Application of Ink Jet Printer Model to Evaluate the Sharpness of Printed Images.

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Abstract

Image sharpness is an important factor for image quality evaluation. This paper investigates the effect of dot misregistration to the sharpness of ink jet image on various type of papers. The printed one-pixel line images are simulated using the proposed ink jet printer model. The model simulates each digital halftone dot in a high resolution grid using ink spread function and optical point spread function of paper. The variables in the experiment are the degree of dot misregistration and optical point spread function of paper. Fourier analysis is applied to those simulated images and the sharpness parameter is evaluated and compared. The results show that when dot misregistration is about 1/3 of dot diameter off its intent location, the MTF at 6 cy/mm is lower than 0.5 therefore poor sharpness is observed.

Introduction

Sharpness of ink jet image is usually determined by the resolution of printer, dot volume and interaction of ink and paper. New model of ink jet printer has the resolution that reach 2,880 dpi and the dot volume is small as 2 pl. With tiny dot and high resolution, the misregistration of dots will affect to small line and text, consequetly, reduce the sharpness of printed images. To study the effect of dot misregistration, a printer model that can separate mechanical dot gain and optical dot gain is required. In the next section, printer models will be reviewed and described.

Printer Model

The purpose of printer model is to estimate the reflectance of printed image[1]. There are two categories which are empirical based model and theoretical based model. In this study, theoretical model that can simulate the printing system is used.
Since ink jet printer is a binary printer, therefore any gray scale or color image has to be transform to halftone image which will turn the printer dot "ON" or "OFF". Halftone image is denoted by $b(m,n)$, where m and n are integer represent numbers of row and column. If the grid of halftone and printer are the same, one pixel of halftone will be printed by an ink dot.

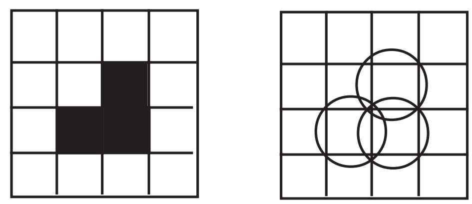

Figure 1 Ink jet dot: (a) ideal square dot (b) round dot with > √2 diameter

Since ink jet printed dots are more closely round than square, it is reasonable to assume that printer will print circular dots on Cartersian grid. The ink dot must big enough to cover paper surface without gap at 100% dot area, therefore, dot diameter will be $\sqrt{2}L$, where L is the diameter of printer grid. The density of overlap area has been consider as an "OR" operation, not the addition of dot density. Toetling and Holladay[2] used circular dot overlap model for dither calculation. Pappas and Neuhoff[3] used it for model-based error diffusion. Rosenberg[4] proposed a model that included light scattering into the paper or Yule-Nielsen effect. Emmel and Hertz[5] introduced an unified mathematical model that consider dot spreading and also light scattering of paper in high resolution grid. Koopipat et al[6], proposed a novel measurement technique to measure actual dot profile on paper surface and predicted the reflectance of printed image on various types of papers. This printer model consists of two parts. The first part is the simulation of image transmittance and the second part is the simulation of printed reflectance.

Simulation of image transmittance

Single dot profile is the key element in ink jet printer model. Dot profile from actual printed image are measured by underneath illumination. This will capture the transmittance of ink dot without optical dot gain effect. Figure 2 shows transmitted image of single dot profile printed by Epson PM770c on glossy photo paper.

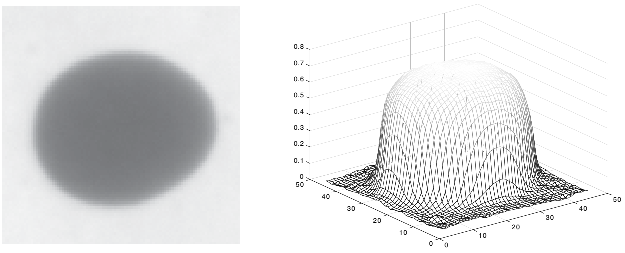

Figure 2 Ink jet dot transmitted image (a) and dot profile (b) on glossy paper.

From single dot profile, printed image can be simulated in high-resolution grid. The high-resolution grid is created by considering the size of dot profile, *s(i,j)*, a halftone image, *b(m,n)*, and the overlap distance, (*a*). If the dot is not overlap the grid base will be *g(mi,nj)* as shown in Fig. 3 (a). Since the dots of ink jet printer always overlap for some distances, therefore, the grid base is reduced as shown in Fig. 3 (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)*.

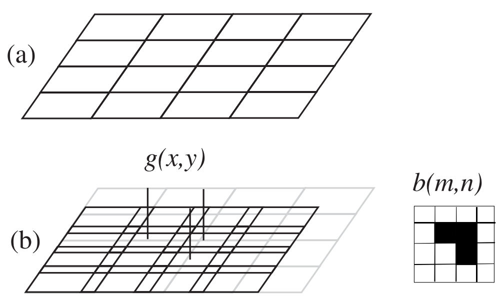

Figure 3. The grid base that corresponding to halftone image.

