Measurement of Mechanical and Optical Dot Gain of Ink Jet Printing and Its Application to Estimate the Reflectances of the Images

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Abstract

In this paper, we propose a method to separately measure the ink dot transmittance on paper without the effect of optical dot gain. The single dot profiles on paper are measured by a monochrome digital camera attached on a microscope using underneath illumination in order to capture only ink dot distribution (mechanical dot gain). From single dot profile on glossy, matt and uncoated paper, the transmittances of the ink image are simulated using dot overlap model in the high resolution grid. The reflectance of ink jet images are estimated from the simulated ink image transmittance and the optical point spread function of paper using the image reflectance model. The result shows that the image transmittance and reflectance are well estimated if the paper behaves as a perfect diffuser.

Introduction

The printed halftone image is usually observed darker than it is intended because of the mechanical dot gain and optical dot gain effects. To predict the halftone reflectance, both mechanical and optical dot gain must be taken into consideration. Recently, the halftone reflectance is modelled by two approaches, the probability approach[1] and the convolution approach.[2,3] Equation (1) shows the convolution approach which defines the reflectance of a halftone, *r(x,y),* as follows:

$$r(x,y) = \left\{ \left[t(x,y) * psf_p(x,y) \right] t(x,y) \right\} \quad (1)$$

where $t(x,y)$ is the transmittance of ink image on paper, $psf_p(x,y)$ is the optical point spread function of paper, and * denotes the convolution integral.

In this model, the $psf_p(x,y)$ that causes the optical dot gain, can be obtained from the inverse Fourier transform of the modulation transfer function (MTF) of paper. However, the $t(x,y)$ is not easy to measure because the optical dot gain always included in normal viewing condition. The method that used to obtain $t(x,y)$ is to print an halftone image on a transparency, so that the $t(x,y)$ can measure easily. The printed image is observed by the contact of that transparency on the paper.[4] This method is not applicable if coated layer on the transparency has different absorption properties from the coating of the paper.

In this paper, we propose an approach to separately measure a single dot profile of ink on the paper without the effect of optical dot gain. The image transmittances on paper are estimated using the dot overlap model in high resolution grid and the image reflectance is estimated from the estimated image transmittance using reflection image model.

Measurement Instrument

The concept of measuring the ink dot image on paper without the effect of optical dot gain is to illuminate the printed sample from underneath (Light B) as shown in Fig. 1. The image reflectance is measured by using another light sources illuminates on the printing surface (Light A). The image transmittance and reflectance are captured by a monochrome digital camera (Kodak DCS420) attached on a microscope. The effective CCD sensor in this camera is 1012 x 1524 pixels with 9 µm pitch and the magnification of optical system is 10X. Two polarizing filters are used, one in front of light source and the other in front of camera sensor in order to eliminate the specular reflection because the measurement geometry is 0/0 degree. The two illuminants are adjusted independently until the transmittance and reflectance of bare paper base give the same reading by the camera photocell. If the light that enter ink is totally diffused by paper, then the transmittance measuring by underneath illuminaiton will equal to the transmittance of ink as normal illumination.

Figure 2 shows the transmitted dot profiles from the measurement, $s(i,j)$, on glossy, matt and uncoated paper respectively. The i and j indicate the integer coordinate of the dot pixel. It can be seen from these dot profiles that the distribution of ink on each type of paper is different due to ink and paper interaction.

