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The effect of paper's properties on the dot reproduction of image in ink-jet printing

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Abstract
The property of printing substrate plays an important role in the image reproduction of ink-jet printing. The paper's properties such as roughness, gloss, surface wettability and other factors have great influence on the dot reproduction attributes of presswork. The main purpose of this paper is to provide a new method to analyze the influence of paper's properties on the dot reproduction. Different paper factor has different effect weight on the image reproduction. The grey relational analysis is a multi-factor statistical analysis method, which is based on the sample data and the grey incidence of various factors and is used to describe the strength, size and the order of the relationship between the factors. The grey relational analysis is applied to analyze the influence law and the effect weight of paper factors on the dot reproduction during ink-jet printing, which could provide theoretical guidance for improving the printability of paper.

In this experiment, five types of ink-jet printing paper were used to test their printing performance, and then the dot gain data were dealt with by the grey relational analysis method. The parameters of the inkjet printer were adjusted to match the paper type. And then, the CMYK step-wedges designed by Adobe Photoshop CS were printed by the printer with 600dpi print resolution. The step-wedge consisted of the color patches with 1%, 2%, 5%, 25%, 50% and 75% dot coverage respectively. The printed dots were taken photos by Microscope to analyze the ink setting condition. The dot gains of highlights, mid-tone and shadow area in each printed sample were measured by the spectrophotometer. At last, the grey relational analysis was used to analyze the dot reproduction attributes.

Results showed that paper properties had a great influence on ink setting. Ink drop diffused and deformed less and dot gain was small when paper had smooth surface and tight texture. According to the correlation coefficient degree of paper properties which influence on the dot gain of inkjet printing, the sequence was whiteness, roughness, surface wettability and gloss. Whiteness and roughness could significantly influence dot gain, followed by surface wettability, and gloss with minimal impact. Experiments indicated that the grey relational analysis was a simple and effective tool to analyze the influence of paper properties on the dot reproduction of presswork.

Introduction
Patterns are reproduced by dots in printing, so that dot gain has great influence on the reproduction of the printing pattern. Dot gain includes optical dot gain and mechanical dot gain. Optical dot gain is a kind of visual phenomenon which is influenced by the absorption properties of the ink and the light scattering of the substrate. Mechanical dot gain is the actual physical increase, which is non-directional [1]. The dot gain is closely related to the paper properties.

Grey relational analysis is the most widely used part in the theory of Grey System [2,3]. Grey relational analysis is a multi-factor statistical analysis method, which based on the sample data and the grey incidence of various factors and is used to describe the strength, size and the order of the relationship between the factors. The correlation between all factors and sub-factors were constructed an incidence matrix, and the influence between different factors could be obtained by analyzing the matrix [4]. In this paper, the influence laws of substrate properties on dot gain were studied based on the grey relational analysis by discussing the effect of paper properties on the dot gain in inkjet printing.

Experiment
Materials and Equipment
Materials: 5 types of Inkjet printing Paper, 1 # Satin matter paper, Hp; 2# Advanced photo glossy paper, Hp; 3 # Premium presentation matter paper, Epson; 4 # Inkjet paper, Epson; 5 # Semi-gloss paper, Hp. Equipments: Computer (eMac, Apple Co.); Profile Maker 5. 0 (Gretag Macbeth); Inkjet printer (Epson Stylus C88+); Brightness tester (L&W Co.); Monitor/Smoothness-II (Testing Machines Inc, N.Y., USA); Gloss tester (Qili, Tianjin); Microscope (AXIO Imager).

Method
The parameters of the inkjet printer were adjusted to match the paper type. And then, the CMYK step-wedges designed by Adobe Photoshop CS were printed by the printer with 600dpi print resolution. The step-wedge consisted of the color patches with 1%, 2%, 5%, 25%, 50% and 75% dot coverage respectively. The printed dots were taken photos by Microscope to analyze the ink setting condition. The dot gains of highlights, mid-tone and shadow area in each printed sample were measured by the spectrophotometer. At last, the grey relational analysis was used to analyze the dot reproduction attributes.