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

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

where x and y are the coordinate of the output. Equation (1) 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. (2).

$$t_{sim}(x,y) = 10^{-[g(x,y)*s(i,j)]} \qquad (2)$$

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. Since Beer-Lambert's law assumed to held in dye based ink, therefore, the density values in overlap region are the product of adding density of the first dot with the second dot.

Simulation of image reflectance

In the simulation process of reflected image, the point spread function of paper is required. The contact sinusoidal method was used to measured the MTF of glossy and matt paper[7]. The measured MTF values were fit with the empirical MTF model as show in Eq. (3).

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

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

$$psf_p(x,y) = \frac{1}{2\pi d^2} e^{\frac{-\sqrt{x^2+y^2}}{d}}. \qquad (4)$$

The point spread function of papers from the measurement are shown in Fig. 4.

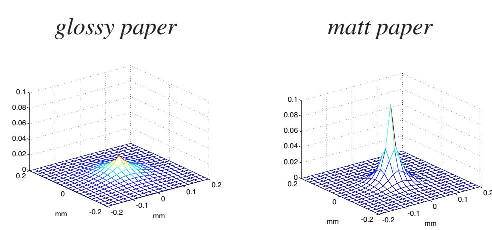

Figure 4. The PSF of gloss and matt and paper with d values 0.052 and 0.025.

With single dot profile and simulation techniques, printed reflectance can be simulated with or without optical dot gain effect

$$r(x,y) = \left\{\left[t(x,y) * psf_p(x,y)\right] t(x,y)\right\}, \qquad (5)$$

Dot misregistration

Dot misregistration is a characteristic of ink jet printer. It will reduce the sharpness of printed image, especially small text and line. From the observation of one-pixel printed line, dots are misregistration about 1/8 to half-dot distance from it intent position.

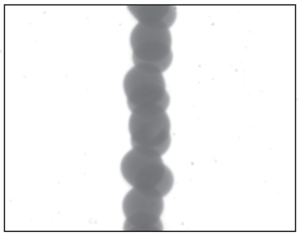

Figure 5. The transmittace of one-pixel line image.

To simulate dot misregistration, random noise *(η)* has been added in to Eq.(1).

$$g(x,y)=\begin{cases}1 & \text{if} \quad x = mi - i/2-(m-1)a+\eta \\ & \text{and} \quad y = nj - j/2-(n-1)a+\eta \\ & \text{and} \quad b(m,n)=1 \\ 0 & \text{elsewhere}\end{cases} \qquad (6)$$

when using printer model, various degrees of misregistration dot can be simulated.

Fourier analysis of one-pixel line

If dot is square and lies on the position that intent to be, one dimensional of one-pixel line dot profile will be a rectangular function, With circular dot, dot overlapping and point spread function of paper, the width of one-pixel line will larger as shown in Fig 6.

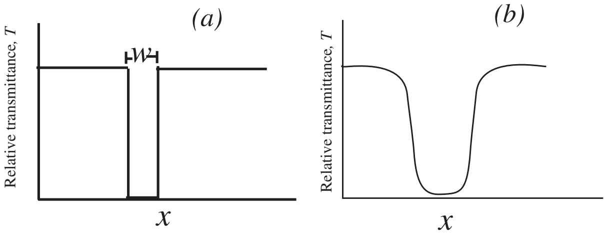

Figure 6. The transmittace profile of one-pixel line: (a) ideal square dot, (b) circular dot

If we reverse the transmittance of the one-pixel line, we will obtained the line spread function.

$$lsf(x) = 1.0 - r(x), \qquad (7)$$

where *r(x)* is the reflectance*, lsf(x)* is the line spread function of one-pixel line image. The line spread function of ideal printer at 720 dpi and possible the actual printer's line spread function are shown in Fig. 7

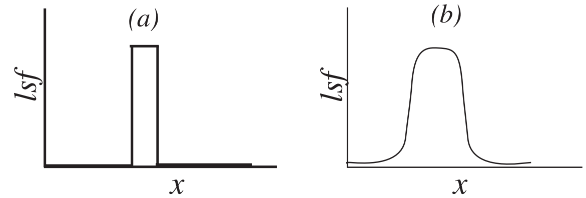

Figure 7. Line spread function: (a) ideal square dot, (b) circular dot

Since the ideal line spread function is a rect function, its Fourier transform will be an sinc function. When normalized the area under line spread function is equal to 1.0. The amplitude of its Fourier transform at zero frequency will be 1.0. In linear and stationary system, the Fourier transform of line spread function is the modulation transfer function (MTF). However, since the line spread function of one-pixel line image is not linear, it is worth to define here that the Fourier trnsform of this line spread function is not a real MTF of the imaging system but rather the spatial frequency information due to the spread of a printed line. The MTF of ink image (MTF), can be calculated as shown in Eq. (8).

$$MTF(u) = \left| \int lsf(x) e^{-j2\pi ux} dx \right| \qquad (8)$$

where *u* is the spatial frequency of interest.

