Optical Dot Gain Study on Different Halftone Dot Shapes

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Abstract

Optical dot gain occurs because of the fact that a photon entering the non-inked substrate might scatter underneath a dot and be absorbed instead of reflected. This effect is dependent on the optical properties of the materials (paper, ink) and geometrical distribution of ink dots such as printing resolution, dot size and shape. In this paper, we compare the optical dot gain of halftone dots with different shapes and perimeters but with the same area size. For these purposes six dot shapes halftoned by using three different halftoning methods are considered for investigation. An effort is made to keep the area of the dot shapes constant for all six samples. Comparing the optical dot gain for different dot shapes shows the dependency of optical dot gain on the dot shape perimeter. Here we also show that there is a limit at which the optical dot gain is saturated. The dependency of optical dot gain on the dot shape perimeter verifies the fact that the amount of optical dot gain is different for different types of halftoning.

Introduction

The appearance of printed images is affected of the light scattering in paper, which also affects the quality and calibration of color printers. The lateral light scattering in the paper yields a shadow around the halftone dots, whereby the dots appear larger than their actual sizes, and hence the image appears darker.

There have been researches carried out to estimate the optical dot gain based on Yule-Nielsen, and Clapper-Yule model using spectral reflectance measurement, transmission scans and microscopic images of halftone prints (Garg, 2008), (Herbert, 2006), (Yang, 2007).

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In (Koopipat, 2002) and (Yamashita, 2033), it has been reported that the reflected images are images that include both physical and optical dot gain, while the transmitted images only include the physical dot gain effect. However by studying the reflected and transmitted image histogram, the authors showed that transmitted images are indeed affected by optical dot gain (Namedanian, 2011).

In previous works the physical and optical dot gains were mostly analyzed by illustrating their respective dot gain curves. These curves only show the relationship between the effective dot area and the reference (or nominal) dot area, and they do not illustrate the shape of the optical dot gain, which is closely related to the optical properties of the paper and physical dot shape. Different paper substrates might have different scattering properties. This fact could result in symmetrical or unsymmetrical behavior of light scattering, which cannot be studied by the mentioned models.

A simple approach based on the reflected microscale image histogram has been proposed by the authors (Namedanian, 2012) to estimate the physical dot area of the halftone print. Since in the study, they have separated the physical dot shape, it is possible to simulate the optical dot gain effect by using point spread function PSF or its modulation transform function MTF. Researches have previously been carried out to propose a model to approximate the paper's MTF. In some reports, the Gaussian model for paper's MTF (Dainty, 1974) has been suggested. However, other literatures suggest the different exponential functions to estimate the MTF of paper (Ukishima, 2009), (Rogers, 1998), (Inoue, 1997). The authors also reported that among different functions, the model, which is proposed by Rogers (Rogers, 1998), would actually give a better fit to the MTF obtained with the knife-edge method (Yule, 1967), and MTF simulated by Monte Carlo simulation (Coppel, 2009).

Material and measurements

In this study several patches with different reference coverage of black are printed. All the patches are halftoned by AM (Amplitude Modulation), (150lpi, 1200dpi), second generation FM (Frequency Modulation) and the popular stochastic halftoning or FM1st halftoning. A high resolution camera with a resolution of 1.94 μm/pixel, a field of view of 2.65 mm×1.99 mm, and with a 45◦/0◦ geometry is used for microscale image capturing the reflected light.

Simulation of optical dot gain

In this paper we are going to simulate the optical dot gain effect by using PSF or its Fourier transform function MTF. Here we consider the halftone printed-paper as being made of two layers: the ink layer made of ink dots and voids, and the paper substrate layer. Incident light on the printed-paper which goes through the ink layer, is scattered in the substrate layer and goes back through the ink layer again (Inoue, 1998), (Engeldrum, 2004). These steps can be expressed as,

$$r(x,y) = \left\{t(x,y) * PSF_p(x,y)\right\} \cdot t(x,y) r_p, \quad \text{Eq (1)}$$

where r(x,y) is the spatial distribution of reflectance of the halftone print, t(x,y) is the ink layer transmittance, $PSF_p(x,y)$ is the PSF of the paper, and r_p is the reflectance of the paper. The sign (*) denotes convolution and (·) denotes element wise multiplication. The Fourier transform of $PSF_p(x,y)$ is $MTF_p(u,v)$. Eq. (1) can now be expressed using the MTF of the paper in the Fourier domain.

