

# Mechanical and Optical Dot Gain in Halftone Colour Prints

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## Abstract

A method for determining the dot gain, both physical and optical, based on the colourimetric properties of the halftone dots is presented. To estimate the physical dot gain the method identifies the ink and discriminates between the different colours and the paper using normalized colour distributions for each printing ink. The colour distribution idea is based on the fact that between the colourimetric centers of gravity (in CIELAB colour coordinates), the possible colours of the print are almost one dimensionally distributed. This has been established through three dimensional visualizations of the colour gamut for different printers and also for news print. In this approach a simulation how light is scattered in the paper is used to complement the measurement of optical dot gain. Using digital image processing and data modelling through Singular Value Decomposition, properties of the colour distributions for halftone prints are identified. The properties are identified by examining the basis functions corresponding to the largest singular values. Links to the physical properties of the ink and the paper are discussed.

## Introduction

The output image is analysed in micro scale to be able to view the different coloured areas in the halftone cell and to make the calculations on the micro scale image. Studying the micro scale properties of the print are the key to determine how well the device is capable of reproducing the input test pattern. The test pattern is a chart of different coverages of the primary ink and the combinations thereof. By using a high resolution scanner to scan the output we obtain a digital representation of the test pattern. The scanner has no correction made to the RGB (Red, Green, Blue) data and the transfer function is therefore well known. The authors have presented an introduction to this approach by in [7].

The gamut of the printing process can be viewed as Figure 1 which is a schematic representation. If a real halftone pattern is studied in micro scale resolution the result can be as in Figure 2. It is the three dimensional histogram of a 60% blue halftone dot pattern. Note that the distribution of colours in the halftone print are clearly four clusters with almost one dimensional structures between them.

This problem has briefly been studied before<sup>3,4</sup> but with a different method both concerning how to model the colour distribution and the colour space used. The approach in this paper uses CIELAB where colour differences can be calculated using the CMC colour difference formula. The modelling of the colour distribution is made by Singular Value Decomposition.

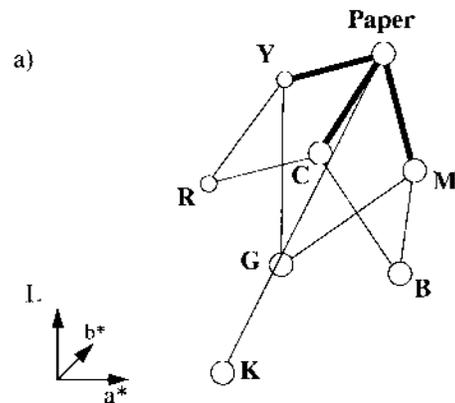


Figure 1a. A simplified picture of the placement of the clusters in the colour space histogram which is the base from which the colour distribution is made.

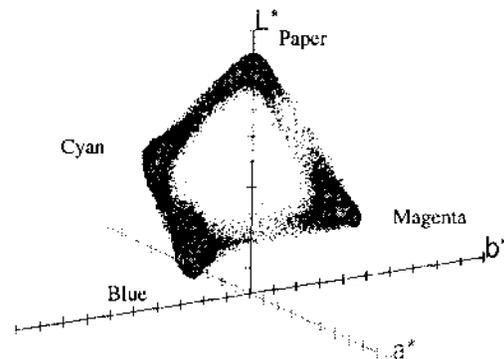


Figure 2. A view of the three dimensional colourimetric histogram which is the base from which the colour distribution is made.

## Colour Distributions

The idea of one dimensional colour distributions are based on the fact that the colour co-ordinates for the

subtractively mixed printing inks are almost one dimensional between the large clusters corresponding to colour co-ordinates for the inner of the halftone dot. The colour distribution theory is based on the three dimensional histograms of the CIELAB colour co-ordinates for different ink coverages which typically are varying from unprinted paper to the full tone in steps of 10%. The three dimensional colour co-ordinate histogram are decomposed into one or several one dimensional histograms or, what we hereafter will call colour distributions.

When examining the histograms the three dimensional center of gravity for the different coloured areas in the test print are determined. All colour co-ordinates found in the sample images are orthogonally projected onto the vector between the clusters in the colour space. In the case of one colour printing, two major clusters are present, namely one corresponding to the colour of the unprinted surface (paper) and the other to the dot colour.

The number of clusters are increasing if we are considering more than one printing ink, for two colour printing case there are four clusters present. The clusters are the two primary printing inks, the overlap of the primary inks and the unprinted surface. See Figure 2 for an example of a three dimensional histogram of a two colour print which is the raw input data for the process of making the distributions.

