Research on Quality Evaluation Method of Color Reproduction of Ink-jet Image

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Abstract

The color evaluation of ink-jet based on simulation of human vision system by S-CIELAB color spacee is presented in this paper. dark tone, high-light tone, neutral grey, skin color, color gamut and memory color are used as six quality factors which affect ink-jet's color reproduction, and the parameter weight of color evaluation is determined by fuzzy hierarchy analysis. Then, a parameter model of fuzzy evaluation which is about the color reproduction quality of ink-jet is established. The experimental results show that color quality evaluation parameter ΔE_{IC} *which is proposed in this paper is more prise than traditional* ΔE_{00} *in the color quality evaluation of ink-jet. the methord in this paper can maintain consistency of the subjective and objective evaluation.*

1 Introduction

With the rapid growth of digital printing system of ink-jet, the application area is even more extensive. In the meanwhile, the higher quality of ink-jet image is demanded. And then, the quality evaluation method of ink-jet image is receiving much attention. There are two methods to decide the quality of ink-jet image, the one is objective evaluation which uses physical measurement, and the other is subjective evaluation which based on human vision system. The former method use mathematical formula to decide image's quality, although the result of color aberration is close to the original, the quality of image may not accepted by human vision system. This explains that traditional metrizable way cannot provide a precise decision. In the opposite, the subjective evaluation could use limited model to simulate human vision system. Even though this is the most accurate method to express visual perception, the subjective evaluation is short of stability, efficiency and repeatability.

The quality of printing paper which is connected with visual characteristic is particular. So the quality evaluation method of ink-jet image should use the combination of objective method and subjective evaluation which adopt a model to describe the function of human vision system. For this reason, the method that combine objective survey with subjective inspection, physical index with psychology parameter, will be the perfect evaluation mode, and will obtain the whole result of color reproduction quality[1]. Based on S-CIE LAB color space and measure theory, the paper established a fuzzy evaluation system on color reproduction quality of ink-jet, provided a color evaluation parameters model, and held physical index together with psychology parameter in the color reproduction quality evaluation method of ink-jet image.

2 The S-CIE LAB color aberration calculation

2.1 The advantage of S-CIE LAB system

CIELAB (CIE1976L*a*b*) is an important uniform color system, and CIE LAB color aberration is also widely used in the field of printing and imaging science, which is established with simple color lump, cannot in accordance with the real feel of human vision. Based on CIE LAB color space, Xuemei Zhang and Brian A.Wandell in Stanford University had proposed S-CIELAB system in 1996, which used for quality evaluation of image [2]. The S-CIELAB increased space pretreatment step, the space mixing efficiency of human vision system would be compensated. It also changed halftone dot to human vision fuzzy model, and one by one calculate the pixel in the whole image. This calculation was based on psychophysics experiment, it considered that human vision system will use the separation of pattern and color to show a color image, and it named Pattern-color Separable Method, that is why the result of S-CIE LAB color aberration is nearer to visual sense, and it contains both objective survey and subjective inspection in the quality evaluation of image [3].

2.2 The process of S-CIE LAB color aberration calculation

(1) Choosing an original copy, and printing the same image with a suited ink-jet printer and paper.

(2) Scanning the two images above, changing RGB color space to CIE XYZ color space.

(3) Transforming the opposite color space. The advantage of S-CIE LAB is having a space wave filtering pretreatment step. Because the pretreatment should be done in the opposite color space, we have to change the XYZ image to three opposite color channels. The conversion equation as follows:

$$\begin{bmatrix} A \\ C_1 \\ C_2 \end{bmatrix} = \begin{bmatrix} 0.2787 & 0.7218 & -0.1066 \\ -0.4488 & 0.2898 & 0.0772 \\ 0.0860 & -0.5900 & 0.5011 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{1}$$

In the equation, A: Illumination, C_1: Red & Green, C_2: Yellow & Blue.

(4) Space wave filtering. The space wave filtering is used for simulating the space mixing efficiency of human vision system. After two images changing into opposite color space, three irrespective channels will perform wave filtering which filter is close to contrasting sense function of human vision system.

The wave filtering makes a two-dimension convolution calculation on each opposite color, and convolution kernel is determined by space response characteristic of human vision. The convolution kernel of S-CIELAB color space is the total convolution kernel in Gaussian function form, and the aberration evaluation of large acreage uniform gamut is in keeping with CIE LAB. Equation (2) and (3) indicates the spatial pattern of convolution kernel:

$$f = k\sum_i \omega_i E_i \tag{2}$$

$$E_i = k_i \exp\left[-(x^2 + y^2)/\sigma_i^2\right] \tag{3}$$

Choosing normalized factors k_i and k when achieved discretization, added k_i to 1, and k made the sum of f to 1, so the average color value in uniform gamut would be conserved. Parameter ω_i and σ_i indicates weight factor and expansibility respectively in Gaussian function.

