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Tristimulus Value Measurement of Textile Materials with Digital Device

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Abstract*:* In this paper, space conversion model between color solid RGB and CIE XYZ is established. The objective to measure materials' accurate tristimulus value with EPSON PERFECTION 1260 scanner is achieved, which supply other scanner with systemic method to measure materials' accurate tristimulus value. The results are more accurate and steady when using the fitting conversion formula than common linear conversion formula. Take the textile color fastness estimation for instance, the practical application of this systemic method is recommended. The contrastive analysis of testing results is made with traditional color-measured equipment. The conclusion of this study could be applied in research fields such as color identification, the measurement of fabric count and the estimation of color deviation, color fastness and so on.

Keywords Scanner, RGB, CIE XYZ, Mathematic model, Color fastness

INTRODUCTION

Since 1931, the CIE (Commission Internationale de I'éclairage) has promulgated a series of study on standard chroma systems to provide the theory basis to color measurement. With the rapid development of color industry, the problems in color measurement, calibration and dyeing fastness need more accurate optics models, [Cui, *et. al.*, 2003] algorithmic techniques and corresponding testing systems to be researched and developed.

The precision and stability of traditional color-measured equipment are not so good. Thus people begin to develop computer to measure color. The key question using computer is to realize the space conversion model between color solid RGB and CIE XYZ in computer. However, the veracity and stability of existing linear conversion formulas can not meet the demand [Dong, *et. al.*, 2001]. Therefore, space conversion model between color solid RGB and CIE XYZ is established. In this paper to achieve the objective to measure materials' accurate tristimulus value with EPSON PERFECTION 1260 scanner, which supply other scanner with systemic method to measure materials' accurate tristimulus value. The results are more accurate and steady when using the fitting conversion formula than common linear conversion formula.

COMPUTER STATIC COLOR VISUAL SYSTEM

The corresponding RGB values of each image color can be obtained by the equipment, while there are three tristimulus values -X, Y, Z values when colors act on human eyes. If the accurate corresponding relationship between RGB values and XYZ values of the same color can be found, then computer may be used to measure the color of objects accurately instead of human eyes. And in this process the most important step is to realize the transformation of color three-dimensional space between computer RGB and CIE XYZ.

EPSON PERFECTION 1260 Scanner is adopted to get the corresponding RGB values of fabric hue. A model of color cubic space conversion between computer RGB and CIE XYZ is established through the cube polynomial equation and matrix fitting optimal value function in MATLAB and so on. After getting XYZ values, colors can be calculated with formulas offered by national standards: textiles industry standards ISO 105-A04:1989" Method for the Instrumental assessment of the degree of staining of adjacent fabrics" and ISO 105-J01:1997" Textiles-Tests for color fastness-General principles for measurement of surface color" GB/T 8424.3-2001, ISO 105-J03:1995" Textiles-Tests for color fastness-Calculation of color differences".

EXPERIMENTAL

Selection of the Camera Explore Equipment and the Determination of Test Exterior Conditions

The final goal is to make the description, reconstruction and measurement of nature be consistent with its visual judgment result. Therefore, the stability and accuracy of the camera explore equipment is required to be as high as possible. However, if only its error is limited in accepted range in the actual application, it can be adopted. This

paper selects EPSON PERFECTION 1260 scanner as camera explore equipment to obtain fabric color image.

In traditional optical test, light source, demands for exterior conditions, such as light source and so on, are determinated (videlicet, the light source D65 10°or 2°field-of-view). In order to make images gained with digital instruments have the same color with images saw by human eyes under that condition, Kodak[Q60 2000.04] standard color card must be contrasted and measured to get one standard RGB value under standard exterior conditions in traditional optical test. To get exact RGB value of the standard color card, Datacolor 550 desk spectrophotometric tintometer produced by Switzerland Data Color Co. is used to mensurate and converse the RGB value of the color blocks in Kodak [Q60 2000.04] standard color card.