$$r(x,y) = \Im^{-1}\left[\Im\left\{t(x,y)\right\} \cdot MTF_P(u,v)\right] \cdot t(x,y) r_P \quad \text{Eq (2)}$$

where $\Im$ and $\Im^{-1}$ denote the Fourier transform and the inverse Fourier transform, respectively. The reflectance r(x,y) is affected by both physical and optical dot gain, while t(x, y) is only affected by the physical dot gain. Using reflectance images, the spatial distribution of transmittance of the ink layer t(x, y) is given by,

$$t(x,y) = \begin{cases} 0 & \text{if} \quad I(x,y) \le R_{th} \\ 1 & \text{otherwise} \end{cases} \quad \text{Eq (3)}$$

where I(x,y) is the microscale image of the halftone area. The threshold Rth is found by the microscale image histogram MIH approach proposed in (Namedanian, 2012). The threshold R_{th} is the position of the minimum value of the histogram between two peaks corresponding to the reflectance values of the ink and paper between ink dots. It has to be pointed out here that t(x,y) represents the actual physical dot shape after print [see Figure 1 (b)].

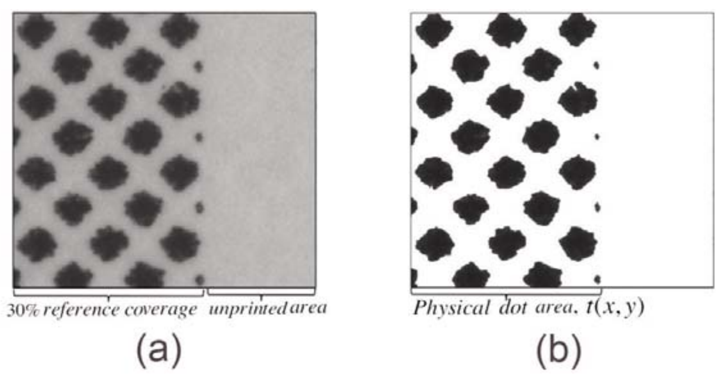

Figure 1 : *(a) Microscale image with 30% reference coverage.*
(b) Estimated spatial distribution of the ink layer t(x; y); (physical dot shape)

The MIH approach can be useful for the study of the behavior of the ink spreading on different types of paper. Figure 2 illustrates the 3D simulation of the ink dot, which is obtained by MIH approach and printed on both coated and uncoated paper. Due to the paper's structure the dots will get different formations. The coated paper has a uniform surface and most of the ink spreads on top of the paper surface. Therefore the ink dots have a homogeneous shape [see Figure 2 (c)]. As it can be seen in Figure 2 (d) the shape of the dot, which is printed on an uncoated paper, looks like a mountain and valley. In the uncoated paper more ink is spread into the pore of the paper and therefore the surface of the dot is not uniform.