(5) Transforming the opposite color space into CIE XYZ. This process is the inverse transformation of step (3). It is designed to converting to CIE LAB color aberration conveniently on next step.

(6) Using universal conversion equation for transforming CIE XYZ to CIE LAB color space.

(7) Calculating color aberration. When receiving the CIE LAB coordinates of filter image, the color aberration will be calculated one by one pixel. And then we will use the newest color aberration formula for calculating S-CIE LAB color aberration[2]. Because of the space wave filtering, the calculated aberration is nearer to human visual sense. Usually we use the average aberration of pixels to indicate the image color aberration.

3 The algorithm of color rendering quality value and the determination of quality weighting factors.

3.1 The algorithm of color rendering quality value

Choosing 7 PIA/GATF digital images for subjective evaluation of ink-jet, shown in Figure 1.

(a)Low key (b)High key (c)Group portrait (d)Portrait (e)Gray neutrals (f)Fruit (g)Memory color

Figure1. *Images for subjective assessmen*

Color matching between the original and printing paper is influenced by a lot of elements, and it also varied along with the process of color reproduction. In the paper, we choose 6 quality factors which influenced ink-jet image, there are Low key (L), High key (H), Grey neutral (G), Skin tone (S), Color gamut (C) and Memory color (M). The images Group Portrait and Portrait are influenced skin color. Based on S-CIELAB color space, we worked out the equation of ΔE_{IC} as follows, and ΔE_{IC} is the color rendering quality value.

$$\Delta E_{IC} = w_1 \cdot \Delta E(L) + w_2 \cdot \Delta E(H) + w_3 \cdot \Delta E(G) + w_4 \cdot \Delta E(S) + w_5 \cdot \Delta E(C) + w_6 \cdot \Delta E(M) \tag{4}$$

In the equation, ΔE(L) , ΔE(H) , ΔE(G) , ΔE(S) , ΔE(C) , ΔE(M), indicates the aberration between original copy and Low key, High key, Grey neutral, Skin tone, Color gamut, Memory color respectively, and $w_1, w_2, w_3, w_4, w_5, w_6$ are weighting factors of color quality.

The skin quality factor in color rendering is mainly determined by the aberration $\Delta E(S)$ between original copy and images Group Portrait and Portrait, the equation as flowers:

$$\Delta E(S) = w_1 \cdot \Delta E(G_P) + w_2 \cdot \Delta E(W_P) \tag{5}$$

The above w_1, w_2 are weighting factors of skin color quality.

3.2 The determination of quality weighting factors

3.2.1 The determination of hiberarchy of quality factor

The paper is founded on Fuzzy Analytical Hierarchy Process (FAHP) to calculate the weighting factors, so we should determine the hiberarchy of color rendering on FAHP firstly, shown in Figure 2.

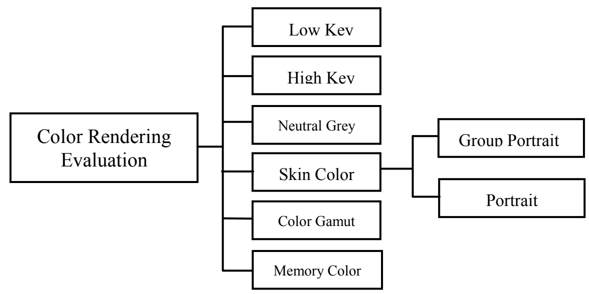

Figure2. *Hiberarchy of Color rendering on FAHP*

3.2.2 Determine the importance of quality evaluation factor

Based on a questionnaire survey of experts, we ordered the quality factors in importance sequence, and indicated in Triangular Fuzzy Number.

Suppose the triangular fuzzy number $p_{ij} = (l_{ij}, m_{ij}, u_{ij})$, it means factor x_i is more important than factor x_j under given constraint condition, and l_{ij}, m_{ij}, u_{ij} are the most pessimistic estimate, the most likely estimate and the most optimistic estimate when factor x_i and x_j compared with a given factor. Evaluation criteria usually makes the scale of 0~1, 0~10 and 0~100, and we choose scale 0~1 in this paper. The triangular fuzzy number scale is shown in Table 1.

