

Context Dependent Colour Halftoning in Digital Printing

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Abstract

Halftoning of a colour image is normally performed by halftoning the colour separations independently. Each halftoned image then builds the corresponding colour separation of the final halftoned colour image. In conventional halftoning methods different screen angles for different separations are being used to reduce the correlation between the separations to reduce artefacts in the form of moiré patterns for example. In FM screening, due to the random placement of dots, this effect is reduced without the need for using different orientations.

With a detailed control of the dot placement it is possible to increase the colour gamut and reduce the colour noise of the image. The present paper discusses the problem and presents a halftoning method that halftones the colour separations dependently, that is, it can control the dot placement not only in each separation by itself, but also in each separation in relation to the others.

Predicting and modelling the dot gain accurately is another problem of image reproduction in general since the effect of dot gain has to be considered in one way or another when the halftoned image is to be printed on a substrate. This paper also discusses how the effect of dot gain can be taken into account within the algorithm presented.

Introduction

Many methods for the halftoning of monochromatic images have been explained and proposed in literature, among others [1], [2], [3], [4], [5], [6], [7] and [8]. One of the reasons for so many methods being presented is that there is no specific criterion for a "good" halftoning method. Another reason is that some methods work well for some kind of images but produce results of low quality for other kinds. Another factor that can be important in some applications is the computational complexity of the methods. Halftoning of colour images brings up some new problems. For example, if all the separations in a colour image are halftoned with some conventional method, artefacts in the form of moiré patterns can appear in the final colour image. These artefacts can be avoided by using different screen angles for different separations. However, when the number of separations is large the stochastic approach is necessary. In this paper we focus our attention on the latter case.

Halftoning of a colour image is normally performed by halftoning the colour separations independently. Each of the resulting halftoned images then builds the corresponding colour separation of the final halftoned colour image. The question we ask here is whether we can increase the quality of the halftoned colour images by performing the halftoning process of the separations dependently in some manner? How the separations should actually be halftoned dependently to get results of higher quality can vary from algorithm to algorithm. However, what is certain is the fact that with a detailed control of the dot placement it is possible to increase the colour gamut and reduce the colour noise of the image.[9]

It has been shown that if error-diffusion is applied independently to each colour separation, artefacts in the form of correlated noise or "worms" appear. *Sullivan*, *Miller* and *Wetzel* proposed a method, *error-diffusion in colour space*, in order to reduce these artefacts.[10] *Ostromoukhov et al*. have proposed another method, *colour error-diffusion with constraints inhibiting dot over dot printing*, which also reduces these artefacts.[11] Another method using different Blue Noise Masks for different colour planes has also been proposed.[12]

In this paper we concentrate on an algorithm we developed earlier for halftoning of monochromatic images, *Near-optimal halftoning*. This algorithm is briefly explained in next section. For a thorough explanation of this algorithm see [8] or [13]. In section 3 we explain a possible way of extending this algorithm to an algorithm for halftoning of colour images. We call this extended algorithm *Near-optimal colour halftoning*. We will show that in this algorithm we can control the dot placement not only in each separation by itself, but in relation to the dot placement in the other separations as well.

One of the advantages of *Near-optimal halftoning* is that the effect of physical and optical dot gain can be taken into account within its process. In section 4 we will give a review on how models of physical and optical dot gains can be used in this algorithm. We will also show that this advantage is extensible to *Near-optimal colour halftoning*.

Near-Optimal Halftoning

Near-optimal halftoning belongs to the iterative type of frequency modulated halftoning techniques. It 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 coloured 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 some distribution function that affects some neighbouring area 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. This process will continue until a given condition is fulfilled. In our experiments the algorithm is terminated when the difference between the mean values of the original and the halftoned image is minimum.

Near-Optimal Colour Halftoning

Like other halftoning techniques *Near-optimal halftoning* can be used for halftoning of colour images by applying it to the separations independently. The structure of the dot placement in each of the separations of the final halftoned colour image resembles that of the monochromatic ones.

Since the colour perception is very much dependent on how the separations behave in relation to the others, having a good structure of dot placement in each separation independently does not necessarily guarantee a very good colour perception of the halftoned colour image. Therefore, what one really wants is to have control not only over the dot placement in each separation by itself, but also over the dot placement in each separation in relation to the others. To gain such a control we extended this algorithm to be used for halftoning of separations in a correlated manner. We call the extended algorithm *Near-optimal colour halftoning*. We describe the most natural way of this extension in the following.

We assume that the colour image is divided into several separations and each separation is represented by a digital continuous-tone image. For the sake of simplicity we also assume that the colour image is represented by its C, M and Y separations (the image can be represented by C, M, Y and K or other separations as well). Further, we consider the colour image as a multi-dimensional signal (each pixel holds a vector of data, the C, M and Y data in this case). As in the monochromatic case, the algorithm begins with finding the position of the maximum in the colour image and places a dot at this position in the halftoned colour image. The halftoned colour image is assumed to consist of only zeros at the start. Note that the maximum can be found on each of the separations. Like in the monochromatic case the impact of this rendered position should be fed back now. Suppose that we perform the feedback process only on the same plane as the maximum was found, that is we use a two-dimensional distribution function. If we do so, the final result would exactly be the same as if we run the process independently. Using a "three-dimensional distribution function" can be a direct extension of the monochromatic halftoning method to a colour one, see Figure 1. With the help of such a function we can control the dot placement in the three planes dependently.