Fixed exterior conditions of digital equipment to obtain RGB value in computer gained through experiments are as follows:

Equipment: EPSON PERFECTION 1260 camera explore equipment

Conditions:[DPI=200、gray level＝60、exposure rate＝0、shadow＝26、Saturation＝0，Gamma＝3.10，high gloss＝251]

ESTABLISHMENT OF CONVERSION MODEL

Measurements of Experimental Data

RGB chroma space coordinate is one stereo chroma space which is used to define and represent colors in computer. RGB represents three colors respectively: R, red; G, green; B, blue; When all the values of these trichroisms are minimum, black is gained; while maximum, white is gained. Increasing or decreasing single primary color amount between the maximum and the minimum or the different combination of primitive colors can get systematic and continuous color order. Color order is expressed as the RGB chroma cube with 0 ~ 255 values.

In the accustomed color description, it is needed at least three dimensions to define one stimulus color, such as hue, lightness and chroma; or three stimulate value X, Y and Z; and also can be the three primary colors RGB and CIE-Lab. Anyhow, the mathematics relation here is always surrounding three variables, three unknown factors, three simultaneous equations and three-dimensional chroma space. Therefore, matrix algebra can be regarded as a means of finding the solutions to establish a correspondence relationship of stereo region of the color description between two kinds of different color spaces.

Kodak [Q60 2000.04] standard color cards are collected as the benchmark to calculate the conversion model of these two coordinate spaces. In 248 groups standard color cards of Kodak [Q60 2000.04], all corresponding colors are defined standard CIE XYZ tristimulus values of the standard values of CIE XYZ color space coordinate are given, it is merely required to mensurate the RGB value under specifically external conditions, and then these two groups of data can be calculated.

Under the fixed exterior conditions of digital equipment to obtain RGB value in computer, EPSON PERFECTION 1260 Scanner is used to get the RGB value of color blocks in each color series of the color cards. Sequentially, the experimental data required by conversion model are gained.

Establishment of Conversion Model

Let three stimulate values X, Y, Z be indicated respectively by the relational expression of R, G and B. Now the corresponding model between $\begin{pmatrix} x \\ y \\ z \end{pmatrix}$ and $\begin{pmatrix} R \\ G \\ B \end{pmatrix}$ is established as,

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = F \begin{pmatrix} R \\ G \\ B \end{pmatrix}, \quad \text{here} \quad F = \begin{pmatrix} f1 \\ f2 \\ f3 \end{pmatrix};$$

In this process, linear, quadratic and cubic polynomial fitting are adopted respectively to make the fitting effect of curves reach the best. Cubic polynomial fitting is selected based on the fitting effect.

To establish the cubic polynomial of F, i.e.,

F=aR3+bG3+cB3+dGR2+eRB2+fGB2+gRB+hRG+iGB+jR2+kG2+lB2+mR+nG+oB+p （1）

Here $a = \begin{pmatrix} a1 \\ a2 \\ a3 \end{pmatrix}$ $b = \begin{pmatrix} b1 \\ b2 \\ b3 \end{pmatrix}$ …… $p = \begin{pmatrix} p1 \\ p2 \\ p3 \end{pmatrix}$ （2）

Seek a, b, c……p

In this equation, some items are omitted because their constants are very minor (tend to 0) and have no effects on the whole fitting effects. Equation (1) is one simplified style.

Solving the Equation

The process of solving the equation for its coefficient vectors is to achieve the best degree of the anastomosis between the curves from the measured RGB value conversed by matrix and CIE XYZ standard curves, that is to say, obtaining the least Euclidean vector norms (closer to 0, better fitting effect) between calculating points in RGB coordinates and CIE XYZ, i.e., solving the optimization problem as follows:

$$\min \sum_{i=1}^{m} \left\| F\begin{pmatrix} R_i \\ G_i \\ B_i \end{pmatrix} - \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} \right\|_2^2 \quad (3)$$

Mathematical calculation is complex and trivial, so scientific calculation software MATLAB can be used to reduce manpower and simplify calculation process. Matrix fitting optimal function of MATLAB regards all data of RGB as one group and XYZ as another, and then seeks the conversion relationship between them.

