Chapter 57
Effect of Paper Optical Characteristics on Tonal Gradation Reproduction in Inkjet Printing

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Abstract Paper characteristics are important determinants to print quality, especially the optical characteristics of paper to color reproduction. In order to analyze the correlation between characteristic details and results, a simulation experiment was conducted. Five kinds of paper in three major categories were selected and three major optical characteristics, including whiteness, opacity, and chromaticity, were detected. Then a standard digital test format was printed with digital inkjet printer to optimize the output color quality. The tone reproduction and color gamut accuracy were analyzed by comparing the tonal gradation of primary color, secondary color and tertiary color. And the color gamut was created by Verify module in EFI software and was compared by pairwise comparison analysis. Finally, the primary relationships between paper optical characteristics and tone reproduction were summarized tentatively. The experimental results show that paper whiteness and chromaticity have a significant effect on tone reproduction, yet the effect of opacity is not obvious. This study provides good foundation to further mechanism study in the future work.

Keywords Optical characteristics of paper · Printing quality · Color reproduction · Color tonal gradation

57.1 Introduction

Paper is the most popular printing material used in printing products. The effect of paper optical characteristics on tonal gradation reproduction is one of the hot research focuses for domestic and overseas researchers to promote the development of new theory and technology study in printing quality optimization continuously [1]. The paper optical characteristic will determine the color reproduction in inkjet

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Table 57.1 The paper type and number

The paper number	Paper type	Grammage
1#	High glossy photo paper	240
2#	Semiglossy paper	190
3#	Semiglossy paper	180
4#	Matte inkjet paper	130
5#	Matte inkjet paper	130

printing [2]. In this research, the effect of optical characteristics was emphasized by analyzing tonal gradation reproduction in color printing which could be of some help to technologists in choosing appreciate paper in craftsmanship design. And a simulation experiment was carried out to discuss the primary relationships between paper optical characteristics and tonal gradation.

57.2 Experiments

In this experiment, whiteness, opacity, and chromaticity of paper were tested. Then a simulated printing with standard digital inkjet printer was conducted by using color management technology, and the chromaticity reproduction accuracy was measured.

Samples

In the experiment, five kinds of three categories of paper selected are shown in Table 57.1.

Detecting equipments

YT—48 Digital whiteness meter
X—rite I1 Pro2 Spectrophotometer3
GretagMacbeth Profile maker 5.0.8 software
Target A 600dpi CMYK 071025color standard digital format

Inkjet printing equipments

Epson stylus Pro 7880C
Epson eight-color ultra Chrome K3 ink
EFI Colorproof XF software driver

57.3 Results and Discussion

57.3.1 Paper Optical Characteristics Analysis

In this study, five kinds of three categories of paper were detected. On each sheet, 10 different positions were selected randomly to measure the paper optical

Table 57.2 Optical characteristic parameters of five kinds of paper

Sample	Opacity (%)	Whiteness (%)	Lab		
			L	a^*	b^*
1# 240 g/m^2 High glossy photo paper	98.07	87.27	94.94	−0.49	−2.20
2# 190 g/m^2 Semiglossy paper	94.93	88.39	94.76	−0.09	−3.12
3# 180 g/m^2 Semiglossy paper	92.69	87.66	94.51	0.25	−4.24
4# 130 g/m^2 Matte inkjet paper	97.33	91.90	96.05	0.84	−4.67
5# 130 g/m^2 Matte inkjet paper	99.41	92.93	90.91	2.83	−12.56

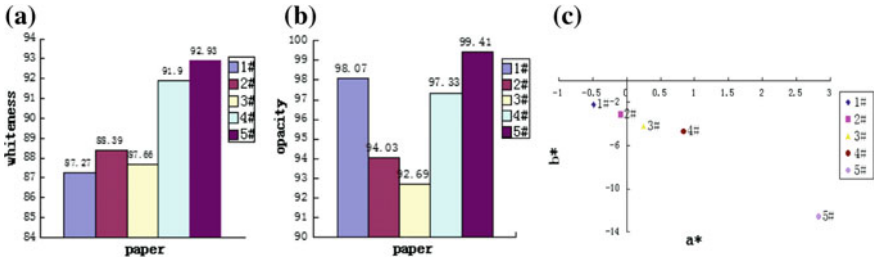

Fig. 57.1 The figures of optical characteristics of five kinds of paper **a** Whiteness of samples. **b** Opacity of samples. **c** Relative position of chromaticity

characteristics including whiteness, opacity, and chromaticity. Then the average values were calculated and were accurate to 0.01. The experimental results are listed in Table 57.2.

The charts of different optical characteristics are shown in Fig. 57.1.

Figure 57.1 describes paper whiteness. The whiteness of paper 1#, 2#, and 3# are close. The whiteness of 4# is close to 5#, both of which are higher than the other three. Correspondingly, the opacity of 4# and 5# are also higher. That is because white paint leads to the increase of opacity which is coated on paper surface [3].