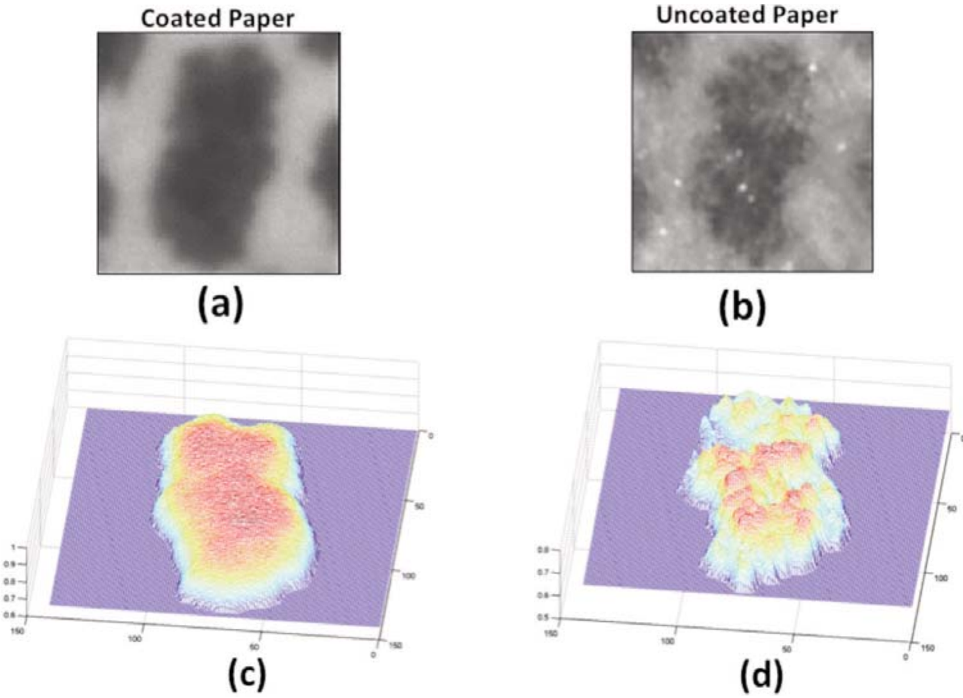

Figure 2: *The 3D simulation of the dots printed on coated and uncoated papers.*

Figure 3 illustrates the side view of the printed coated and uncoated papers captured by the high-resolution camera. In the uncoated paper, first the ink goes through the paper and fills the very small cavities of the paper, then it is spread on the paper's surface, hence the dots have an inhomogeneous shape. An inhomogeneous ink shape affects the print quality. To achieve a better quality with uncoated paper, more ink has to be applied on the surface of the paper. As discussed above, the same amount of ink will cover less area on the uncoated paper compared to the coated one.

Now the question is why the dot gain of uncoated paper is more than the coated paper in the offset press? Dot gain includes both physical and optical dot gain. Hence in order to answer this question, we have to simulate the light scattering effect or optical dot gain. Once we have separated the physical dot area, it is possible to simulate the light scattering effect by using the MTF through Fourier transform of the PSF which is a conditional probability density that characterizes the photon migration within the paper.

Figure 3: *The captured microscale images from the paper thickness view.*

Measuring the paper's MTF is a complicated task and until now several methods have been proposed in the literature. In order to estimate the MTF of the paper, three functions proposed in references (Rogers, 1998) (Ukishima, 2009), (Rogers, 1998), (Inoue, 1997) are used;

$$MTF_{1p}(u,v) = \left[1 + (2\pi d_1)^2.(u^2 + v^2)\right]^{\frac{-3}{2}} \qquad \text{Eq (4)}$$

$$MTF_{2p}(u,v) = \left[1 + (2\pi d_2)^2.(u^2 + v^2)\right]^{\frac{-1}{2}} \qquad \text{Eq (5)}$$

$$MTF_{3p}(u,v) = e^{\frac{-d_3^2.(u^2+v^2)}{2}} \qquad \text{Eq (6)}$$

where u and v are the spatial frequency (cycle/mm) and d1, d2, and d3 are fitting coefficients. Eqs. (4-6) are used separately together with Eq. (2) to simulate r(x, y) for the given t(x,y) estimated with the MIH approach. The fitting coefficients (d1, d2, d3) are determined by minimizing the difference between the measured and simulated effective coverage. The effective coverage can be approximated by Murray-Davies (MD) equation,

$$a_{eff} = \frac{r_{ave} - r_p}{r_{ink} - r_p} \qquad \text{Eq (7)}$$

The value of rave for the measured and simulated effective coverage is obtained differently. For the measured effective coverage, r_{ave} is the average value of the halftone patch, while for the simulated case, r_{ave} is the average value of r(x,y) in Eq. (2). In the measured effective coverage, r_{ink} and r_p are the reflectance of the full-tone ink and paper, respectively. In the simulation, due to the binary characteristic of t(x,y) in Eq. (3), r_{ink} is 0 and r_p is 1. By subtracting the average of ink transmittance t(x,y) from a_{eff}, optical dot gain can be achieved.

