Image Evaluation and Analysis of Ink Jet Printing System (II)

Measurement MTF of paper by Micro-digital Camera

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Abstract

In this study, we propose a method to measure MTF of paper by using monochrome digital camera attached on a microscope. The instrument can provide incident light to both sides of paper sample and can be adjusted independently in order to normalize reflectance and transmittance of bare paper. Transmittance and reflectance of sharp edge contact on paper are measured. MTF of papers are obtained from image reflectance model. Measurement results are fit with an empirical MTF model.

Introduction

Optical dot gain or Yule-Nielsen[1] effect caused by the penetration and scattering of light within the paper has been studied for many decades. The direct measurement of light scattering within the paper is to illuminate a paper sample by a small pencil of light and measures the quantity of diffuse light from the paper.[2] Recently more practical methods have been studied. The point spread function of paper is obtained by inverse Fourier transform from MTF of paper, MTFp.[3-7] To find MTFp, projection or contact of test image on the paper are usually used. In this study we propose a new approach to measure MTFp from sharp edge image on paper with micro-digital camera.

Image Reflectance and Transmittance

Recently, halftone reflectance is modeled by two approaches, the probability approach[8-10] and convolution approach.[11-13] In our study we take the convolution approach which defines reflectance of an halftone, *r(x,y),* as follow:

$$R(x,y) = \{[t(x,y)*psf(x,y)]t(x,y)\}, \quad (1)$$

where *t(x,y)* is the transmittance of ink on the paper, *psf(x,y)* is the point spread function of paper, and * is convolution integral.

From Fig. 1 when a unit of light (a) enters printed halftone image on the printed surface, first it is filtered by image transmittance *t(x,y).* After penetration and scattering in the paper it is filtered again with *t(x,y)* on the way back from the surface.

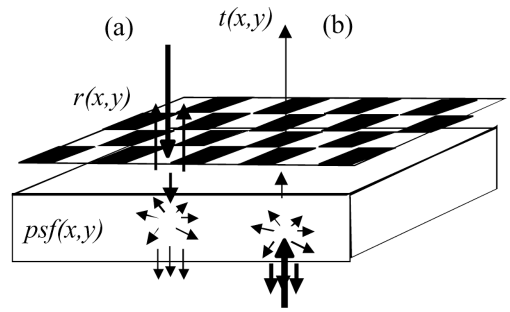


Figure 1. Schematic Diagram of (a) reflectance and (b) transmittance from a halftone image.

Because paper is usually thin, it will transmit a portion of incident light. If we assume that the paper base is an perfect diffuser, light that enter paper from underneath (b) will scattering and some part will passage through the ink dot and emerge from the printed surface. This *t(x,y)* will be equivalent to *t(x,y)* from the reflection illumination when bare paper of both illumination are normalized.

Eq. (2) is the rearrange of Eq. (1) and $T_{psfp}(x,y)$ is defined as the transmittance of image after scattering within the paper. Eq. (3) is the Fourier transform of Eq. (2) and the MTF of paper (MTFp) can be obtained by Eq. (4). From these equations if we know the r(x,y) and t(x,y), we can calculated the MTFp.

