# A New Model to Estimate Optical Dot Gain in Printings and its Applications


***S. Inoue*, N. Tsumura†, and Y. Miyake†***

**** Tokyo Research Laboratories, Mitsubishi Paper Mills Limited***

***†Department of Information and Computer Sciences,Chiba University***



## Abstract

It is well known that the optical dot gain in halftone image is produced by the light scattering in the printing paper. The phenomenon has been explained by Yule-Nielsen equation. However, *n* in the Yule-Nielsen equation is empirical value, therefore it is not possible to estimate *n* theoretically. In this paper, we introduce a new model to predict reflection density of halftone image and optical dot gain based on the point spread function of paper. It is shown that the predicted density is approximately same to the measured density and the calculated optical dot gain by the proposed model is well correlated to the measured optical dot gain by "The System Brunner Print Control Strip". Digital halftone images by ordered dither method are also analyzed by using the proposed method.


## Introduction

It is well known that the paper greatly gives an influence on the image appearance. Incident light is absorbed by ink recorded on the paper or by the paper itself. If the print is ideal, paper would not have any absorption. However, practical paper is a turbid medium, therefore, incident light has absorption, direct transmission, specular reflection, diffuse reflection and diffuse transmission in the paper. These phenomena complicate the image analysis of halftone reflection printing images.

In conventional halftone printing, Yule-Nielsen equation defined by Equation (1) has been widely used for analyzing the relationship between halftone dot area and reflection density for different kinds of papers[1,2].

$$Dr = -n \log\left(1 - a(1 - 10^{(-Ds/n)})\right) \qquad (1)$$

where $D_r$ is the density of halftone print, $D_s$ is the solid ink density, *n* is a factor to allow for the amount of light diffusion in the paper and *a* is the dot area. When *n* equals to 1, it corresponds to no penetration of light into the paper, then the equation becomes Murray-Davies Equation. In Yule-Nielsen equation, *n* is constant to represent light scattering of paper, and it is determined by measured data, and its value is usually the range $1<n<2$. Namely, *n* is empirical parameters, therefore its value cannot predict theoretically. The purpose of this paper is to predict both reflection densities of conventional printings and digital halftone images theoretically by using a new prediction model.

## A New Model to Predict the Reflection Density

We assume that the reflection image consists of two layer, recording paper and ink. Figure 1 shows the model of two layers. In the model, we may consider that the ink and paper are the transparent image layer and the diffuse reflection layer respectively, then the incident light $i(x,y)$* transmitted through the ink layer to paper can be explained as follows;

Step 1: Incident light is transmitted to the ink layer.
Step 2: The ink absorbs the incident light
Step 3: Incident light is scattered and diffused in the paper, and these phenomenon is represented as the Point Spread Function (PSF).
Step 4: The reflected and scattered light in the paper is absorbed in the ink layer again.

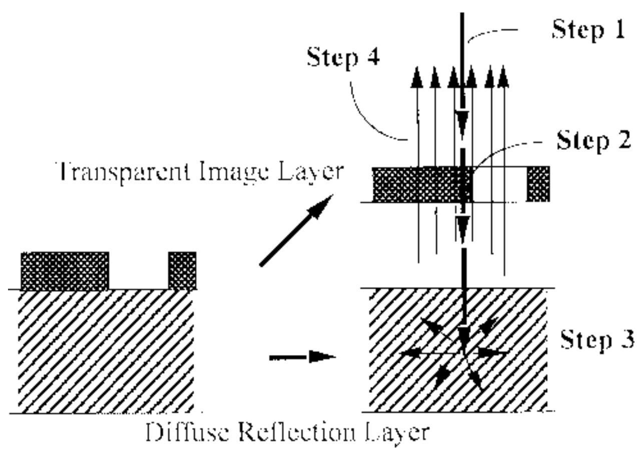


*Figure 1. Diagram of proposed model.*

These steps can be explained as the following equations.

$$r(x,y) = \{[i(x,y) \times t(x,y)] * h(x,y)\} \times t(x,y) \qquad (2)$$

where $r(x,y)^{\dagger}$ is reflection intensity, $t(x,y)$ is transmit-

* $i(x,y)$ should now be read as $i_{in}$

tance of the ink layer, *h(x,y)* is normalized PSF of paper, and * presents convolution integral. Then the reflection density Dr(x,y) can be calculated by the Eq.(3).

$$Dr = -\log\{r(x,y)/i(x,y)\} \quad (3)$$

Same equation was also proposed by B. Kruse et al[3].* The mechanism of an optical dot gain can be explained by using a new model. Figure 2 shows a light intensity distribution of the cross section of dot area. The intensity of incident light is distributed at border zone as the increased dot area a equal to reduced area a'. The spread light in dot area, a', is absorbed again in transparent image layer as shown in Fig. 1. Therefore the intensity of light in dot area is reduced a' to b, namely the difference a'- b may be considered as the optical dot gain.

