DOT GAIN MODELLING APPLIED TO STOCHASTIC SCREENS

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Abstract: The art of making frequency modulated halftones and stochastic screens is still evolving. The success of rendering images using such halftones is to a large extent determined by the paper and the actual algorithm used. The paper surface topography, the light diffusion properties of paper, the paper—ink interaction and many other materials properties are essential to the outcome. It has been noted empirically that the optical scattering in paper generally causes the dot gain to increase with decreasing dot size. In stochastic screens where dot size is dramatically smaller than in conventional halftoning its effect has to be compensated for. This is usually done by transforming the C,M,Y and K channels individually so as to counterbalance the dot gain on the input side of the screening algorithm. This paper deals with the effects of the optical dot gain of "stochastic patterns". The conclusions of the paper show that the compensation should be made not on the input side, before the halftone is produced but during the halftoning process itself. If the stochastic nature of the microstructure cannot be controlled during the process the optical (and physical) dot gain may cause strong variations in the resulting tone with a noisy or grainy result. It is also shown that adaptive algorithms can overcome the problem by incorporating a dot gain model in the algorithm. Iterative adaptation specifically, has been suggested as one way of incorporating the dot gain into the halftoning procedure.

Introduction

The difference between conventional halftones and frequency modulated ones lies in the microstructure. In conventional algorithms halftone dots of various sizes form a regular grid. The distribution of the halftone dots over the surface is uniform. The dots are made different in size according to the desired density. Since the shape of the dots is the same and only the dot size varies conventional screens behave rather uniformly throughout the density range. The frequency modulated screens do not have this uniformity. Instead the size of the dots is the same and the density variation is created by a more or less dense population of dots. A very popular way of accomplishing this is to use some sort of error diffusion algorithm [1] or using dispersed dots [2]. The literature on this subject is

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very extensive. Variations of this scheme includes methods that lie in the range between the conventional halftones and the frequency modulated ones.

It is a well-known fact that the dot gain is increasing with decreasing dot size. This is definitely true for the optical dot gain. It is also true for the physical dot gain at least when negative plates are used. When positive plates are used some of the increase in optical dot gain may be compensated for by the decrease in physical dot gain making the total gain less accentuated as compared to the case with negative plates. It should be made clear here that the optical dot gain is an effect that you cannot do much about. It is desired to have a paper surface that appears white. This requires the light scattering in the bulk of the paper to be large which in its turn makes the optical dot gain large. Therefore the uniformity in optical dot gain is very important for the quality of the paper. Printing with small dots makes this even more important.

In order to summarize, the variation in dot gain is an effect of at least three important factors

- The halftoning algorithm
- The uniformity in light scattering of the paper bulk
- The surface topography

In this paper we will only cover the influence of the algorithm. We will show that in frequency modulated halftones one can expect a variation in tone rendering that can only be fully compensated for by adaptive halftoning algorithms.

The model for optical dot gain

The conclusions of this work relies heavily on the model for optical dot gain. Although the model has been presented at previous TAGA meetings it merits a brief and simplified description here [3,4,5,6]. The model as we will describe it here applies to offset printing.

The model is based on the fact that light is scattering in the paper bulk. The scattering is assumed to be uniform. Light that enters through the top of the paper sheet has to pass the layer of ink. This layer is specially modulated in the form of ink dots with a bare paper surface in between. Light that passes a dot is attenuated before it reaches the bulk whereas the light that enters through the bare surface is not. Thus the spacially modulated light flux is scattered in the bulk. The scattered light will travel some distance until it is absorbed in the bulk or it leaves the paper on one of the two sides of the sheet. Some of the light escapes from the bottom side of the sheet and some is leaving the sheet through the top layer of ink. This is what we observe. The scattering within the paper bulk results in a diffusion that to some extent smooths the contrast edge between areas directly beneath the dots and the bare paper respectively. This diffused flux is once again attenuated by the ink layer on its way to the observer. The net result is that along the border of each printed area there will be a zone with increased density. The amount of the increase as well as its extent outwards from the border depend on the mean length of the light scattering distance. This is precisely what the model describes. In mathematical terms the model for the reflected image, R, as viewed from the top can be described by the following expression:

$$R(x, y, \lambda) = I(T(x, y, \lambda) * P(x, y, \lambda))T(x, y, \lambda)$$

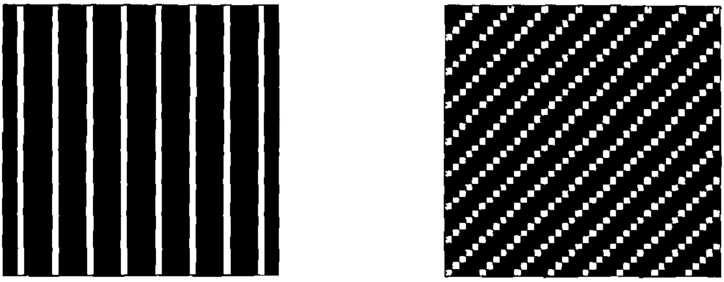
where I represents the illumination, T represents the transmission properties of the ink film and P represents the projection to two dimensions, x and y, of the scattering properties in the bulk. In this sense P is nothing but a 2D point spread function. The expression also indicates that the whole spectral range should be taken into account. The dependence on wavelength, λ, may be difficult to measure. It should be taken into account in reproduction of colour images. In this paper we will limit ourselves to the study of monochromatic prints so the influence of λ does not have to be taken into account.

Halftoning

The algorithms for halftoning range from conventional closed form dots to highly dispersed dots. It is interesting to note that the number of ways to render a tint by halftoning is extremely large. Even a moderately sized halftone cell of 10x10 microdots gives rise to 2 raised to the power of 100 binary patterns. The number is in effect so large that it is impossible to investigate them all (It will take 4,019693684133e+16 years if one million patterns a second are examined, which is a reasonably high speed). Now, from the point of rendering only the number of microdots that are turned on determines the density at least in principle. So, the number of densities that can be accommodated by a halftone cell NxN microdots large is only $N^2 + 1$. In the preceding case where N is equal to 10 only 101 tone values may be generated. This comparatively small number results since we disregard the positioning of the microdots within the halftone cell. In practice, due to the dot gain, this is impossible to disregard from and consequently the number of actual densities is much larger. In [] conventional halftoning and frequency modulated halftoning are compared.

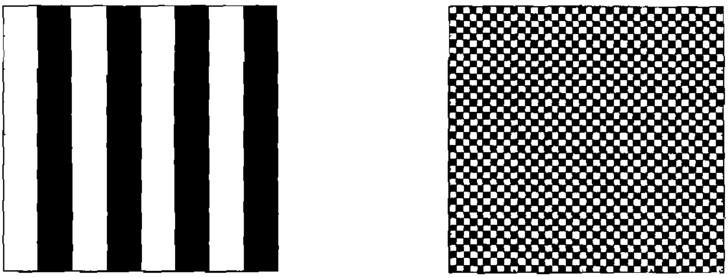
We will show a very simple case here where the halftone pattern is changed marginally. The form of the halftone is originally a vertical line pattern where the turned on microdots lie side by side, figure 1a. If we change this pattern to into a diagonally oriented pattern where the turned on microdots meet at their corners we still have a line pattern, figure 1b, but the microstructure is different and consequently the dot gain is different also. The change in optical dot gain by this simple rearrangement of the turned on dots is close to 2 percent according to the model - definitely a notable change. A more drastic rearrangement gives rise to a more pronounced change, figure 2a and b.