$$\frac{r(x,y)}{t(x,y)} = \{t(x,y) * psf_p(x,y)\} = t_{psfp}(x,y) \quad (2)$$

$$T_{psfp}(u,v) = \{T(u,v) \cdot MTF_p(u,v)\} \quad (3)$$

$$MTF_p(u,v) = \frac{T_{psfp}(u,v)}{T(u,v)} \quad (4)$$

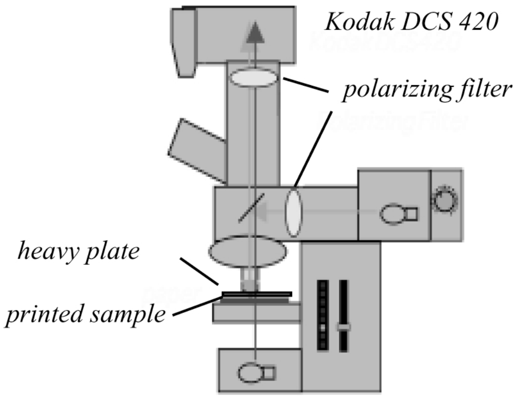


Figure 2. Micro-Digital Camera

Micro-Digital Camera

Figure 2 shows the micro-digital camera used in this study. It consists of a monochrome digital camera (Kodak DCS420) attached on a microscope. The CCD sensor in this camera is 1012 × 1524 pixels with 9 µm pitch and the magnification of optical system is 10 times. There are two identical light sources, one illuminates printed sample on printing surface (for measuring reflectance) and the other from the paper base surface (for measuring transmittance). 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. Each illumination can be adjusted independently.

Calibration

Since the pixel value from CCD is not linear to the intensity of incident light, therefore we created look up table (LUT) by capturing a series of gray patches with known reflection density.

Before capture printed samples, those two light sources were calibrated to bare paper by adjusting the intensity of light until the sensor of camera gives the same normal reading. This means that the average pixel value of *r(x,y)* and *t(x,y)* from bare paper will be the same. Effective shutter speed of the camera was 2 stop over from the calibration.

Measuring MTF of Paper

By using the micro-digital camera capture *r(x,y)* and *t(x,y)* of the sharp edge which is optical contact on the paper surface, we can find MTFp from Eq.(4). The sharp edge in this experiment was from Edmund Scientific Co,. Calibration was also carried out as described earlier. Figure 3 shows results of *r(x,y)* and *t(x,y)* of sharp edge on glossy, matte and uncoated paper respectively.

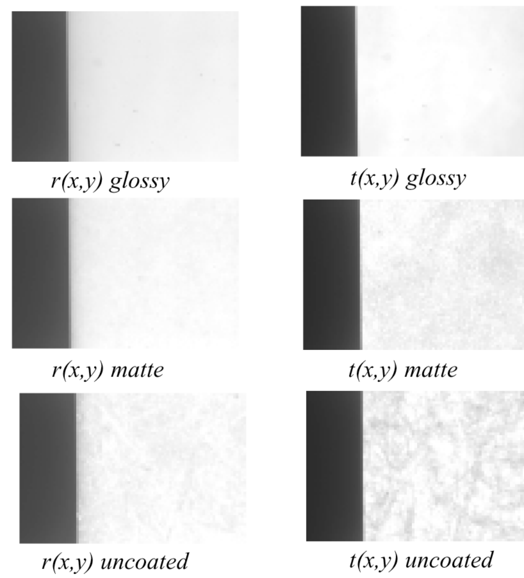


Figure 3. r(x,y) and t(x,y) of sharp edge contact on glossy, matte and uncoated paper.

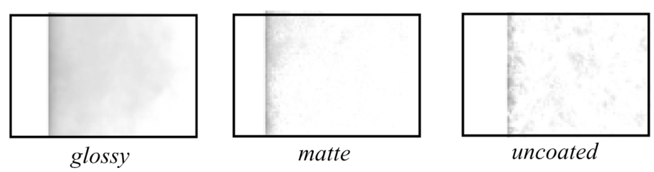


Figure 4. $t_{spf}(x,y)$ *calculated from Eq. 4 of glossy, matte and uncoated paper.*

When we used Eq. (2) to calculate $T_{psfp}(x,y)$ from *r(x,y)* and *t(x,y)* the resultant images are shown in Fig. 4.

The result was not what we had expected. Because in the image reflectance model, the $t_{psfp}(x,y)$ is the image that has been scattered by the point spread function of paper. We should see the similar image to *t(x,y)* but with blur edge as shown by the simulation in Fig.5.