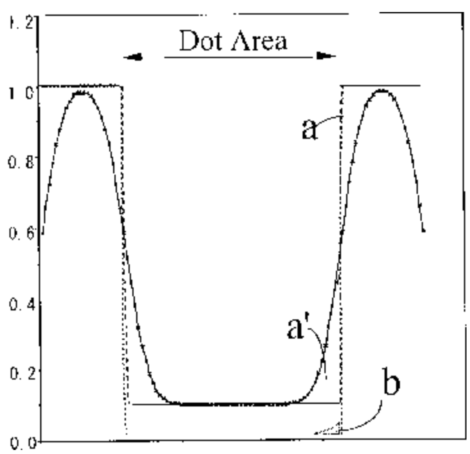


*Figure 2. The mechanism of optical dot gain. Transmittance of dot area is 0.1. Transmittance of nondot area is 1.0.*

## Prediction of Reflection Density

On the basis of proposed model computer simulation has been done and predicted the reflection density of halftone image, and those obtained densities were compared to the measured density. In this experiment, The System Brunner Print Control Strip was put on the coated and uncoated papers, and the density was measured. Table I shows measured and predicted densities for two screens 25 lpi and 150 lpi. These density data have been subtracted the density of paper *-log(r)* in Eq.(3).† It is apparent that the predicted and measured densities are approximately same.

In this simulation, the normalized‡ PSF *h(x,y)* of the paper is assumed as Gaussian distribution as follow:

$$ho(x,y) = \exp\{-1x[(x^2+y^2)/(2\times SD)^2]\} \quad (4)$$

$$h(x,y) = ho(x,y)/hi \quad (5)$$

* B. Kruse et al[3]., *is now replaced with* Ruckdeschel et al[3].
† For clarity, this sentence is now added by the author.
‡ For clarity, this word is now added by the author.

where *ho(x,y)* is Gaussian distribution, SD is standard deviation, *hi* is the integral of the *ho(x,y)*. Figure 3 shows an example of *h(x,y)*. Figure 4 shows the dependence upon the PSF of paper.§

**Table I. Measured and Predicted densities of The System Brunner Print Control Strip on sample paper. The PSF (standard deviation) of coated paper is 0.024 mm, uncoated paper is 0.040 mm.**

| | | Coated Paper | | Uncoated Paper | |
|---|---|---|---|---|---|
| Screen | [%] | Measured | Predicted | Measured | Predicted |
| 25lpi | 50 | 0.32 | 0.32 | 0.36 | 0.34 |
| 150lpi | 25 | 0.18 | 0.19 | 0.21 | 0.22 |
| 150lpi | 50 | 0.44 | 0.44 | 0.51 | 0.51 |
| 150lpi | 75 | 0.82 | 0.81 | 0.97 | 0.97 |

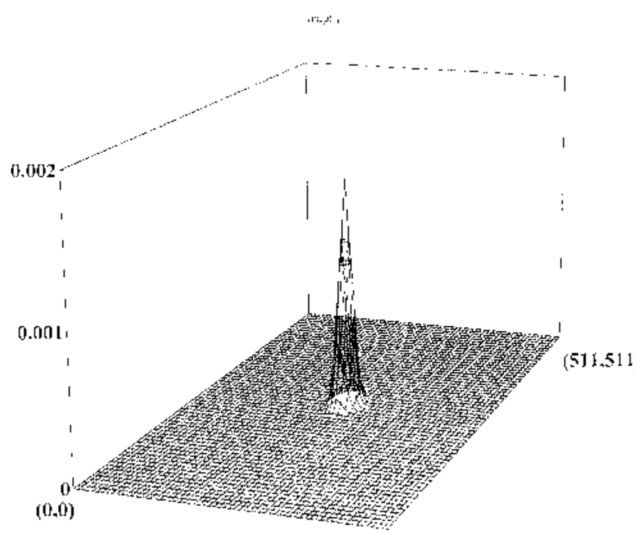


*Figure 3. An Example of the PSF, h(x,y), of paper. Standard deviation is 0.02 mm.*