In frequency modulated halftoning the resulting microstructures are more or less deterministic. Even the deterministic ones vary over short distances. This means that, in a tint for example, the resulting microstructure is not constant although the same tone is being reproduced. There is no halftone cell that is replicated over the tint and the varying microstructures do not render the tone value in exactly the same way. This gives rise to the following question. How much can the local tone be expected to vary? This does of course depend on the algorithm that produces the halftone. Some algorithms are better than others. In the following we will study the possible variation.



a) *b)*

Fig 1: a) A vertical line halftone with dot gain 9.9%, b) A slanted line halftone with dot gain 11. 7%.



a) *b)*

Fig 2: a) A vertical line halftone with dot gain 8. 7%, b) A checkerboard half-tone with dot gain 21.1%

Dot gain variation

We have seen that the dot gain is very much dependent on the microstructure of The halftone. We have shown the extremes in figure 2a and b above but what can be expected in reality. How large is the variation if we pick a random set of microstructures that in principle (without dot gain consideration) should be equivalent? The following sections shows how to compute a reasonable statistic for the variation of the dot gain.

a:	0	0						
	0	0						
b:	0	0	0	0	0	1	1	0
	0	1	1	0	0	0	0	0
c:	0	0	1	1	0	1	1	0
	1	1	0	0	0	1	1	0
d:	0	1	1	0				
	1	0	0	1				
e:	0	1	1	1	1	1	1	0
	1	1	1	0	0	1	1	1
f:	1	1						
	1	1						

Table 1. The table shows the distinct 2x2 patterns a-f under shifting, rotation and flipping

The large number of patterns that resulted from using a 10 by 10 microdot half-tone cell are not all distinct in terms of their rendering. Obviously by symmetry all flipped versions of any of the original patterns are equivalent. The same applies to wrap around in 2D. Thus among the 16 possible patterns in a 2x2 matrix only 6 are distinct in the above sense. There are four equivalent patterns having a single turned on microdot and by symmetry there exist four with three microdots turned on. Among the ones with two dots turned on there is one set consisting of the patterns containing the diagonals and one set containing the rest of the patterns. The table *1* shows the equivalent patterns. Due to the combinatorial explosion is has not yet been possible to compute the distinct sets for more than 4x4 patterns. Given more computing time it is in principle very easy to extend.

Having computed all the equivalent sets it is fairly easy to compute the optical dot gain and to plot it against the nominal density. This has been done in the following figures 3 a,b,c and d for different scattering distances. From the diagrams in figure 3 it is evident that the variation in optical dot gain is not possible to neglect. It may be even higher than 5% as in figure 3b. Without control of the actual pattern used for each tone value it is evident that there may be a dot gain induced variation caused by the algorithm.

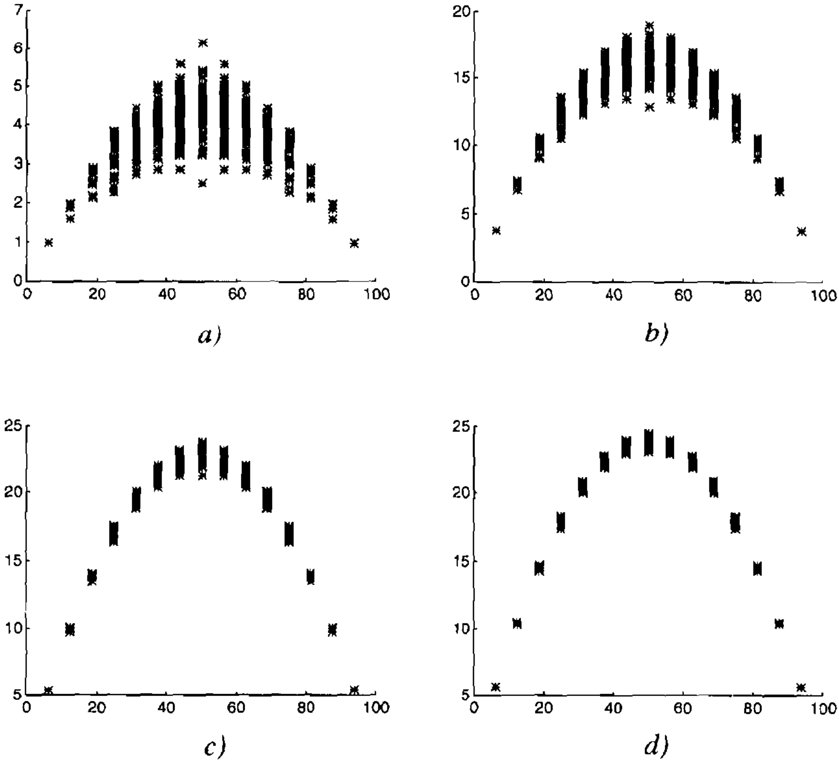


Fig 3: The dot gain plotted against the nominal density for increasing relative scattering length. a) 1:1, b) 2:1, c) 4:1, d) 8:1