The distributions are established by the following processing steps:

- Convert the RGB sample images from the scanner to CIELAB and make a histogram of the colours present in the image. This will lead to a three dimensional colour space histogram.
- Calculate the colourimetric centers of gravity for each major cluster in the sample image. This involves finding the most frequent colour co-ordinate and calculating the centre of gravity for the sphere centered around that point. The radius of the sphere is  $4\Delta E$  which is based on measurements and visual assessment of the three dimensional data.
- Make an orthogonal projection, of all colours present in the three dimensional histogram, on the vector between the centers of gravity (COG). If more than one printing ink is used there will be several vectors between the COGs and the projection will be made on the closest vector. The colourimetric distance is defined by the CMC colour difference formula. See the book by Hunt<sup>2</sup> for a description how to calculate the CMC colour difference for two colours in the CIELAB colour space.

## Mechanical and Optical Dot Gain

When the halftone dots actually are larger than they should be, the phenomenon is called physical dot gain. The physical dot gain is dependent on a number of factors, for example the viscosity of the printing ink, i.e. the inks tendency to spread after it has been deposited on the paper. Previous work by the authors in the area is presented by Wedin and Kruse<sup>7,8</sup> and thresholding algorithms can be studied in the book by Gonzalez<sup>1</sup>.

## The Transition Area Method

The method of determining the amount of printing ink applied on the paper is using the fact that there is a certain diffusion of printing ink around the edges of the halftone dot. To define the threshold in the colour distribution, where the distinction between dot and the paper is to be made, we maximize the colourimetric difference for the transition area,  $T_d$ , of that specific coverage, see Eq. (1), and take the midpoint in this interval as the threshold. Due to the fact that the halftone cell colour distribution function,  $C_d(x)$ , is discrete, there can be several candidates for the largest interval  $x_0 - x$ . If this is the case the middle interval of these, largest colour distance, candidates is taken. The effect of this approach corresponds to a densitometer which finds the maximum derivative of the colour change.

$$\max_{x_0 - x}^{x_0} \int_x C_d(x) dx \leq T_d \quad (1)$$

Optical dot gain depends on light scattering in the substrate interacting with the printed image on the paper surface. Some of the light rays hitting the paper surface are scattered laterally in the paper far enough to make them emerge under a halftone dot causing a decrease in overall reflectance of the print. This is exactly the same effect as if the halftone dots actually were larger than they really are, thus the term dot gain.

## Theory

The calculation of the optical gain is based on the shift of the entire colour distribution in colour space. In the way optical dot gain is defined there is no dot gain in either 100% full tone coverage or the unprinted paper. This fact gives two fixed points for the quantification of the gain dependant on the paper and ink.

The proposed measure is the integrated center of gravity for the colour distribution constructed by orthogonal projection on the vector between the unprinted paper and the full tone area. The area of the halftone dot including optical dot gain,  $A_{opt}(x, d)$  is calculated for all coverages,  $d$ , available in the test ensemble. The respective areas  $A_{opt}(x, d)$  are calculated as shown in Eq. (2) where  $x$  is the co-ordinate along the projected axis with zero at the COG of the projected full tone colours.

$$A_{opt}(x, d) = 1 - \int C_{opt}(x, d) dx \quad (2)$$

where  $C_{opt}(x, d)$  is the colour distribution along the projection axis for area coverage  $d$ .

This integral is to resemble with the integration in the eye when the sample is viewed by an observer and the perceived coverage is proportional to the colour shift of the inner of the halftone dot when the dots are getting larger and the optical gain are increasing.

## Prediction of Optical Dot Gain

The optical dot gain depends almost entirely on the properties of the paper the image is printed on. How far light can travel in the substrate is dependant on the internal

light scattering of the paper. If the paper has a large scattering effect, the distance is relatively small. Studies of how far the light can travel in different common paper grades can be found in Oittinen and Saarelma<sup>6</sup> were distances up to 0.10 mm are reported. This is equivalent to one third of the width of a halftone cell when you are printing 85 lpi, i.e. an effect that must be accounted for.

### Theory

The properties of the point spread function has been studied at our laboratory by Kruse<sup>5</sup>, and could be approximated as  $P(x,y)$ . Where  $P(x,y)$  is an approximate exponential which are presumed circular symmetric as an initial assumption. More work are done at our laboratory to acquire an accurate PSF. The PSF is characterizing the light scattering properties of the paper. To obtain the modelled dot gain effect kernel the  $Kp(x,y)$  is convolved with the image  $C(x,y)$  to obtain the scattering effect in the paper. This is the multiplied by  $C(x,y)$  giving the emerging light pattern (the observed image), see Equation (3).

$$OG(x, y) = C(x, y) \int_{Image(x,y)} K_p(\xi) C((x, y) - \xi) d\xi \quad (3)$$

where the result  $OG(x,y)$  is an image with simulated dot gain.