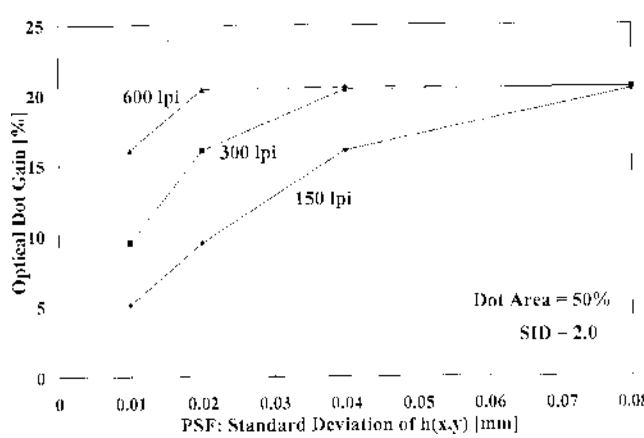


*Figure 4. Optical dot gain vs. standard deviation of h(x,y).*

§ shaded items should now be read as $h_o(x,y)$, $h_i$, $h_o(x,y)$, and $h(x,y)$ respectively.

## The Application to Digital Halftone Image

We applied this equation to digital halftone images by ordered dither methods. These digital halftone images have different dot geometry. We used the three ordered dither matrices in Fig. 5. We present their calculated optical dot gain curves in Fig. 6: Bayer matrix (B); Halftone matrix (H); and Screw matrix (S). The matrix width of 600 dpi is as same as the width of 150 lpi dot in halftone printing. The optical dot gain curve of 600 lpi in halftone printing looks like the Bayer matrix curve and the curve of 150 lpi looks like the screw matrix curve in Fig. 6 and Fig. 7.

| | | | |
|---|---|---|---|
| 0 | 8 | 2 | 10 |
| 12 | 4 | 14 | 6 |
| 3 | 11 | 1 | 9 |
| 15 | 7 | 13 | 5 |

Bayer matrix (B)

| | | | |
|---|---|---|---|
| 10 | 4 | 6 | 8 |
| 12 | 0 | 2 | 14 |
| 7 | 9 | 11 | 5 |
| 3 | 15 | 13 | 1 |

Halftone matrix (H)

| | | | |
|---|---|---|---|
| 13 | 7 | 6 | 12 |
| 8 | 1 | 0 | 5 |
| 9 | 2 | 3 | 4 |
| 14 | 10 | 11 | 15 |

Screw matrix (S)

*Figure 5. The used ordered dither matrices.*

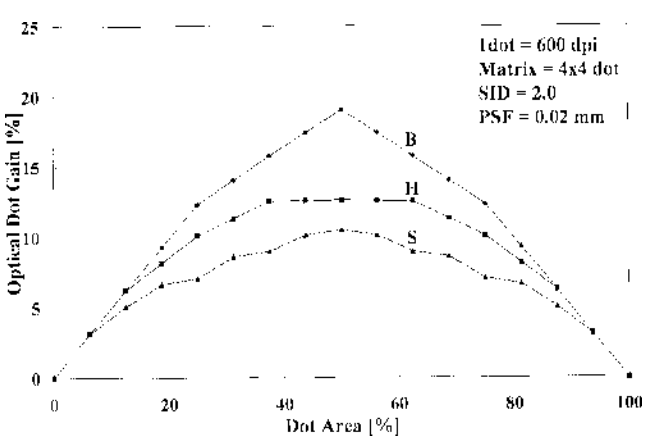


*Figure 6. Optical dot gain curves for different dither matrices.*

## Discussion

### Comparison with Yule-Nielsen Equation

In halftone printing simulations, the results by Yule-Nielsen equation and the proposed equation are well correlated. Yule-Nielsen equation is practical, therefore it is useful to estimate the factor *n* using the proposed equation. Optical dot gain curves from *n=1.0* to *n=2.0* become not symmetry in Yule-Nielsen equation in Fig.7. The simulations of dot geometry in the proposed equation is diamond. It is considered that dot geometry in Yule-Nielsen equation is different from diamond.

