Hybrid Halftoning in Flexography

Sasan Gooran*

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Abstract: Most printing devices, such as laser and Inkjet printers, are restricted to very few colors. The continuous-tone images should therefore be transformed into binary ones before being printed. The techniques doing this transformation are referred to as halftoning methods. Halftoning methods can be divided into two main categories, namely AM (Amplitude Modulated) and FM (Frequency Modulated). In the AM method the size of the dots are changing while their frequency is kept constant, that is the darker the tone the bigger the dot. In the FM method the size of the micro dots are constant while their frequency (number of micro dots) varies. In other words the darker the tone the more the number of micro dots.

Some printing methods, such as Flexography, can not produce the dots sufficiently small. Therefore, if only an AM halftoning method is used the highlights (and the shadows) of the original image can not correctly be reproduced. In this paper we present a hybrid halftoning method that incorporates AM and FM halftoning in order to overcome this problem. The proposed method uses a FM method for the highlights (and shadows) and an AM method for the rest of the original image.

Introduction

There are two main types of halftoning, AM (Amplitude Modulated) and FM (Frequency Modulated). In the AM technique the size of the dots is variable while their spacing is constant. The single dot within the halftone cell grows larger as the tone value becomes darker and smaller as the tone value becomes lighter. In the FM technique, contrary to the AM technique, the size of the dots is kept constant while their spacing varies. The number of micro dots within the halftone cell increases as the tone value becomes darker and decreases as the tone value becomes lighter. Many AM and FM halftoning methods have been proposed in literature (Ulichney, 1987), (Kang, 1999), (Floyd, 1976), (Analoui, 1992), (Gooran, 1996) and (Gooran, 1998). Both methods have their own

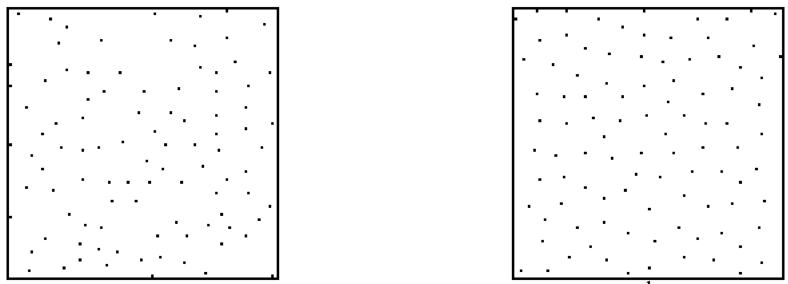
*Department of Science and Technology, Linköping University, Sweden

advantages and drawbacks. The AM methods normally result in more homogeneous halftoned images when the gray tones of the original image vary slowly. Add to this the fact that AM methods suffer less from dot gain than FM methods do. The FM methods, on the other hand, are superior when dealing with heavily textured original images.

A possible application of hybrid halftone is when dealing with a printing method that is not able to produce the dots sufficiently small. Flexographic printing can be mentioned as an example of such printing methods. As we discussed earlier, in the AM methods the lighter the tone the smaller the dot. When the printing method is unable to produce the dots smaller than a specific size it is impossible to correctly reproduce the gray tones lighter than the tone corresponding to the smallest possible dot. Therefore, AM halftoning fails to give a good perception of highlights and shadows in Flexography, see the highlights of the image shown in Figure 3. In Section 3 we will describe how AM and FM methods can incorporate in order to make this printing method correctly handle the very light (highlights) and dark parts (shadows) of the original image. The FM method used in this paper has already been presented and described in a number of publications but it is briefly described in Section 2, (Gooran, 1998) and (Gooran, 2001).

FM Method

The FM method is based on a successive assessment of the near optimum sequence of positions to render a halftone dot. The impact of each rendered position is then fed back to the process by a distribution function, thereby influencing subsequent evaluations. This distribution function plays a significant role in the placement of dots. We want the dots in the halftoned image to be placed as far apart as possible provided the halftoned image fulfils some conditions that connect its appearance to that of the original continuous-tone image. The problem of halftoning is the problem of placing a certain number of dots on a blank page so that the result "resembles" the original continuous-tone image. In this algorithm we begin with placing a dot at the position where the original image is darkest. Since we assume that "1" and "0" represent black and white respectively, finding the position of the darkest pixel means finding the position of the pixel that holds the largest density value. This is exactly what this algorithm does at the first step, i.e. the algorithm finds the position of the largest density value (or the maximum) in the continuous-tone image. Then it places a dot at the same position in the binary image, which is totally white to begin with. The currently placed dot is then represented by a distribution function (filter) that affects a neighboring region of the position of the maximum in the original image. After that, the algorithm finds the position of the next maximum and performs the same feedback process for that position. The algorithm is terminated when the difference between the mean value of the original and the halftoned image is minimized. As mentioned, the filter used within the algorithm plays a significant role in the appearance of the final image. By using a filter with an appropriate size for different gray-tone regions the dots can be placed homogeneously over the entire image, see Figure 1.



a b

Figure 1: A constant image with a gray value of 1% is halftoned by the proposed FM method. a) The filter size is 11 x 11. b) The filter size is 21 x 21.