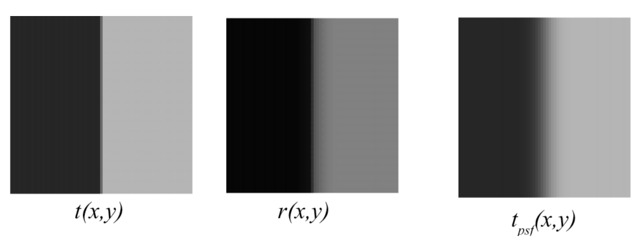


Figure 5. Simulation of t(x,y), r(x,y) and tpsf(x,y).

When investigated into what is the cause of this phenomenon by comparing the histogram of *r(x,y)* and *t(x,y)* from glossy paper as shown in Fig. 6, we found that black area of the *r(x,y)* had more intensity than the solid area of *t(x,y)*. This might cause by imperfect elimination of specular reflection.

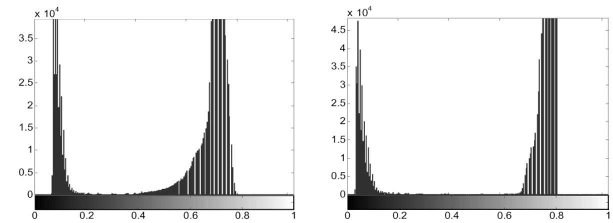


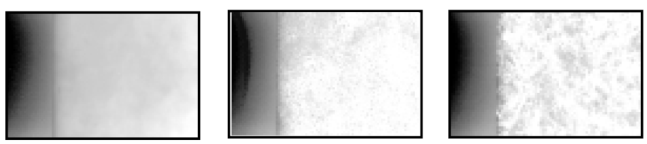
Figure 6. Sharp edge image histogram of glossy paper.

According to Lambert-Beer's Law, the reflectance of solid area should be equal to the square of its transmittance as light passage through the absorption layer twice, therefore we compensated for this phenomenon by adding k factor to adjust the $r(x,y)$ as shown in Eq. (5) and Eq. (6).

$$r_c(x,y) = r(x,y) - k \tag{5}$$

$$k = r_{min} - (t_{min})^2, \tag{6}$$

where r_{min} and t_{min} is the average intensity of the solid area form $r(x,y)$ and $t(x,y)$ respectively. The corrected $t_{psfp}(x,y)$ was calculated from the $r_c(x,y)$ and $t(x,y)$. The resultant images are shown in Fig. 7.



glossy *matte* *uncoated*

Figure 7. The corrected $t_p(x,y)$.

From Eq.(4) if paper has isotropic property, the one dimensional MTF can be obtained from Eq.(7) - (10).

$$MTF_p(u) = \frac{T_{psfp}(u)}{T(u)}, \tag{7}$$

$$T_i(u) = \Im\{lsf_i(x)\}, \tag{8}$$

$$lsf_i(x) = \frac{d(e_i(x))}{d(x)}, \tag{9}$$

$$e_i(x) = \int t_i(x,y)dy \; . \tag{10}$$

where i is $psfp$ or none, $e_i(x)$ is the edge spread function, $lsf_i(x)$ is the line spread function and $\Im$ denotes Fourier transform.

In order to extend calculation window, we used folding technique to obtain the line spread function of the solid area from the line spread function paper area. Figure 8. shows the result of $lsf_{psf}(x)$ and $lsf(x)$ of glossy coated paper. The MTFp are shown in Fig 9. The solid and dash line are the fitting curve from empirical MTF model in Eq. 11. The d value is the coefficient account for scattering distance and ω denotes the spatial frequency in mm^{-1}. The corresponding point spread function of paper is shown in Eq 12.

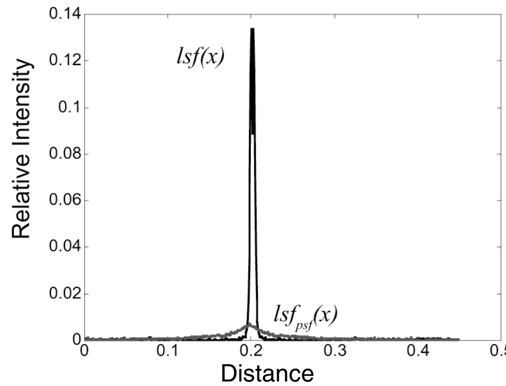


Figure 8. Line spread function of $l_{psf}(x)$) and $l(x)$ from glossy paper.