The corresponding relationship model of these tow chroma space coordinates is gained by using Gauss-Newton iterative method to solve this problem:

X=-0.10789138296353+0.03315514801143×R+0.02737947120245×G+0.01558613275666×B+0.00009629792895×R2+0.00002675177447×G2-0.00004663421678×B2+0.00000259499239×R×G+0.00003441149591×R×B-0.00010400969387×G×B+0.00000199104653×R3+0.00000027121004×G3+0.00000046499433×B3+0.00000115952817×R×G2+0.00000050778692×R×B2+0.0000000630162×G×B2

Y=0.71477853490965+0.00863818989788×R+0.04996747083566×G-0.00151644227814×B+0.00006968341466×R2+0.00013882592258×G2+0.00009651866987×B2-0.00001893619652×R×G+0.00004865526516×R×B-0.00002949181328×G×B+0.00000102192005×R3+0.00000197431297×G3-0.00000056401267×B3+0.00000075579993×R×G2+0.00000090183068×R×B2-0.00000029649475×G×B2

Z=-0.74946872231063-0.00352023583505×R+0.01867131714073×G+0.05826442981373×B+0.00007316495245×R2-0.00002945578498×G2+0.00000622727176×B2-0.00003766434026×R×G+0.00001888973867×R×B-0.00013188245334×G×B-0.00000036654796×R3-0.00000041039957×G3+0.00000179740161×B3+0.00000074601776×R×G2+0.00000266368175×R×B2-0.00000002853754×G×B2

CURVE FITTING

Fitting curves are described by MATLAB program. In the figures, longitudinal axis represents X, Y, Z and horizontal axis represents every group of data in 248 groups; red lines show the measured XYZ value gained from these 248 groups of RGB data by conversion formula and black ones show the standard XYZ value; the transverse lines describe the fitting errors between red and black lines:

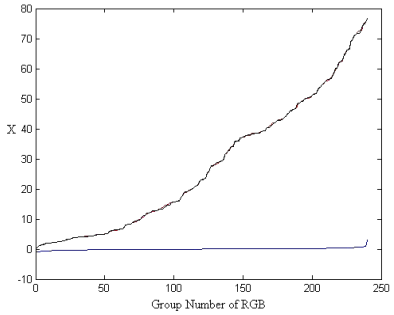

Figure 1 Curve fitting between X and RGB

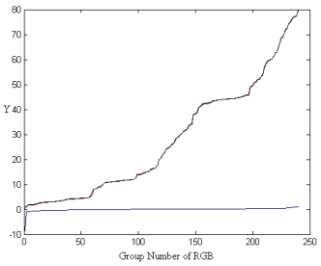

Figure 2 Curve fitting between Y and RGB

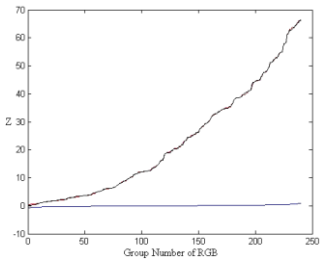

Figure 3 Curve fitting between Z and RGB

These three fitting curves are curve comparisons between CIE XYZ value and XYZ value gained from calculating measured RGB value. From the figures, the coincidence rates of X, Y, Z fitting curves are quite high and maximum errors are within 0~0.8.

CONTRASTIVE ANALYSES WITH COMMON LINEAR CONVERSION FORMULA

By now, somebody else have so studied the space conversion model between color solid RGB and CIE XYZ in computer and established several linear conversion formulas. The contrastive analysis of testing results is made with common linear conversion formula. It is indicated that the results are more accurate and steady when using the fitting conversion formula than common linear conversion formula.