Hybrid Halftoning

Before going into details of the hybrid halftoning method we give a short description of the terms *ppi*, *lpi* and *dpi* as they sometimes seem to be very confusing.

lpi, dpi, ppi:

To be able to represent a photo in a computer it has to be digitized (or scanned). This is done by measuring the gray tone or the color of the photo in a number of distinct positions over the entire photo. The term *ppi* (pixels per inch) is the scanning resolution and means the number of taken samples per an inch when scanning. Therefore, the higher the *ppi* the better the quality of the digital image. On the other hand, the higher the *ppi* the bigger the memory that is needed to store the image in computer. Therefore *ppi* shouldn't be unnecessary high. The question of what *ppi* you should choose cannot be answered before you know how you are going to reproduce your digital image. For example if you want to show your image using a computer screen which normally has a resolution of 72 *ppi* it is just a waste of memory if you scan your image with a *ppi* higher than 72.

In Section 1 we introduced and discussed the concept of halftoning. Since in the most of black and white printers and printing presses only one color (black) is used different gray tones should somehow be represented by this only color. In the conventional methods the original image is divided into small areas. Each small area is then represented by a halftone cell, which includes a background (white) and a black dot (or a number of black micro dots). The fractional area of each halftone cell covered with black represents the gray tone of the corresponding area in the original image. The number of halftone cells per inch is called line screen frequency and is denoted by *lpi* (lines per inch). There is a rule of thumb, which says that the scanning resolution (*ppi*) should almost be twice as high as the screen frequency (*lpi*) for a better reproduction of the photo if the printed image is to be the same size as the original. For example, if the image is supposed to be printed in 100 *lpi* the photo should be scanned with a *ppi* of about 150 to 200. Choosing a *ppi* higher than 2**lpi* is unnecessary and doesn't lead to any higher quality of the printed image. Notice that if the scanning resolution (*ppi*) is twice as high as the screen frequency (*lpi*) each 2 x 2 pixel area in the original digital image should be represented by a halftone cell.

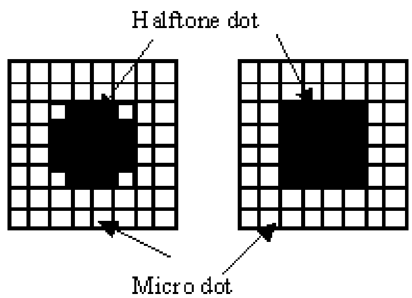


Figure 2: Two halftone cells are shown. The halftone cell to the left represents a gray value of 12/64=18.75% and the one to the right 16/64=25%.

Each halftone cell in the printers or the image setters consists of a number of micro dots. Two halftone cells, each consisting of 64 (8 x 8) micro dots are shown in Figure 2. The halftone cell to the left corresponds to a gray level of 12/64 = 18.75% and the one to the right represents the gray value of 25%. The number of micro dots per inch is what we call printer resolution and is denoted by *dpi* (dots per inch). The ratio dpi/lpi decides the size of the halftone cells, which also decides the number of gray levels that can be represented. For example, the halftone cells shown in Figure 2 can represent 65 (8 x 8 + 1) levels of gray. Therefore the number of gray levels that can be represented is equal to:

$$\left(\frac{dpi}{lpi}\right)^2 + 1 \qquad (1)$$

For example, a 600 *dpi* printer resolution combined with a 100 *lpi* halftone would only represent 37 levels of gray. Notice that, if the printer resolution cannot be increased then the higher the *lpi* doesn't necessarily mean the better the print quality.