The comparison of three functions with the MTF obtained with the knife-edge method (Yule, 1967), and MC simulations (Coppel, 2009) for a 150 g/m^2 paper sample, clearly illustrates that MTF_{2p} better represents the measured MTF. The analysis of the three MTF functions is not in the scope of this paper, but is thoroughly described in (Namedanian, 2012).

Method

In this study we show how to simulate the optical dot gain of dots produced by different types of halftonings. Conventionally, digital halftoning is accomplished either by changing the size of the printed dots or by changing the relative density of dots. The halftoning methods can mainly be divided into two main types, namely AM (Amplitude Modulation) and FM (Frequency Modulation). In AM, the size of the halftone dots varies, while their spatial frequency is constant. On the other hand, in FM, the dot size is constant while the frequency (the number of micro dots) varies.

Another representative model of FM halftoning is the so called FM second generation in which both the size of the dots and their frequency vary.

So far the assumption has been that the halftoned dots are circular or square, but this is not necessary as the dots can be set to any shape. Figure 5 shows the dots with the same original shape and with the same amount of ink printed on two different types of paper (coated and uncoated). The proposed approach in (Namedanian, 2012), has been used to estimate the inked area on the paper surface. The proposed MTF2p function in this study has been applied to simulate the light scattering effect or optical dot gain around the dots. Figure 5 (c) and (d) illustrate the simulated optical dot gain for the dots halftoned by FM second generation [figure 2 (a) and (b)], which are printed on coated and uncoated papers.

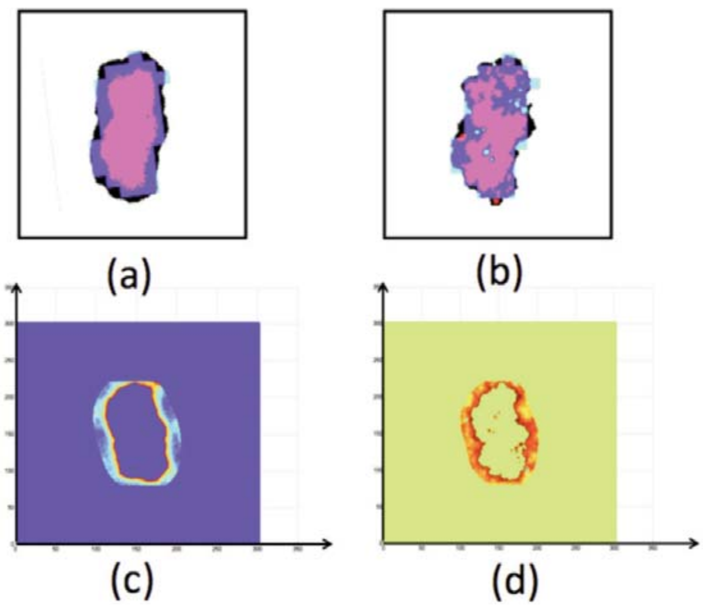

Figure 5. (a), (b) The physical dot area with the same original shape and with the same amount of ink printed on coated and uncoated papers.
(c), (d) The optical dot gain simulated by using MTF2p function on (a) and (b) respectively.

Comparison of optical dot gain for different dot shapes

Here we compare the optical dot gain of dots with different shapes and perimeters but with the same area size. For these purposes six dot shapes [see Figure 6] are considered for investigation. In Figure 6, the first two dot shapes are the basic AM circle and square haftoning shapes. The dot shapes No. 3, 4 and 5 are chosen from FM second generation. Dot shape No. 6 is a collection of FM first generation dots, in which the sum of their areas is equal to the areas of other shapes in Figure 6. An effort is made to keep the area of dot shapes constant for all six samples. The numbering of the dot shapes is based on the size of their perimeters, i.e. the first dot shape has the minimum perimeter and the sixth dot shape has the maximum perimeter among all.