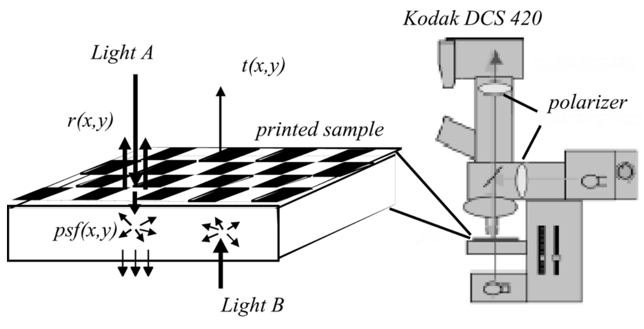

Figure 1. The measurement of reflectance and transmittance of halftone image

Single Dot Profile

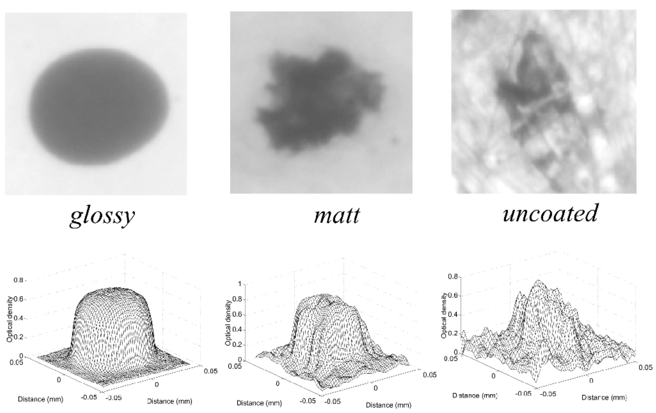

Figure 2. The density profiles, s(i,j), on glossy, matt and uncoated paper from an ink jet printer (Epson 770C).

Printed Image Simulation

The simulation of printed image consists of two steps. The first is to simulate the image transmittance on paper and the second is to simulate image reflectance from the transmitted image and point spread function of paper as shown in Fig. 3.

Estimation of Image Transmittance

The high resolution grid base is created by considering the size of a single dot profile (i row and j column), a halftone image (m row and n column) and the overlap distance (a pixel). If the dot is not overlap the grid base will be $g(mi,nj)$ as shown in Fig. 4 (a). Since the dots of ink jet printer always overlap for some distances, therefore, the grid base is reduced as shown in Fig. 4 (b). To prepare the grid base for the next step, the value 1.0 is assigned to the center of each single dot profile grid when there is a halftone dot in the $b(m,n)$.

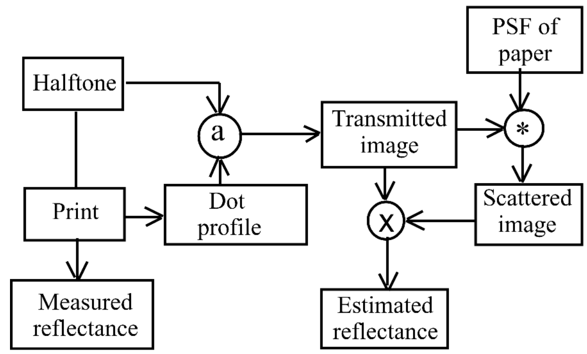

Figure 3. The flow chart of printed image simulation

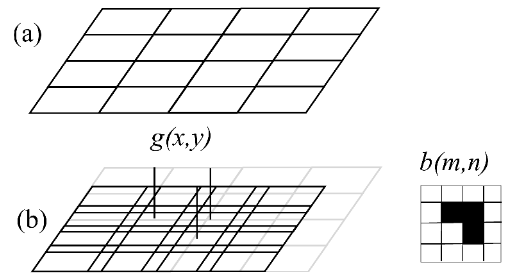

Figure 4. The grid base that corresponding to halftone image.

The grid base that corresponding to the $b(m,n)$ can be written as

$$g(x,y) = \begin{cases} 1 & \text{if} \quad x = mi - i/2 - (m-1)a \\ & \text{and} \quad y = nj - j/2 - (n-1)a \\ & \text{and} \quad b(m,n) = 1 \\ 0 & \text{elsewhere} \end{cases} \qquad (2)$$

where x and y are the coordinate of the output. Equation (2) can be interpreted as it is the two dimensional impulse grid that simulated the output of the printing images. The printed transmittance can be obtained by Eq. (3).

$$t_{sim}(x,y) = 10^{-[g(x,y)*s(i.j)]} \qquad (3)$$

where $t_{sim}(x,y)$ is the simulated transmittance. The convolution between the grid base and the single dot profile will yield the same result as stamping each dot on the grid. The density value in overlap region is the product of adding the density of first dot with the second dot. This is similar to the Beer-Lambert's law. The overlap distance was set to minimize the RMSE of the measured and estimated transmittance from the glossy paper and this overlap distance was apply to other types of paper. The average transmittances from the simulated images on glossy, matt, and uncoated paper are shown in Fig. 5.