Flexography is a modified form of letterpress printing method that is commonly used in the packaging industry for printing on the most varied materials. The print quality in flexography is lower than that in for example offset printing. On the other hand flexography is the only printing method that can print on very thin, flexible, and solid films, thick card boards, rough-surface packaging materials and fabrics (Klipphan, 2001). As discussed earlier, one of the problems with the Flexographic printing is that it can not produce the dots sufficiently small in order to handle the very light and dark parts of the original image by just using an AM method. Experience on AM and FM methods showed that both technologies have their advantages and drawbacks in the Flexographic printing. AM technologies are especially usable in the mid-tones because dot gain is lower than when a FM technology is used there. FM methods, on the other hand, perform very well in the highlights where the optimized dot positioning and the choice of the minimum dot size allow for a perfect match to the technical limitations of the printing process. The possibility of combining these two technologies has been investigated for a long time (Barco). One of the biggest problems with combining these two technologies is how to handle the transition area between the AM-halftoned and the FM-halftoned part. In this section we are going to present two ways of combining AM and FM technologies in order to increase the print quality in Flexography. Let us first illustrate the problem. Figure 3 shows an image halftoned with an AM method in 600 *dpi* and 100 *lpi*. Thus, the halftone cell consists of 6 x 6 micro dots and only represents 37 levels of gray. Suppose that the printing method is not able to produce a dot smaller than 2 x 2 micro dots, i.e. 0.085 x 0.085 mm. Therefore, gray levels less $4/36 \approx 0,11$ than can not be reproduced and those parts of the image will be totally white, see Figure 3.

Instead of decreasing the size of the dots, which is impossible for gray tones lower than 11% in this example, we can use the dots with smallest possible size (2 x 2 micro dots in our example) and change their frequency in order to represent the highlights. This is actually what a FM method does. We are going to present two different ways of doing that. In both methods first of all the original image is AM-halftoned. Suppose that the original image is scanned in 200 *ppi* and the halftoned image is to be printed in 100 *lpi*, as is the case in our example. As was discussed earlier in Section 2 each 2 x 2 pixel area in the original image should be represented by a halftone cell. Since we use a *dpi* of 600 and a *lpi* of 100 the AM-halftoned image is 9 times bigger (pixel x pixel) than the original image. A mask indicating which parts of the original image that should be AM or FM-halftoned is also built. In the FM method, as we discussed earlier, the dot

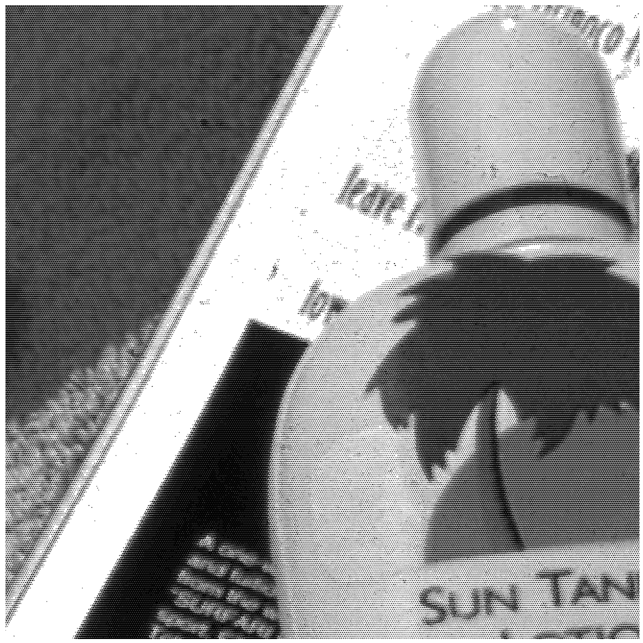


Figure 3: AM-halftoned image in 600 dpi and 100 lpi. The printing method is supposed not to be able to print the dots sufficiently small to manage the gray tones under 11%.

size is 2 x 2, and therefore the parts that is going to be FM-halftoned should be resized before being halftoned. This is done to make the final FM-halftoned image 9 times (pixel x pixel) bigger than the corresponding part in the original image, as it is the case for the AM-halftoned part. We have applied the FM method to our test image in two different ways. In the first way the FM-dots can be placed everywhere in the highlights of the image. In the second one, the FM-dots are only placed at the center of the corresponding halftone cells.