Table 1 Triangle fuzzy number scale

Number Scale	Meaning
0.9	The one risk factor is extremely important than the other one
0.8	The one risk factor is strongly important than the other one.
0.7	The one risk factor is obviously important than the other one.
0.6	The one risk factor is a bit important than the other one.
0.5	The two risk factors have the same importance.
0.1～0.4	Inverse compare, if p_{ij} is the result of factor x_i compares with x_j, that $p_{ji} = 1 - p_{ij}$ is factor x_j compares with x_i.

3.2.3 Calculating the weighting factor

15 person that included 3 printing experts and 12 research men participated in this survey, they had the same weighting factor γ. The fuzzy judgement matrixes were obtained through processing initial data in this paper. The defuzzy judgement matrixes was worked out by calculating the desired value of Triangular Fuzzy Evaluation, then the color evaluation value p_1 and Skin evaluation value p_2 were obtained.

$$p_1 = \begin{pmatrix} 0.5 & 0.43 & 0.5 & 0.43 & 0.43 & 0.43 \\ 0.57 & 0.5 & 0.48 & 0.46 & 0.42 & 0.39 \\ 0.5 & 0.52 & 0.5 & 0.51 & 0.55 & 0.51 \\ 0.57 & 0.54 & 0.49 & 0.5 & 0.53 & 0.47 \\ 0.57 & 0.58 & 0.47 & 0.47 & 0.5 & 0.44 \\ 0.57 & 0.61 & 0.49 & 0.53 & 0.56 & 0.5 \end{pmatrix} \quad (6)$$

$$p_2 = \begin{pmatrix} 0.5 & 0.495 \\ 0.505 & 0.5 \end{pmatrix} \quad (7)$$

The each normalized weighting factor would be determined by AHP method.

The quality weighting factors which included Low key, High Key, Neutral Grey, Skin tone, Color gamut, Memory color were showed as follows respectively, W1=0.1515, W2=0.1514, W3=0.1731, W4=0.1724, W5=0.1666, W6=0.1810.

Skin quality was described by Group Portrait and Portrait, and the weighting factors were W1=0.4975, W2=0.1515.

When took the above color quality factors into equation (8) and (9), we got the algorithm model of color rendering quality value ΔE_{IC} and skin color quality value $\Delta E(S)$ as follows:

$$\Delta E_{IC} = 0.1515 \cdot \Delta E(L) + 0.1554 \cdot \Delta E(H) + 0.1731 \cdot \Delta E(G) + 0.1724 \cdot \Delta E(S) + 0.1666 \cdot \Delta E(C) + 0.181 \cdot \Delta E(M) \quad (8)$$

$$\Delta E(S) = 0.4975 \cdot \Delta E(G_P) + 0.5025 \cdot \Delta E(W_P) \quad (9)$$

The whole image quality evaluation of ink-jet printing was obtained by using the combination of color rendering quality value and sharpness quality value.

Set the image quality evaluation of ink-jet printing to $\text{Image-QA}_{\text{IJP}}$, the sharpness quality value to S_{PMSD}, then got an equation as follows:

$$\text{Image-QA}_{\text{IJP}} = w_1 \cdot k_1 \cdot \Delta E_{IC} + w_2 \cdot k_2 \cdot S_{PMSD} \quad (10)$$

w_1 and w_2 indicated the color quality factor and sharpness quality factor, k_1 and k_2 are normalized factors.

4 Experiment result and evaluation analysis

4.1 Experiment Condition

Select an Epson Stylus Photo2100 ink-jet printer which was linearized, and print the 7 PIA/GATF digital images in Epson Glossy Photo Paper (No.1), Advanced HP Photo Paper (No.2) and Kodak Photo Glossy Paper for Inkjet Prints (No.3) with the resolution 720dpi.

The printed images were scanned into computer, which scanner was linearized too, and we could pick up all the color data for calculating color quality value ΔE_{IC}.

4.2 Experiment results

According to the algorithm mentioned in the section 2, we got the CIELAB coordinate which is processed by space wave filtering. The result we received not only aberration value ΔE but also the color rendering evaluation of ink-jet printing through the equation (8) and (9). There are ΔE_{IC} values of printed image on Epson2100 ink-jet printer, shown in Figure 3.