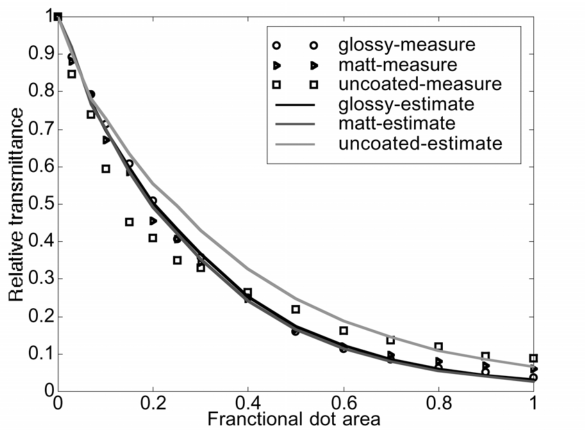

Figure 5. The transmittace of simualted gray ramp comparing to the measured transmittace.

From the comparison of the measured and estimated transmittance, the RMSE from glossy paper, matt, and uncoated paper are 0.0128, 0.0223 and 0.0873 respectively. It is shown that the image transmittance of ink jet papers are well estimated by the dot overlap model in high resolution. However, as the paper structure of uncoated paper is not even and dot size is varied considerably, it is very difficult to find the average dot profile that well represent true average dot profile on the paper.

Estimation of Image Reflectance

For the simulation of reflected image, the point spread function of paper is required. We used the contact sinusoidal method to measured the MTF of glossy, matt and uncoated papers[5,6]. The measured MTF values were fit with the empirical MTF model as show in Eq. (4).

$$MTF_p(\omega) = \frac{1}{\left[1 + (2\pi d\omega)^2\right]^{3/2}}, \quad (4)$$

where ω is the spatial frequency, d is the coefficient account for light scattering distance in the paper. The corresponding PSF of paper is

$$psf_p(x, y) = \frac{1}{2\pi d^2} e^{\frac{-\sqrt{x^2+y^2}}{d}} . \quad (5)$$

The point spread function of paper of these papers from the measurement are shown in Fig. 6.

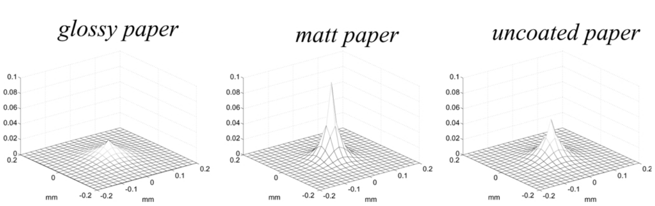

Figure 6. The PSF of gloss, matt and uncoated paper with d values 0.052, 0.025 and 0.035 respectively.

Since the measured reflectance has first surface reflection effect and also the imperfect of polarizing filter, therefore these effects must be added into the simulation process and Eq. (1) will become

$$r(x,y) = \left\{\left[t(x,y) * psf_p(x,y)\right] t(x,y)\right\} + r_s, \quad (6)$$

where r_s is the different of average reflectance that the measured from solid area and the reflectance from the Beer-Lambert's law which obtained from

$$r_s = \langle r_{mea}(x,y)\rangle - \langle t(x,y)\rangle^2 \quad (7)$$

The estimation of printed image reflectance are shown in Fig. 7.

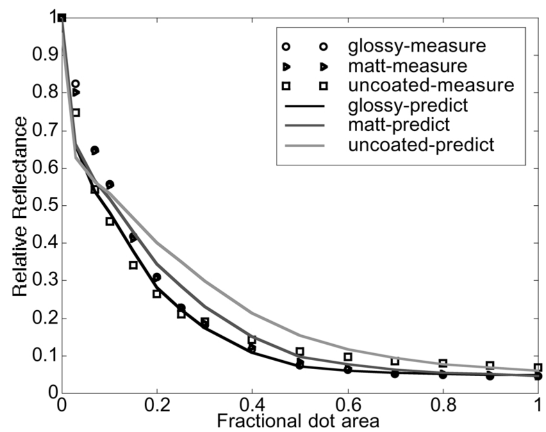

Figure 7. the estimation of image reflectance on gloosy, matt and uncoated paper.