Figure 4 shows two different hybrid halftoned images. In this example the FM-dots are allowed to be placed freely in the highlights. In Figure 4a we used Floyd-Steinberg's error diffusion as the FM-method. In Figure 4b the FM method presented in Section 2 was used. From these images we can easily see that our FM method gives rise to better results. The dots are more homogeneously placed in the highlights of the image shown in Figure 4b than those in Figure 4a.

a

b

Figure 4: Two hybrid halftoned images. The FM-dots are placed freely in the highlights. FM method: a) Error Diffusion. b) presented in Section 2.

a

b

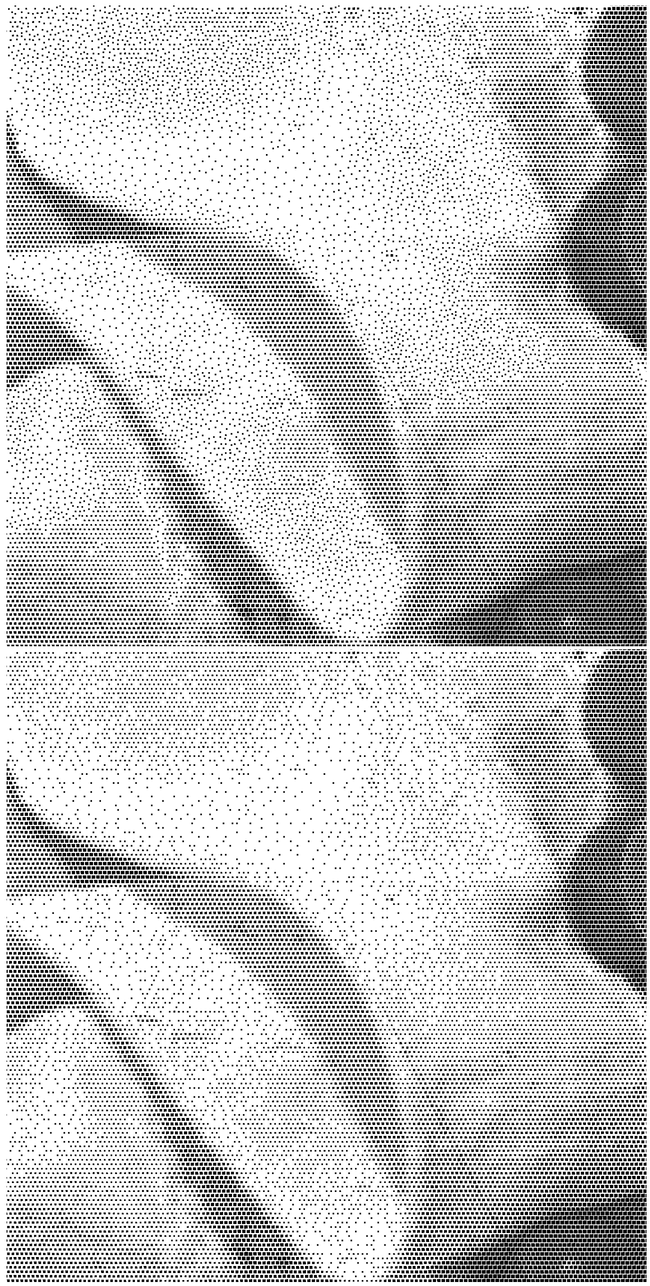


Figure 5: An enlarged version of a hybrid halftoned image using 2100 dpi and 150 lpi. a) The FM dots are placed freely in the highlights. b) The FM dots are placed at the center of corresponding halftone cells.

Figure 5 shows enlarged versions of another two hybrid halftoned images done in 2100 *dpi* and 150 *lpi*. The FM method used in both images are the one presented in this paper. In Figure 5a the FM dots are placed freely in the highlights of the image, which means the area with gray tones less than 13% in this example. In other words the FM dots are 5x5 pixels in our halftoned images, because $(5 \times 5)/14^2 \approx 0,13$. The FM dots in Figure 5b are forced to be placed at the center of corresponding halftone cells.

Conclusions

Using the FM method in the highlights and the AM method in the rest of the original image is a necessity in Flexography. The underlying FM method used in the presented hybrid methods has already been proven to give rise to satisfying results. The dots in the highlights and the shadows of the image are placed homogeneously when it is halftoned by this FM method. That is one of the reasons why we use this FM method. Another reason is that using this FM method for halftoning a constant image the first dot is placed randomly, which decreases the risk of having a disturbing transition from FM to AM or vice versa. In (Gooran, 2001) this FM method is described in details.

Two ways of placing the FM dots have also been presented and illustrated with examples. The FM dots can either be placed freely or at the center of the corresponding halftone cells. According to our experiments placing the FM dots freely gives rise to better results.

In the examples illustrated in this paper the FM dots have a square shape but it is fully possible to use any shape, which depends on the AM method and also the gray tone for less than which the FM method is used. Our future goal is to extend this method to be used for color images. The FM method presented here has already been extended to a color halftoning method (Gooran, 2001). In this method the color separations are halftoned dependently, which results in high quality color images.

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