Results and Discussion
The condition of the setting ink drop.
The ideal inkjet printed dot is perfectly round and without capillary diffusion, feather, penetration and bleeding phenomenon [5]. The matching condition between the properties of ink and paper determines the sharpness of the printed dot [6]. Inkjet printer sprays ink drops at a high speed, so the ink drops diffuse and burst inevitably, coupled with the influence of the paper surface properties, which led to the setting of ink drops on the paper surface is obvious different. The conditions of ink drops setting on different paper surface were shown in Fig.1.

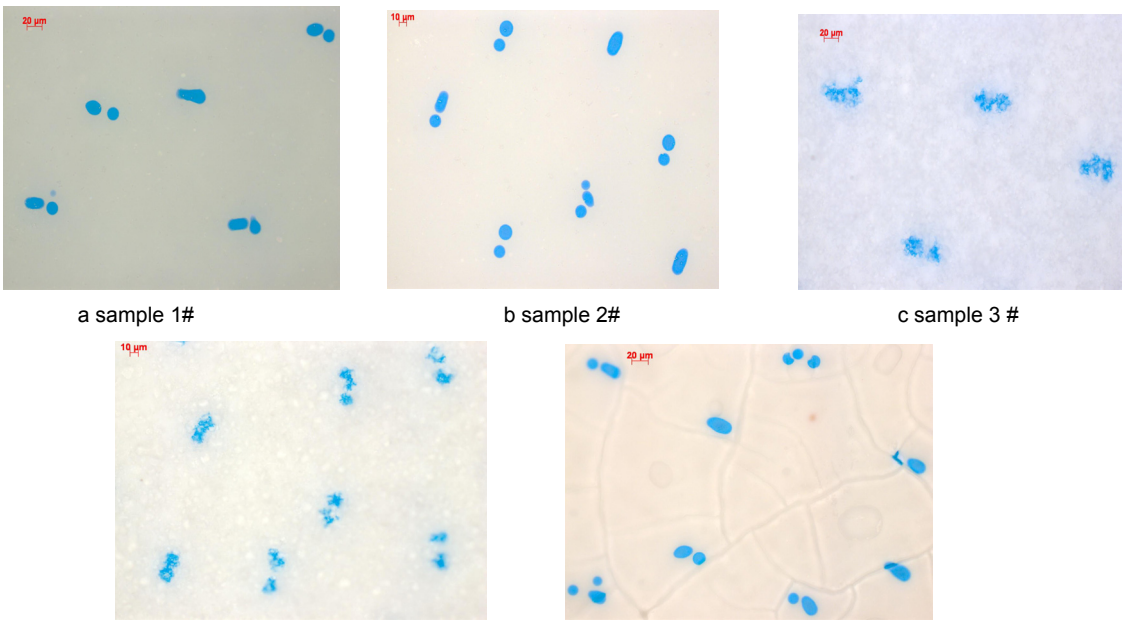


Fig.1 The curing condition of Ink drop on inkjet paper (2% cyan)

Fig.1 showed that the ink dots boundary of the sample 1 #, 2 # and 5 # was clear and sharp, and the roundness degree of dot was high. However, the ink dot boundary of the sample 3 # and 4 # was fuzzy and the roundness degree was low. The main reason was that the surface of sample 1 #, 2 # and 5 # was smooth. When ink drops sprayed on the above paper surface, the ink drop spread was relatively small and its penetrating ability to the fibers was relatively low, so the deformation of the ink drop was small. On the other hand, the surface of sample 3 # and 4 # was rough, so ink drops spread and penetrated along the coatings and fibers of the paper surface irregularly until they cured completely. Therefore, surface properties of paper had great impact on ink dot reproduction. Papers with high smoothness and fine texture could obtain high quality images.

Dot gain.