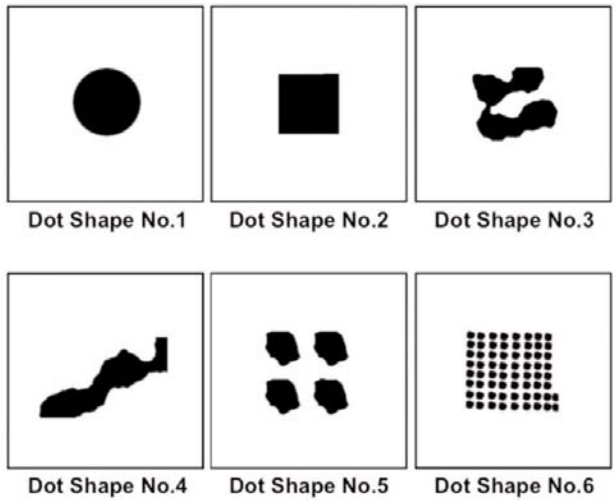

Figure 6. *The six different dot shapes; No.1 and 2 dot shapes from AM, No. 3, 4 and 5 from FM second generation and No. 6 from FM first generation.*

Results

By using Eq. (2) and Eq. (4) the optical dot gain of all six samples are found. Comparing the optical dot gain for different dot shapes shows the dependency of optical dot gain on the dot shape perimeter. As it can be seen in Figure 7 the optical dot gain increases when the perimeter of dot shape increases. However, one can notice from the figure that there is a limit at which the optical dot gain is saturated. It means that above a certain value of the dot perimeter, no matter how much we increase the perimeter the value of the optical dot gain will not be increased.

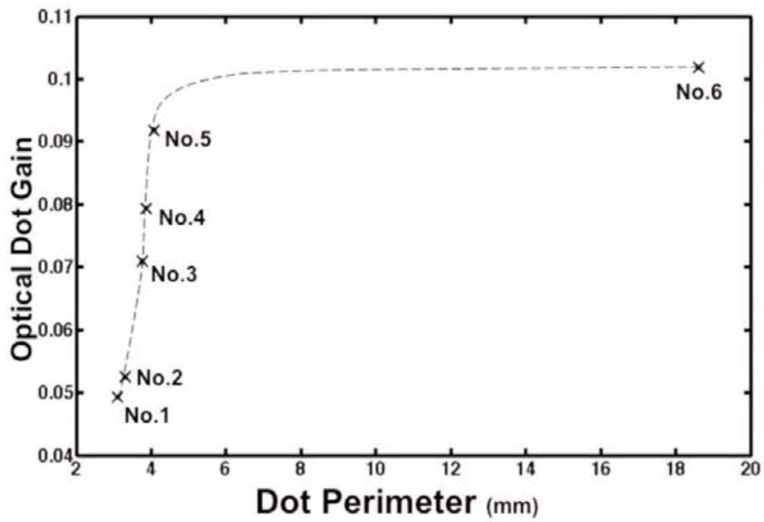

Figure 7. *Comparison of optical dot gain for different dot shapes.*

We observed that the optical dot gain is dependent on the dot shape and therefore we can conclude that the amount of optical dot gain is different for these three types of halftoning. AM has the minimum optical dot gain and FM first generation has the maximum optical dot gain.

Conclusions

By use of the high resolution camera and the method proposed by authors in (Namedanian, 2012) the ink behavior and light scattering effect have been compared for different dot shapes produced by different halftoning methods. The results show the dependency of optical dot gain to the shape of the dots. By increasing the perimeter of the dot shapes, the optical dot gain is increased, however there is a limit to the combination of dot shape and perimeter in which the optical dot gain will be saturated. Separately monitoring physical and optical dot gain can help the paper and graphic art industries to characterize the ink spreading on the paper and the optical dot gain effects.

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