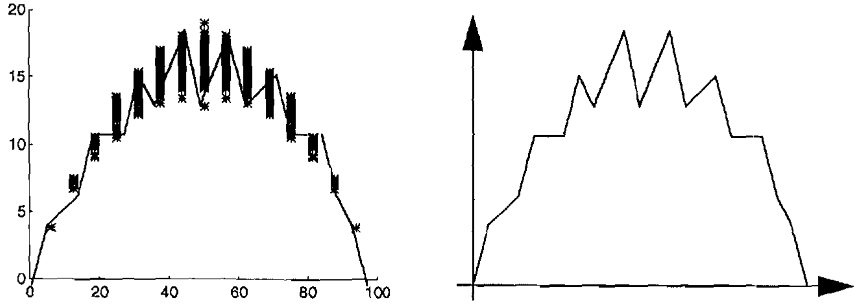


Fig 4: The "worst case" transfer function that might result from a bad choice of microstructure.

Adaptive Halftoning

It has been demonstrated that common halftoning algorithms cannot render properly unless they do take the actual microstructure into consideration. In other words the decision whether to turn a microdot on or not in the halftone cannot be done without the context of the surrounding. In this lies already a problem because you cannot determine the outcome until you have produced the surrounding. But this is impossible as the dot under consideration plays the same role of surround to the surrounding. In other words since everything depends on everything else we will have to solve a gigantic system of equations in order to produce the correct halftone if a solution exists. The size of the system of equations will have the same number of equations as the halftone binary image has pixels. This is of course not tractable especially since the equations contain non linearities.

One solution to the problem can be found in adaptive halftoning. By this we mean a halftoning procedure that adapts the binary halftone bitmap with respect to the dot gain so that it minimizes the difference from the original at low spatial frequencies. The performance of the human visual system at normal reading distance of 25cm (10in) is taken as the standard for the frequency cut-off [7]. Some prefer to call such procedures optimization. Other approaches include neural networks and iterative convolution [8]. Fortunately the form of adaptive halftoning that we are using allows for taking the paper properties into account in forming the halftone.

The adaptive halftoning will be described in the following sections. First a few definitions. Let P be the original continuous tone image and let B be its binary approximation. The low-pass filtered difference LP(P-B) should be small everywhere. The smaller it is the better B approximates P at reading distance. We will propose an iterative procedure to produce B. Let B_i be the i:th approximation. The procedure is a "hill climbing" approach to obtain the goal.

$$M_i = M_{i-1} + k \cdot \mathrm{LP}(P - B_{i-1}) \qquad (1)$$

$$B_i = (P > M_i) \qquad (2)$$

The two equations are updated iteratively as long as there is a worthwhile improvement of the result. In the equations M_i is the integrated difference between B and P in lowpass meaning. The parameter k determines the rate of change in the goal search. The iteration can start with a random B_0 and M_0 equal to zero for example.

From the description above it is easily seen that by changing eq. 1 so that the comparison is made between P and the dot gain model (DG) result applied to B we will be able to make the dot gain compensated halftone directly.

$$M_i = M_{i-1} + k \cdot \mathrm{LP}(P - \mathrm{DG}(B_{i-1})) \quad (3)$$

$$B_i = (\mathrm{P} > M_i) \quad (4)$$

The result is a halftone that incorporates the dot gain behaviour in its rendering.

Conclusions

It has been shown that great care has to be used in frequency modulated halftoning. The variation due to optical dot gain alone may create a noisy or grainy result. The microstructure influence on rendering is strong enough to warrant inclusion of dot gain characterization in the halftoning procedure. Iterative adaptation has been suggested as one way of incorporating the dot gain into the halftoning procedure.

Acknowledgments

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