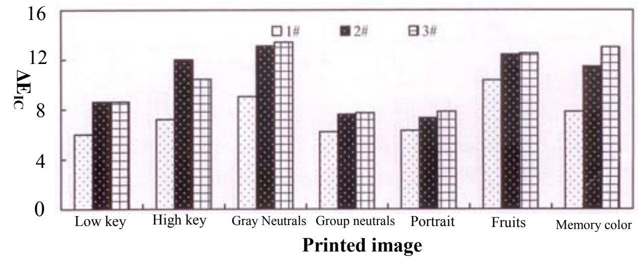

Figure3. ΔE_{IC} values of printed image on Epson2100 ink-jet printer

As best seen in Fig.3, ΔE_{IC} of printed images in sheet No.1 is less than the other two samples, it shows that No.1 has the best color rendering quality, and the high key image in sheet No.2 has a serious gradation distortion. The skin color, neutral grey and memory color are all have the worst performance in sheet No.3, it's ΔE_{IC} is maximum.

4.3 Comparing color rendering quality value ΔEIC with aberration ΔE00

Calculating the traditional CIE LAB aberration ΔE_{00} of 7 images in the three sample sheets, and compares with the S-CIELAB ΔE_{IC}, the result is shown in Figure 4.

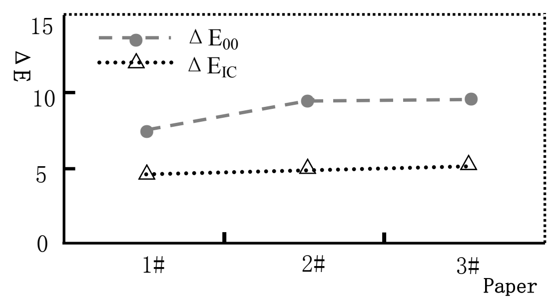

Figure4. Quality evaluations of printed images on Epson2100 based on two methods

As seen in Fig.4, the aberration ΔE_{IC} that based on S-CIE LAB is 1.5 times than traditional aberration ΔE_{00}. The result of ΔE_{IC} illustrates that Sheet No.1 is better than Sheet No.2 and Sheet No.3, although they are the similar in aberration ΔE_{00}.

4.4 Comparing of psychophysics test result of printed image quality

Choose 12 research men who are familiar with printing chromatology to compare the 7 original copies with printed images. Each observer has 504 times (3 sample sheets×7 images×3 quality factors×4 problems×2 repeated test), and viewing distance is 5cm, chromatic adaptation time is 1min.

In the test, we record the frequency which printed images did better performance than original copies, and change the accumulation value into rate value, then transform each printed image quality to the scale value that related to psychophysics though Z-Score algorithm. As a result, arrange the printed images quality according to the value of Z-Score. The test result is shown in Fig.5.

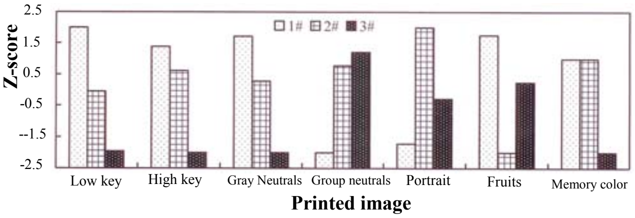

Figure5. *Pair-comparison results of samples on Epson2100 ink-jet printer in terms of z-score scale*

Fig.5 presents Sheet No.1 has the best quality in all printed images except skin color. And performance of quality value ΔE_{IC} is consistent with result of Z-Score, it means Sheet No.1 is the best sample, secondly is Sheet No.2, and Sheet No.3 has the worst image quality

5 Conclusions

Based on S-CIE LAB color space and simulation of human vision system, this paper chose six quality factors which influenced color rendering and used FAHP to determine the weighting factors of image evaluation value, and established a fuzzy evaluation model on color rendering quality of ink-jet printing as a result. The conclusion as follows:

(1)Compared with traditional CIE LAB aberration ΔE_{00}, the color rendering quality value ΔE_{IC} is more nearly accurate in evaluating image quality of ink-jet printing. It also has one by one comparing in a single image when necessary.

(2)Psychophysics test illustrates the value ΔE_{IC} in keeping with the result of subjective evaluation, thus the veracity and validity of new method will be proved.

The color quality model proposed in this paper overcomes some shortcomings such as inaccurate objective evaluation, inefficient subjective evaluation and poor stability, provides an effective measure for the image quality evaluation of ink-jet printing. The Image Quality Evaluation of Ink-jet Printing Value $image - QA_{IJP}$ will be obtained by using combination of color model and sharpness quality value, then the whole image quality of ink-jet printing will be evaluated.

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