In Fig. 57.1, the opacity of 1#, 5#, and 4# is higher, 3# is the lowest and 2# is in the middle. This shows that the paper opacity is associated with grammage and paper surface coating method [4].

Relative position of each paper chromaticity is plotted in CIEL$^*a^*b^*$ color space as is shown in Fig. 57.1. 5# paper looks blue-violet. 4# and 3# paper looks slightly blue. Only 1# and 2# paper are close to visual whiteness. From Table 57.2, compared with the value of a^*, b^*, 5# is obviously different and the visual effect is blue.

57.3.2 Paper Chromaticity Reproduction Analysis

The chromaticity value of the self-made standard board was measured. Then the tonal gradation accuracy was analyzed and the color gamut figure was compared, forming the space figure as follows.

57.3.2.1 Analysis of the Tonal Gradation

Primary color tonal gradation
From Fig. 57.2, except for two apparent measuring errors in K and C tone curves, the coincidence of C tone curve is high. The curves of K and M are relatively centralized. In Y tone curves, the reproduction ability of 5# is obviously inferior to others. The coincidence of 1# and 2# is high.

Secondary color tonal gradation
From Fig. 57.3, the coincidence of secondary color tone is higher than primary color. Except for 5#, other curves are quite similar. The value in shaft b^* of 5# is obviously different from others, which means that the dynamic range of tone is apparently lower than others.

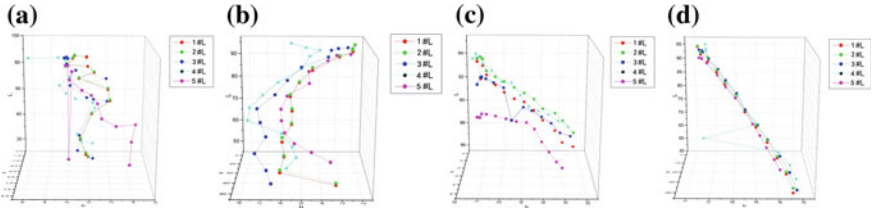

Fig. 57.2 The tone–chroma relationship curves of primary color **a** K tone curve, **b** M tone curve, **c** Y tone curve, **d** C tone curve

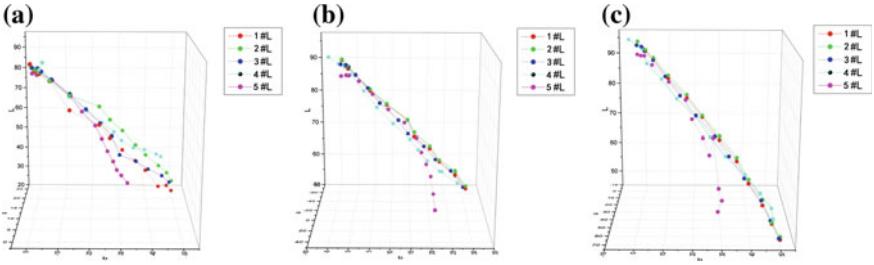

Fig. 57.3 The tone–chroma relationship curves of secondary color **a** B tone curve, **b** G tone curve, **c** R tone curve

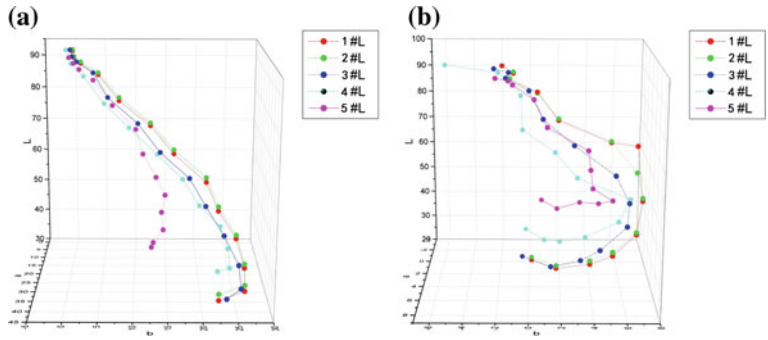

Fig. 57.4 The tone–chroma relationship curves of tertiary color **a** Skin Tone curve, **b** C + M + Y tone curve

Tertiary color tonal gradation

In Fig. 57.4, in skin color reproduction, 5# deviates seriously and shows low dynamic range. The coincidence is higher in other curves. In gray color reproduction, the coincidence of 1#, 2# is higher, while others are more dispersed. These indicate that gray color is more sensitive to optical properties [5], as is shown in highlight and in shadow, the coincidence is high, yet in mid-tone it is scattered.

From above, the comparison of primary color, secondary color, and tertiary color shows that the tone reproduction of 1# and 2# is very close, 4# and 3# is scattered; however, 5# deviates seriously from all the others and the tone compression is serious.