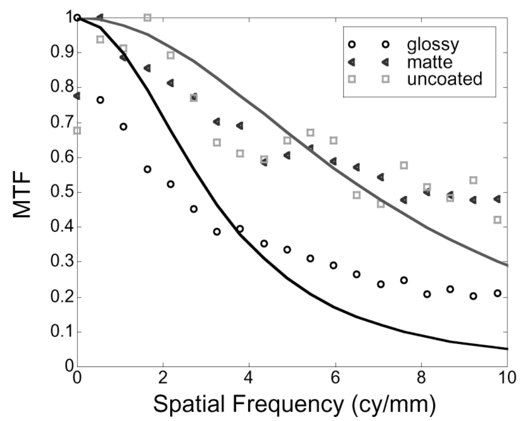


Figure 9. MTF paper measure from glossy coated, matte-coated and uncoated paper. The solid and dash lines are MTFs calculated from modle in Eq. 8. with d = 0.039 and 0.016 respectively.

$$MTF(\omega) = \frac{1}{\left[1 + (2\pi d\omega)^2\right]^{3/2}} \tag{11}$$

$$psf_p(x,y) = \frac{1}{2\pi d^2} e^{\frac{-\sqrt{x^2+y^2}}{d}} \tag{12}$$

Discussion

The merit of this method is that MTFp has been already corrected for system MTF because the divide of $T(u)$. Because $T(u)$ is the MTF from transmission image therefore MTF of the image, system and noise from paper structure are included. We can observe from Fig. 10 that the differences of *T(u)* from glossy, matte and uncoated paper come from the noise of paper structures as image and system MTF are the same. Therefore the MTFp from matted and uncoated paper shown in Fig.9 are higher than it should be. The *d* values measured by contact sharp edge method are 0.039, 0.016 and 0.016 for glossy coated, matte coated and uncoated paper respectively. Since the glossy coated paper provided very less noise we can assume that its *T(u)* can represent the system MTF. Our results show that for high quality ink jet paper this method gives some good results.

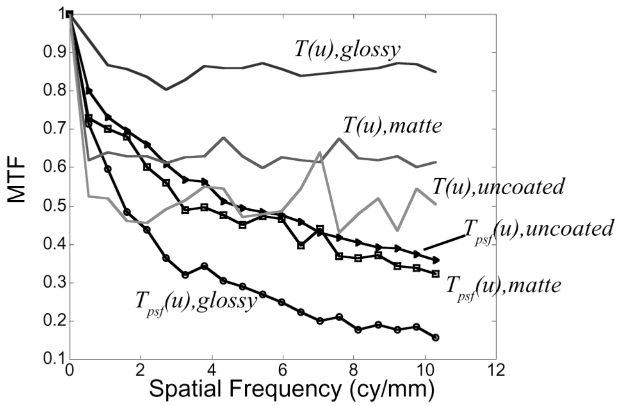


Figure 10. Comparison of $T_{psfp}(u)$ and $T(u)$ from glossy, matte and uncoated paper.

Conclusion

This study demonstrates an alternative approach to measure MTFp by using micro-digital camera capture an sharp edge that from contact sharp edge on the paper from with transmission and reflection illumination. Not only MTFp but also the ink distribution on paper also can be measured with this instrument. This has been investigating in our laboratory.

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Biography

Chawan Koopipat received his BSc. in Photographic Science and Printing Technology from Chulalongkorn University, Thailand in 1989 and MPhil in the work titled The Effect of the Increase of Dot Gain on Colour and Its Relationship with Colour Tolerances of Various Picture Contrasts from University of HertfordShire, UK in 1993. At present he is a PhD. student at Miyake laboratory, Chiba University, Japan. His works focus in the area of image quality evaluation.