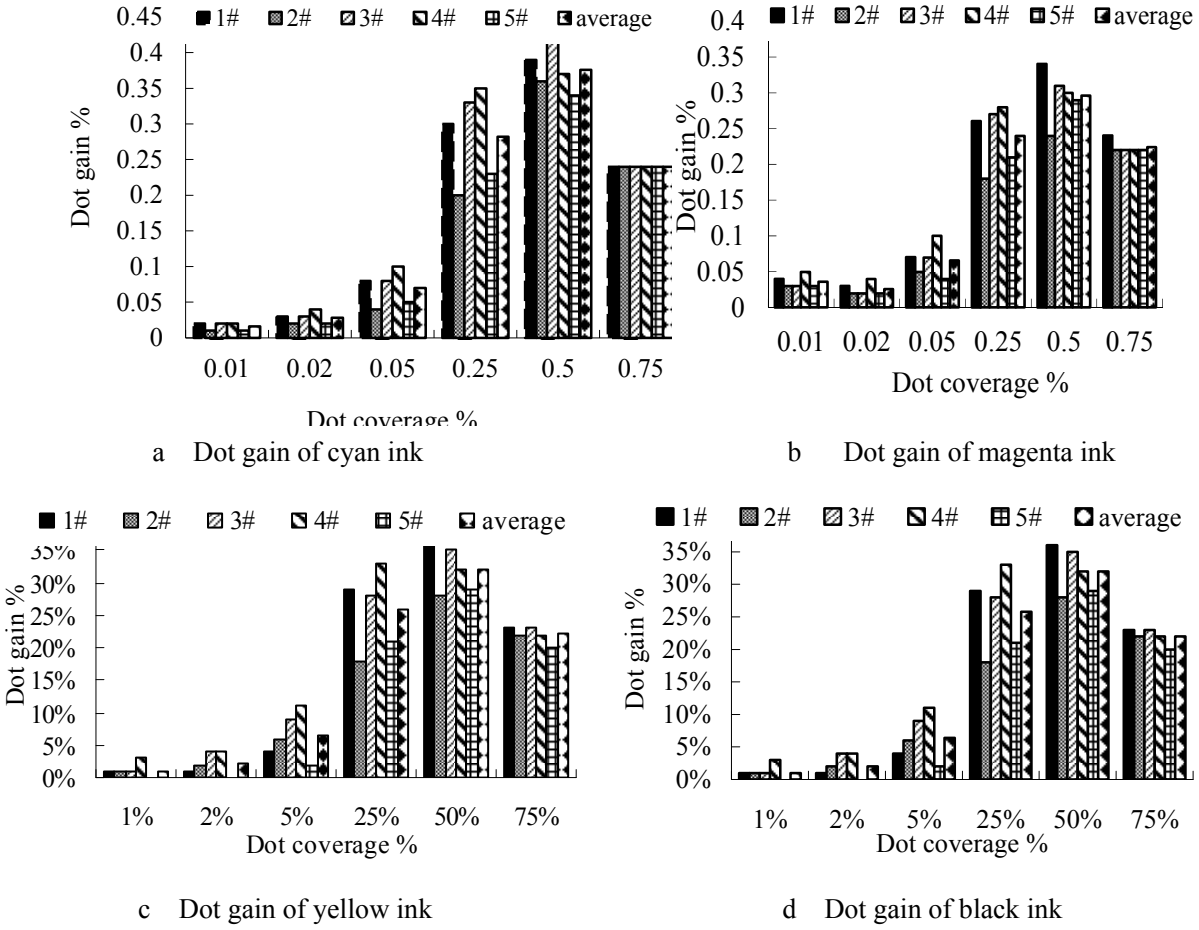
The control of dot reproduction directly affects printing quality. The influence of paper properties on dot gain was showed in Fig.2.

Fig.2 showed that dot gain value of the same color varied greatly with different substrates. At 25% dot coverage, the cyan ink dot gain values of sample 2# and 5# were smaller than those of sample 3# and 4#, and the variation of dot gain values of the yellow, magenta inks showed the same trend as the cyan ink. Fig.2 also showed that the dot gain values changed with dot coverage. Among the highlights (0%~10% dot coverage), the mid-tone area (30%~70% dot coverage) and the shadow area (70%~90% dot coverage), the dot gain value of the mid-tone area was the biggest, followed by the shadow area and the highlights. The difference of the dot gain was mainly reflected at the mid-tone area. For 50% dot coverage, black ink had the biggest dot gain, followed by cyan ink, yellow and magenta ink. Generally, the black ink had the biggest dot gain and the yellow ink had the smallest dot gain.