From the estimation results in Fig. 7, we will not compare the uncoated paper with the others because the estimation of its transmittance is not good at the first place. The estimation of image reflectance on matt and glossy paper is not as good as the transmittance. The reason might come from the fact that the PSF of papers used in the simulation process were measured from the contact method, that is, it will not accurately represent the PSF of paper in the case of real printed image because ink jet ink always penetrate in to the paper. It has been reported by Yang and Kruse[7] that the penetration of ink into the paper will somewhat reduce the distance paper for allowing photons to scatter, therefore reducing the PSF of paper.

With the single dot profile and the simulation techniques, we simulated the printed output from photographic images which were transformed to halftone image by error diffusion algorithm. The simulation was done in the MATLAB software. The simulated images with only mechanical dot gain and with both mechanical and optical dot gain are shown in Fig 8.

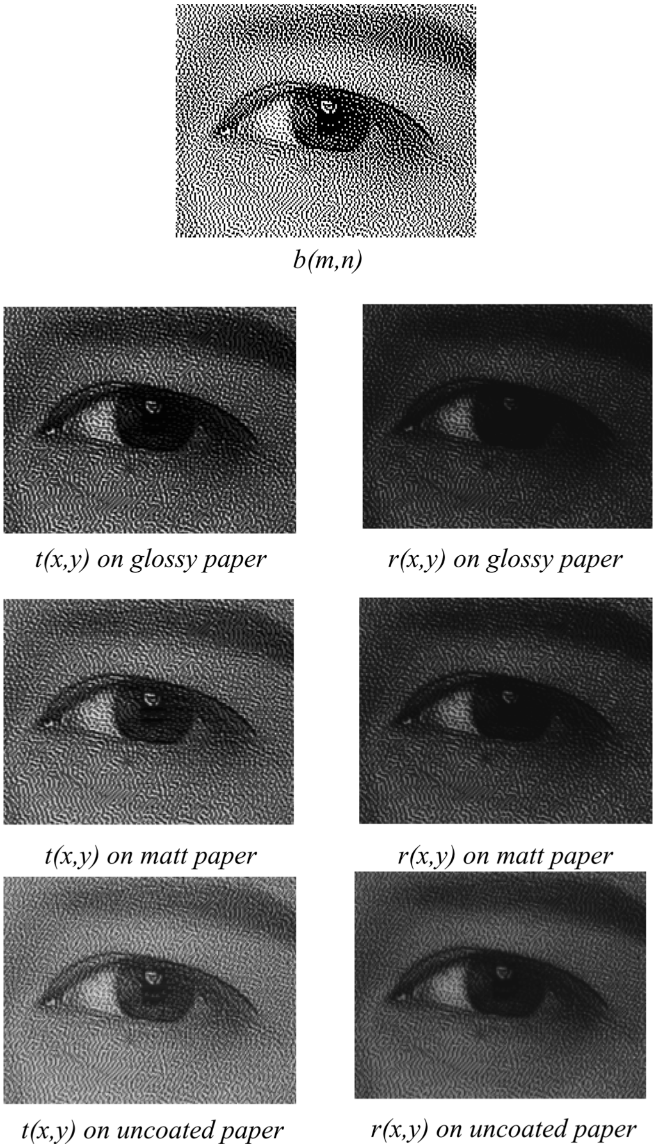

Figure 8. The original halftone image and the simulation of printed transmittances and reflectances on glossy, matt and uncoated paper.

Conclusion

In this study, the simulation of printed image using the measured of single dot profile and optical point spread function of papers is demonstrated. The results show that if paper is a good diffuser and evenly transmitted the incident light, the printed transmittance and reflectance are well estimated by a single dot profile on high resolution grid. The improvement of measuring technique for single dot profile is required to yield a good estimation result for lower grade paper such as uncoated paper. To extend this technique to color estimation, the single dot profile of each primary color in the multicolored printing is needed. One might use photomicrograph of multiband image and Wiener estimation[8] to extract the single dot profile and dot area from the multicolored image.

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Biography

Chawan Koopipat received his B.Sc in Photographic Science and Printing Technology from Chulalongkorn University, Thailand in 1983, MPhil in Printing Technology from West-Herts College, University of Hertfordshire, UK, in 1993. At present, he is a PhD. student at Miyake Laboratory, Chiba University, Japan. His work primarily focused on the evaluation of image quality of hardcopy and printer modeling.