + \beta_c\left(\frac{\Delta C^*{}_{ab}}{S_c}\right)_i^2 + \beta_H\left(\frac{\Delta H^*{}_{ab}}{S_H}\right)_i^2 \qquad (2)$$

where β_l , β_c and β_H are coefficient to estimate in the regression; " i " represents a evaluation.

3.1. Calculate the weighted coefficient

We got the l: c: h value of each color center through linear regression, the l: c average weighted coefficient of the CMC, CIE94 and CIE2000 (setting h=1) respectively is 1.48:1.16、1.81:1.09 and 1.39:0.83. The equation as follow:

$$l = \sqrt{1/\beta_l} \quad c = \sqrt{1/\beta_c} \quad h = \sqrt{1/\beta_h} \qquad (3)$$

3. 2. Correlation

In order to verify the effectiveness of the experimental data, the correlation between the visual scaled color

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difference △V and computed color difference △E by the weighted formulas was analyzed. The result shows in table 2.

3.3. Acceptability threshold

We recored the pass/fail data in the visual evaluation, the data were sorted to two value 0 and 1 as pass and fail, with any category score between "Not perceptible" and "Unacceptable " that was equal or under 3(Barely acceptable) assigned to 1 otherwise it is 0. Then the number of pass and fail sample are counted. Ploting the cumulative percentages versus ordered CMC、CIE94 and CIE2000 color difference, the intersection of pass curve and fail curve is the threshold.

Table 2. Comparison of Correlation

	△*Eab*	△*Ecmc*	△*E*94	△*E*00	△*Ecmc* 1.48:1.16	△*E*94 1.81:1.09	△*E*00 1.39:0.83
Number of point	246	246	246	246	246	246	246
Slope	0.338	0.282	0.353	0.41	0.416	0.512	0.494
Corrlation	0.631	0.6	0.686	0.663	0.643	0.702	0.681

Table 3. Comparison of Acceptability Threshold

Color	△*Eab*	△*Ecmc*	△*E*94	△*E*00	△*Ecmc* 1.48:1.16	△*E*94 1.81:1.09	△*E*00 1.39:0.83
H red	7.04	3.95	3.53	3.53	3.56	2.71	3.32
H orange	8.24	4.15	4.47	4.22	3.22	2.55	3.25
H yellow	7.80	4.20	4.38	4.03	3.39	2.68	3.28
H yellow-green	8.28	4.84	5.95	4.78	3.85	3.56	3.81
H green	8.75	8.42	7.93	7.21	6.90	6.40	6.41
H bule-green	8.46	8.23	8.13	7.35	6.40	5.37	5.96
H bule	7.40	8.36	6.19	4.94	6.08	3.76	4.10
H purple	6.14	6.98	6.50	5.01	6.78	6.23	4.24
gray	3.94	11.71	9.45	4.44	4.43	4.44	2.98
L red	9.46	7.34	5.78	5.53	6.43	4.40	4.48
L orange	8.16	8.03	8.07	4.01	5.77	5.11	3.07
L yellow	8.64	5.86	6.08	4.03	4.74	4.04	3.56
L yellow-green	10.30	8.59	7.55	5.56	6.06	6.04	4.97
L green	9.90	9.89	9.83	7.46	8.82	8.31	6.57
L bule-green	8.99	10.36	9.55	7.67	9.07	7.43	6.01
L bule	6.16	8.26	5.90	4.80	5.80	3.93	3.63
L purple	5.68	8.30	7.11	5.27	4.79	4.79	4.43
mean	7.84	7.50	6.85	5.28	5.65	4.81	4.36

(Note: different color-difference formula has a different unit, the subscript of △E means different formulas.)

4. Analysis and discussion

4.1. The evaluation of correlation

The result shows the correlation of all weighted formulas are better than the original formulas, the highest correlation is 0.702 which obtained by CIE94（1.81:1.09）. That means CIE94 (1.81:1.09) is the most consistent with visual evaluation result in this case, the uniformity of color-difference formulas is improved through visual evaluation and linear regression. The correlation coefficient of all low chroma color centers are bigger than all high chroma color centers.

4.2. The evaluation of acceptability threshold

The threshold for each color center is shown in table 2. Three weighted formulas improved the threshold, the best formula is CIE2000（1.39:0.83）, average thresholds decrease to 4.36. On the whole, the threshold for yellow-green、blue-green、blue and gray in all the weighted formulas are improved markedly. The improvement of low saturated color centers is better than high saturation.

5. Conclusion

A psychophysical experiment and multiple linear regression were performed to determine l:c weighting and acceptability threshold based on glazed coated paper. The correlation between visual scaled color difference △V and computed color difference △E of weighted formulas was improved signally, CIE94 (1.78:1.07) is superior to other formulas. The amended color-difference formula can be better applied to the color measurement, so the human eye's visual results and measurement results as much as possible close to. The results will provide some ideas and methods to the theory research of color difference formula in China, give some guidance to production practices.

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