Grey relational analysis of dot gain.

The above discussions indicated that paper properties had great influence on the dot reproduction. To investigate the role of different paper's property in dot reproduction, the grey relational analysis of dot gain was conducted. Four properties of paper such as the gloss, roughness, whiteness and surface wettability were selected as the sequence variables, namely X1, X2, X3 and X4. Dot gain of CMYK ink at highlights, mid-tone and shadows area were represented by Y1~Y12 respectively.

The variable sequence was nondimensionalized and the original data were initialized to ensure the reliability of the analytical results. The absolute differences between the reference sequence and corresponding comparison sequence were calculated, and then the absolute interpolation matrix was formed. The association coefficient and the incidence matrix (with distinguishing coefficientρ=0.5) were obtained by transforming the data of the absolute interpolation matrix and the incidence matrix was shown in Fig. 2.



a Dot gain of cyan ink

b Dot gain of magenta ink

c Dot gain of yellow ink

d Dot gain of black ink

Fig. 2.Dot gain value of four-color inks on five types of inkjet paper

	Roughness	Gloss	Whiteness	Surface wettability
Y1(C-H) dot gain	0.901	0.731	0.970	0.830
Y2（C-Mid-Tone）dot gain	0.919	0.717	0.989	0.821
Y3(C-S) dot gain	0.920	0.719	0.999	0.820
Y4 (M-H) dot gain	0.906	0.726	0.964	0.824
Y5（M-Mid-Tone）dot gain	0.938	0.705	0.976	0.804
Y6 (M-S) dot gain	0.926	0.719	0.989	0.819
Y7(Y-H) dot gain	0.827	0.708	0.856	0.793
Y8（Y-Mid-Tone）dot gain	0.919	0.720	0.983	0.822
Y9 (Y-S) dot gain	0.922	0.717	0.993	0.818
Y10 (K-H) dot gain	0.918	0.723	0.963	0.822
Y11（K-Mid-Tone）dot gain	0.926	0.719	0.986	0.820
Y12 (K-S) dot gain	0.924	0.719	0.994	0.819

Fig.2. Incidence matrix

As seen in Fig. 2, among the four factors, the whiteness had the biggest impact on the dot gain of CMYK at highlights, mid-tone and shadows area, followed by the roughness and the surface wettability, and the gloss had the smallest impact on the dot gain.

Fig.2 also indicated that the roughness had the biggest influence on the dot gain of the magenta ink's mid-tone area, while had the smallest influence on the dot gain of the yellow ink's highlights. The whiteness had the biggest influence on dot gain of cyan ink's shadows area, but had the smallest impact on the dot gain of yellow ink's highlights. Surface wettability had the biggest effect on the dot gain of cyan ink's highlights, while had the smallest effect on the dot gain of yellow ink's highlights. Gloss had a smaller influence on dot gain of the four-color inks than that of other three paper properties, but had a great influence on the dot gain of cyan ink's highlights, and

had a small influence on dot gain of magenta ink's mid-tones area.

The above analysis showed that paper properties had great influence on the dot gain. The whiteness of paper was its comprehensive light reflection ability under direct illumination and would associate to optical dot gain. The optical dot gain was a visual phenomenon, which was formed by the light absorption properties of ink and the light scattering of paper. Most of the color inks were transparent or translucent, so the reflected light from paper would transmit through the ink layer, which led to optical dot gain.

Conclusions

Paper properties had great influence on ink setting. Ink drop diffused and deformed less and dot gain was small for papers with smooth surface and tight texture.

According to the correlation coefficient degree of paper properties that influence the dot gain of inkjet printing, the sequence was whiteness, roughness, surface wettability and gloss. Whiteness and roughness could significantly influence the dot gain, followed by surface wettability, and gloss with minimal impact.

As a result, the grey relational analysis was an effective method to investigate the effect weight of different factors that influenced dot reproduction attributes.

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