## Experiments

The experiments were carried out using different paper media and printing technologies. Two types of thermal transfer printers, an ink jet printer and an offset press. The thermal transfer prints were made on a Seiko Professional Colour Point 2 and a QMS ColorScript 100 model 10. The ink jet printer were a Hewlett-Packard PaintJet XL300.

The numerically intensive parts of the experiments are done with programs written in C and the data analysis part is done with MATLAB. The structure of the approach makes it possible to do the entire processing and analysis part in a single programming package were the separate parts automatically are interchanging information and presenting the results. The test prints are scanned using a FENIX 6425-C flatbed scanner. The scanner works with an optical resolution of 1024 dpi in both x- and y-directions.

### Modelling with SVD

The colour distributions for a single primary ink can be put together in an ensemble and analysed through SVD, see Appendix A for a short mathematical treatment of SVD. This approach gives us some indications how the colour distributions are changing as the ink coverage increases. The modelling is made by adding weighted base functions together, these base functions are the same for the whole ensemble. In the modelling only five of the possible ten base functions are used. The modelling results are still very good as the important properties of the distributions are modelled by these functions with a high singular value.

**Table 1. Area coverage for real colour distributions and the model.**

N	TT1 cyan		TT1 magenta		TT1 Yellow	
	TA [%]	Model [%]	TA [%]	Model [%]	TA [%]	Model [%]
10	15.6	15.6	15.7	15.3	15.4	15.1
30	42.9	43.3	43.5	43.2	42.9	42.8
50	63.2	62.8	63.3	63.7	63.3	63.6
70	78.2	79.9	78.3	78.7	76.8	76.8
90	88.2	88.2	87.9	87.2	86.9	86.6
100	100.0	98.8	100.0	99.6	100.0	100.0

### Physical Dot Gain

The results are obtained with the adaptive thresholding algorithm, called the Transition Area method (TA), described earlier in the paper. The results are compared to dot area readings of a traditional densitometer, a X-rite model 414. The densitometer was calibrated against the reference delivered with the densitometer and the paper and full tone area were measured before every reading of each printing ink.

**Table 2. Estimated physical dot gain. TT1=Professional Colour Point 2,TT2=QMS ColorScript 100 model 10. Ink Jet=Hewlett-Packard PaintJet XL300.**

N	TT1 yellow		TT2 cyan		Ink Jet cyan		Ink Jet yellow	
	TA [%]	D [%]	TA [%]	D [%]	TA [%]	D [%]	TA [%]	D [%]
10	11.9	19	7.2	11	8.0	36	19.1	33
30	38.6	49	27.5	34	32.0	73	62.3	64
50	58.4	68	50.6	56	61.3	87	80.1	81
70	72.6	81	72.6	76	78.4	97	93.4	94
90	83.8	89	93.0	95	96.0	100	100	99
100	100	100	98.2	100	100	100	100	100

There are large absolute differences between the TA and densitometer readings. But if a comparison between, TT1 cyan and TT1 yellow by the TA approach on one hand and TT1 cyan and TT1 magenta on the other, is made the relative differences are almost identical. It seems that the densitometer has a slight problem measuring small densities or small dot areas.

## Results and Discussion

The Transition Area (TA) approach is shown to give a good discrimination between printing ink and the printing media. Visual comparisons between a traditional densitometer and the TA approach have shown that the TA approach gives a better result for area coverage. The optical dot gain is determined based on the colour shift in the halftone dots. The colour shift is caused by light scattering in the printing media. A model for prediction of optical dot gain is presented. The model uses convolution to account for the scattering effect and the result can be viewed as an image with simulated optical dot gain.

Further work in the area are to be done concerning identification of the parameters of the convolution kernel. The suggestion is to use the following processing steps. Calculate the total reflectance from a real image, with a halftone pattern, for which the coefficients of the kernel are to be determined. Then calculate the total reflectance from the paper the halftone pattern is printed on.

Calculate the relative reflectances between the real image and compare it to the relative reflectances of the simulated optical gain. If it is necessary, adjust the parameters to get a better correspondence between the simulated result and the real data used.

### Acknowledgements

The authors want to thank The Swedish Pulp and Paper Research Foundation, dnr 31B, for financial support to the work carried out as a part of the Swedish interdisciplinary Print Research Program, PFT. We also want to thank the colleagues at the Image Processing Lab for valuable discussions and Marianne Klamann for the test prints made on the offset press.

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- \* Previously published in *IS&T's NIP11 Conference Proc.*, pp. 466-469, 1995.