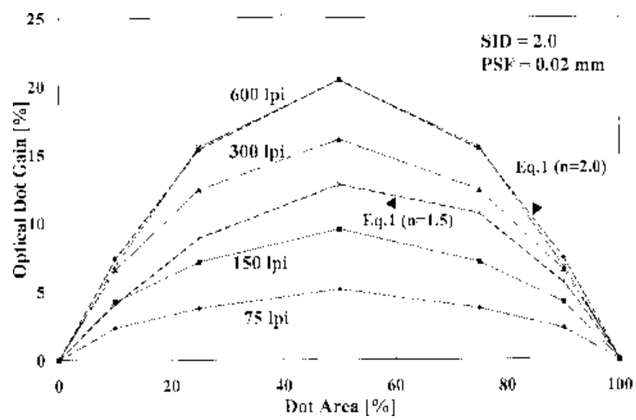


*Figure 7. Optical dot gain curves for screen rulings in halftone printing.*

### The Limit of Optical Dot Gain

Yule et al.[2] pointed out that optical dot gain has the limit and it is 25%. The limit of optical dot gain exists in the proposed equation also. As shown in Fig. 1, it occurs when the incident light diffuses equally in the paper layer and the transmittance of dot area is very low. The special case is 50% of dot area, large distribution of the PSF or small dot size, and low transmittance of dot area.

### Comparison with The Border Zone Theory

It is known that the amount of border zone length is related to the amount of optical dot gain[4]. Each dither matrix has characteristic border zone length curve as Fig.8. These curves agree well with the curves which are shown in Fig.6. However optical dot gain has the maximum limit in spite of border zone length. The border zone theory is hold good in the case that the PSF is smaller than dot area sufficiently.

## Conclusions

We introduced a new model to predict reflection density of half tone image based on the point spread function of paper, and we estimate the optical dot gain using the model. As a result, it was shown that the calculated density is approximately same to the measured density, it is also shown that the calculated optical dot gain by proposed model is well correlated to the measured optical dot gain by "The System Brunner Print Control Strip". Digital halftone images by ordered dither are also analyzed by using the proposed method. These results of simulate optical dot gain are in good agreement with common knowledge in the field of printing. To put the proposed equation to practical use, we have to develop how to measure the PSF of paper easily and accurately.

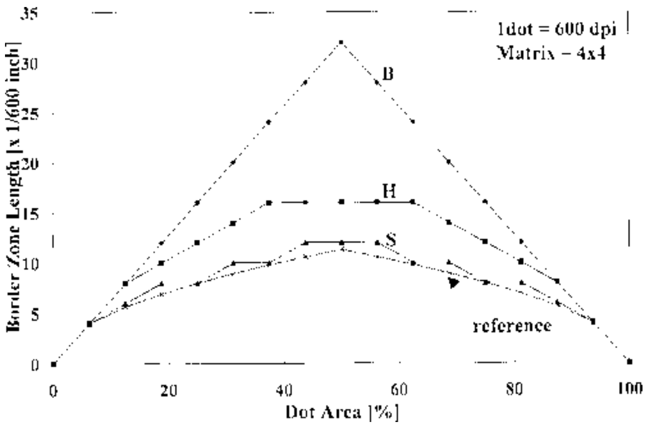


*Figure 8. Border Zone Length curves for different dither matrices. "reference" is it of 150 lpi halftone dot (diamond).*

## Acknowledgments

The authors would like to thank Mr. T.Ogura, director of central research laboratory, Mitsubishi Paper Mills Limited for his support. The authors also would like to express their appreciation to Mr. S.Suzuki, general manager of Mitsubishi Paper Mills Limited for his financial support.

## References

1. J. A.C. Yule and W. J. Nielsen : "The Penetration of Light into Paper and Its Effect on Halftone Reproduction" *TAGA*, 65 (1951)
2. J. A. C Yule et al. : "The Effect of the Spread-Function of Paper on Halftone Reproduction" *Tappi*, 337 (1967)
3. Mikael Wedin and Bjorn Kruse: "Mechanical and Optical Dot Gain in Halftone Colour Prints" *Proceedings of IS&T's 11th International Congress on Advances in Non-Impact Printing Technologies*, p. 500 (1995).
4. Miles Southworth, Donna Southworth: "Quality and Productivity in the graphic arts" Graphic Arts Publishing Co. 15–9.

❋ Previously published in *IS&T's 49th Annual Conference Proc.*, pp. 353–356, 1996.

Reference 3 is now replaced as follows

3. F. R. Ruckdeschel and O. G. Hauser, Yule-Nielsen effect in printing: a physical analysis, *Applied Optics*, **17**, 3376 (1978).