Experiment and results

In order to analyze the sharpness of the ink jet printer in term of MTF, the experiment was carried out by simulating an one-pixel line of black ink on glossy and matt coated paper. The variables are degree of dot misregistration which varied from 0, 1/4, 1/3 and 1/2 of dot diameter on glossy and matt ink jet paper. Figure 8-11 shows the results of the experiment.

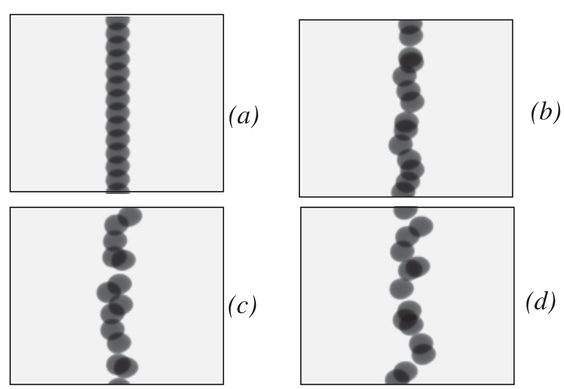

Figure 8. Simulated one-pixel line without optical dot gain of (a) no dot misregistration, (b) 1/4, (c) 1/3 and (d) 1/2 dot mis registration respectively.

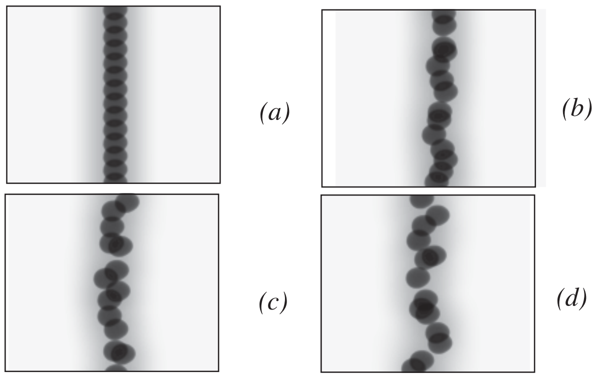

Figure 9. Simulated one-pixel line with optical dot gain of (a) no misregistration, (b) 1/4, (c) 1/3 and (d) 1/2 dot mis registration respectively.

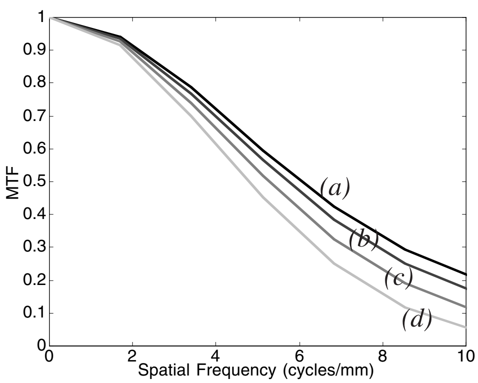

Figure 10. Simulated MTF from mechanical and optical dot gain with (a) no misregistration (b) 1/4, (c) 1/3 and (d) 1/2 dot misregistration

It is obvious from Fig. 10 that dot misregistration affect to the sharpness by reducing information in high frequency. Fig.11 shows the effect of dot misregistration and optical dot gain. Line *(a)* shows MTF of no dot misrgistration image, line *(b)* has 1/3 of dot size misregisteration, line *(c)* and *(d)* are also

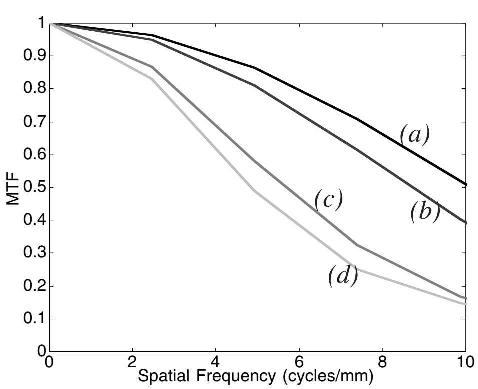

Figure 11. Simulated MTF of (a) no opitcal dot gain and no dot misregistration, (b) 1/3 dot mis registration, (c) optical dot gain on matt paper and 1/3 dot mis registration, (d) 1/3 dot mis registration, (c) 1/3 dot mis registration and with optical dot gain on glossy paper.

1/3 dot size misregistration with different degree of dot gain effect. We can observe that optical dot gain has reduced the MTF of printed image greater than dot misregistration. The greater degree of optical point spread function of paper the lower MTF of printed images.

Conclusion

Traditionally, printer developer aims to reduce the dot size to increase the resolution of printer and therefore yields more details in printed image. However, dot misregistration is a significant factor as shown here that if the dot is miss-located as one-third of dot size from its intent position, the MTF will lower than 0.5 which means that the contrast of printed image will be low and therefore small details cannot be perceived. This proposed printer model can also be used for investigating other factors, for example the dot shape and other type of printing grid such as hexagon that affect printed image quality.

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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 and PhD. in Image Information Processing from Chiba Unversity, Japan in 2002. At present, he is a Lecturer at Department of Imaging and Printing Tech. Chulalongkorn University, Thailand. His work primarily focused on the evaluation of image quality of hardcopy and printer modelling.