57.3.2.2 Analysis of the Color Gamut

The color gamut of pair combination was compared. Three kinds of representative combinations were revealed in the following figures. The color of 5# is partial blue, while 2# is visual whiteness; therefore, they are combined to analyze the effect of paper chromaticity on tonal gradation. Except for 5#, the opacity of 1# is the highest, and 3# is the lowest. The whiteness of 4# is the highest and 1# is the lowest.

In Fig. 57.5, blue-violet part is the color gamut of 1#, which is larger than 3#, blue part is the overlap of 1# and 3#, cyan-blue part of 3# is more than 1#. The majority of the stereogram is blue, indicating the color space of 1# and 3# is close. While there is more color reproduction in 3#. In the lightness, the reproduction of 1# is better than 3# paper.

In Fig. 57.6, blue-violet part is the part of 1#, which is beyond 4#, the emerald green part is the overlap of 1# and 4#, and the blue part of 4# is beyond 1#. Differences are in light tone, and the color reproduction of 4# is better than 1#. In shadows, the reproduction of 1# is better than 4#.

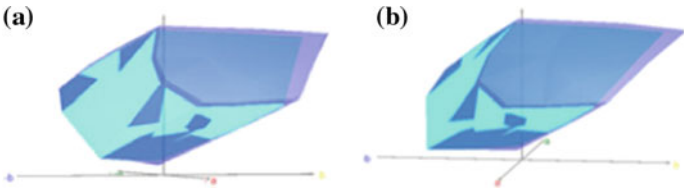

Fig. 57.5 Color gamut comparison of 1# and 3#

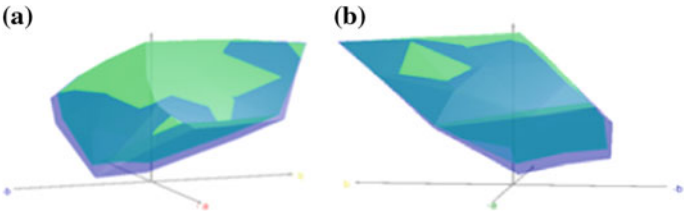

Fig. 57.6 Color gamut comparison of 1# and 4#

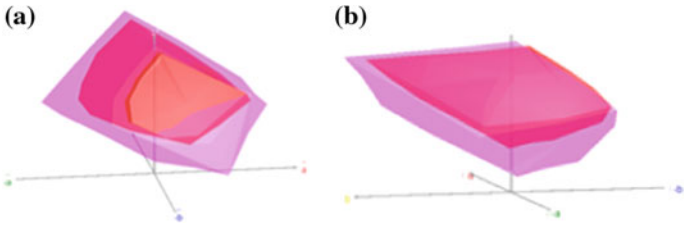

Fig. 57.7 Color gamut comparison of 2# and 5#

In Fig. 57.7, the pink part of 2# is beyond 5#; the rose red is the overlap of 2# and 5#. The color space of 5# is smaller. In the shadow, the ability of color saturation reproduction in blue space of 5# is stronger.

57.3.3 Analysis of Effect

In the simulation experiment, the effect of optical properties on tonal gradation was analyzed.

Concerning whiteness characteristic, the whiteness of 5# is the highest, but the tone copy and color gamut is poor, which was mainly affected by the partial color [6]. The whiteness of 4# is higher and its color is not partial. In light tone and mid-tone, the color gamut of 4# is very rich. So if the whiteness is higher, the printing color in light tone and mid-tone is better.

Concerning opacity characteristic, except for 5#, the opacity of 1# is the highest. The tone copy of 1# is good, which is close to 2#, but the opacity of 2# is far lower than 1#. The opacity of 3# is the lowest, but its color gamut and tone copy are also good. So in a certain range, there is no obvious effect of the opacity on the color of printed image.

Concerning $L^*a^*b^*$ value characteristic, the color of 5# is serious blue-violet. Although the whiteness and opacity of 5# is higher, the tonal gradation copy is poor, and only the blue reproduction is better than that of others. The color of 1# and 2# is close to visual whiteness. Their tonal gradation copies are all good. It is obvious that the color of paper has an effect on tonal gradation reproduction.

57.4 Conclusions

In this study, three paper optical properties, including whiteness, opacity, and chromaticity, were focused. A simulation experiment was carried out to analyze the effect of optical properties on different tone range gradation. Through the experimental data and the above analysis, conclusions can be drawn as follows.

The whiteness of paper has an obvious effect on tonal gradation. The higher the whiteness of paper is, the better the printing color in light tone and mid-tone would be. In a certain range, both the highest opacity in 1# and the lowest in 3# are all good at color image reproduction, so there is no obvious effect of the opacity on tonal gradation. The color shift of paper has an obvious impact on the copy of tonal gradation. When the color of paper is visual whiteness, the tonal gradation reproduction is good. The color shift causes the tonal gradation reproduction inaccurate. In this case, special attention should be paid to the color shift phenomenon when doing technological design.

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