The conversion formulas from RGB to XYZ in CIE1931 standard chroma system are as follows:

X=2.7689R+1.7517G+1.1302B

Y=1.0000R+4.5907G+0.0601B

Z= 0+0.0565G+5.5943B

The RGB values of Kodak [Q60 2000.04] standard color card, obtained by the scanner under the fixed exterior conditions of digital equipment, are transformed using this linear conversion formula and the fitting conversion formula respectively, and then contrast with their standard CIE XYZ values. Experimental data distributions are as follows:

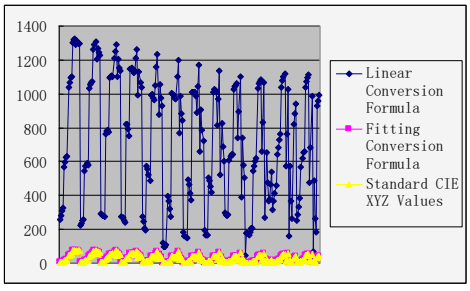

Figure 4 Distribution of X value after conversion

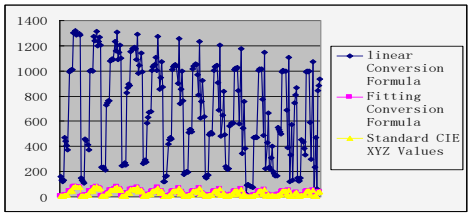

Figure 5 Distribution of Y value after conversion

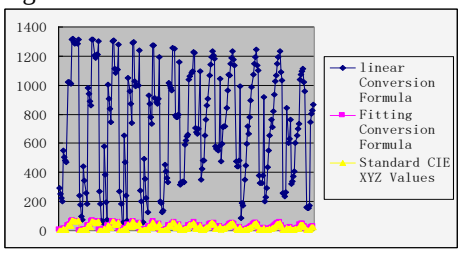

Figure 6 Distribution of Z value after conversion

From these figures above, the departure between the results of common linear conversion formula and the standard values is very evident. However, the results of the fitting conversion formula accord perfectly.

A CASE OF THE SYSTEMATIC METHOD

The chroma, hue and lightness of fabric hue may change because of insolation weathering, drenching, rubbing, perspiration, scrubbing, ironing and so on in using and machining processes of the color textile. Therefore, color fastness of textiles is the extremely important inherent quality to consumers. The worldwide standards of ecological textiles some color fastness index in a certain range. Thus it can be seen that the evaluation of color fastnesses is quite important. Whereas, when using the traditional methods, the results of color-identification with much subjective components have very large correlation with people's mental states, ages, environment, weary degree. At present, it has been applied in an extensive range to use the apparatus to assess the differences and matching degree between colors instead of eyes.

The computer static color visual system constructed by this article can replace eyes to measure and match colors exactly by computer, measurement fabric count and whiteness degree, accurately estimate color deviation, color fastness and so on. The next, taking the textile color fastness estimation for instance, the practical application of this systemic method is recommended. And the contrastive analysis of testing results is made with traditional color-measured equipment.

Digital devices are adopted to get the corresponding RGB values of treated sample's colors and untreated ones'. The conversion model established in the article realizes the conversion between computer RGB and CIE XYZ, and then XYZ value, which is much closed to the tristimulus value when using eyes, is obtained. The flowchart of measuring fabric color fastness by this system method is as figure 7:

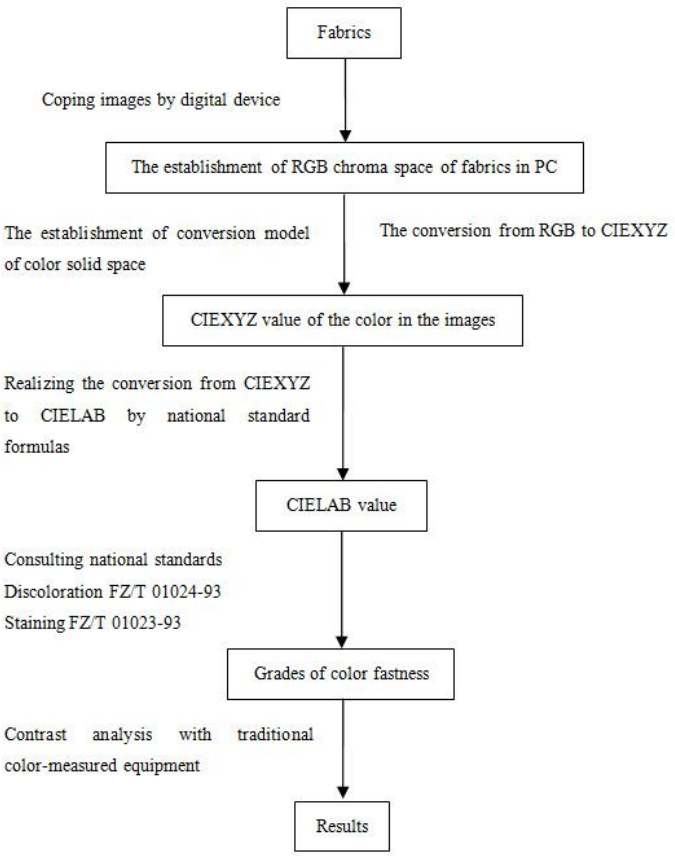

Figure 7 Flowchart of the assessment of the gray scale rating of change of shade by the scanner method

Scanner is used to measure the color of the samples which have been experienced color fastness tests and the color of untreated fabrics to get their corresponding RGB values in computer. The conversion model established in the article, which realizes the solid spatial conversion between computer RGB and CIE XYZ, is used to get the exact corresponding XYZ tristimulus values.

RESULTS AND DISCUSSION

Contrast of Testing Results with Traditional Color-Measured Equipment

Spectrophotometer Macbeth 7000 Color-eye System is used to test the samples by means of random sampling under the conditions below:

Spectrophotometer:

Testing instrument: Macbeth 7000 Color-eye System;

Testing conditions: D65 light source, CLE LAB color space and 10 °field-of-view;

Testing methods: Each sample is tested 4 times. The apparatus calculates the Mean Value of color difference (ΔE) and assesses the grade of discoloration fastness according to ISO 105 A 03 automatically. The results are analyzed within the allowable range of 0.5 grades errors compared with the standard color fastness assessment values got from the tests using experts' eyes.

Spectrophotometer testing: 14 groups' grade differences in 91 groups of discoloration samples are above 0.5 compared with the standard color fastness assessment values got from the tests using experts' eyes, and the qualification rate is 84.62%; 5 groups staining samples are unqualified in 20 groups, and the qualification rate is 75%. When using this system method, the Results obtained are: 3 groups discoloration samples are unqualified in 91 groups, and the qualification rate is 96.7%; 2 groups staining samples are unqualified in 20 groups, and the qualification rate is 90%.

Contrast analysis diagram of these three testing results is as follows. It is found that rating with traditional instruments also has certain gaps with visual observation. Moreover, using this system method (dashed line in the figure) to measure the discoloration fastness of textiles, the conformity with experts' eyes and the stability of the evaluation are better than using traditional spectrophotometer (solid line in the figure 8).

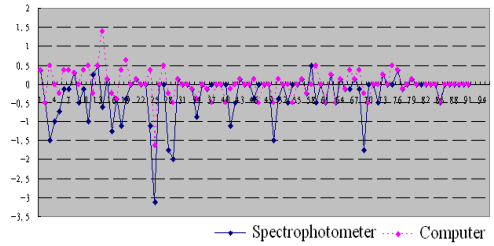

Fig.8 Contrast analysis diagram of color difference between spectrophotometer\the vision system and experts' eyes

CONCLUSIONS

It is seen that the precision of the conversional model of color three-dimensional space established by this system between computer RGB and CIE XYZ is very high from the coincidence rate of ultimate fitting curves. Because the conversion of this model is from actual measurement data to standard data and the hardware errors of part measuring processes have been eliminated in the fitting procedure. Furthermore, it also overcomes many defects of traditional color measuring such as conversion devices of photoelectric signal which are expensive, deep color-week reflected light is received badly and so on.

It establishes the foundation of the application of other digital equipments that the success of using EPSON PERFECTION 1260 scanner to measure the accurate XYZ values of materials. The results are more accurate and steady when using the fitting conversion formula than common linear conversion formula. Through the contrastive analysis with traditional color-measured equipment, the testing results are more accurate and steady-gonging. And it can be used to measure and assess instead of human eyes. The conclusion of this study could be applied in research fields such as color identification, the measurement of fabric count and the estimation of color deviation, color fastness and so on.

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