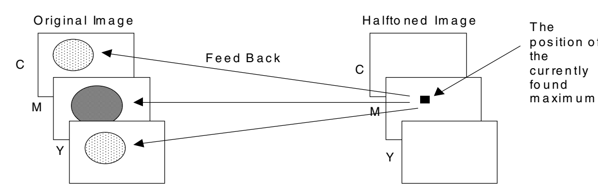


Figure 1. The impact of the rendered position affects all separations in the original image.

In [8] and [13] we have suggested a two-dimensional distribution function that gives rise to results of high quality. We can still use this distribution function on the same plane the maximum is found. What the "three dimensional distribution function" should look like exactly in the other planes is under investigation, but we know that both its size and shape are dependent on the density value of the maximum found. After affecting all separations, the algorithm finds the position of the next maximum and affects some neighbouring area of this position in all separations of the original image. This process continues until the difference between the mean values of all corresponding separations of the original image and the halftoned one are minimised.

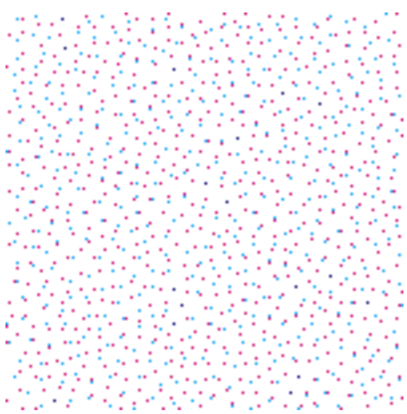
In order to show that running this halftoning process dependently can lead to better results, we halftone three colour images by *Near-optimal halftoning*. The images are halftoned firstly by applying *Near-optimal halftoning* to its C, M and Y separations independently and secondly by *Near-optimal colour halftoning*. The first image has 2%, 3% and 0% coverage in its Cyan, Magenta and Yellow separations respectively, see Fig. 2. In Fig. 3 an image with 20%, 30% and 40% coverage in its C, M and Y separations is halftoned. The third image that was halftoned has 40%, 50% and 60% coverage in its C, M and Y separations. Please have a look at the Proceedings CD for seeing Figures 2, 3 and 4 in colour. One of the first notable aspects about these images is that in Figures 2b, 3b and 4b we actually prevented many (in two cases all) of the dots in different separations from being placed on top of the dots in the other separations. Tables 1, 2 and 3 show the ratio of the number of the dots in different separations that are placed on top of each other to the maximum number of the dots that can be placed on top of each other for our three examples, respectively. For example the number of the dots in Cyan and Magenta separations of Fig. 3a that are placed on top of each other is 1345. The maximum number of the dots in Cyan and Magenta separations that can be placed on top of each other is 0.2*150*150 (150 x 150 is the size of the images). Therefore, the ratio will be 29.9%.

Table 1. The ratio (in percent) of the number of the dots in images shown in Fig. 2 that are placed on top of each other to the maximum number of the dots that can be placed on top of each other.

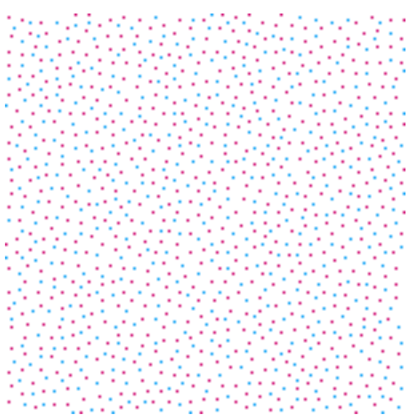
	Independent	dependent
C & M	3.8	0

Table 2. The ratio (in percent) of the number of the dots in images shown in Fig. 3 that are placed on top of each other to the maximum number of the dots that can be placed on top of each other.

	Independent	dependent
C & M	29.9	0
C & Y	41	0
M & Y	40.7	0
C & M &Y	12.5	0

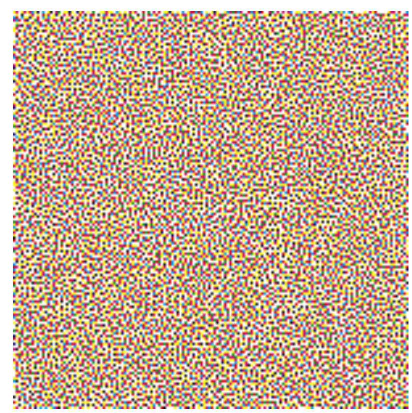


a

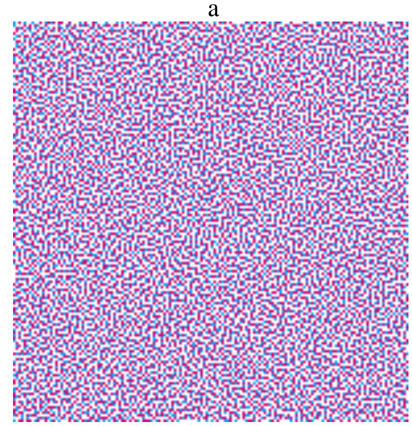


b

*Figure 2. A colour image with 2% and 3% and 0% coverage in its C, M and Y separations is halftoned with Near-optimal halftoning. In **a** the separations are halftoned independently. In **b** the separations are halftoned dependently as explained in the text.*



a

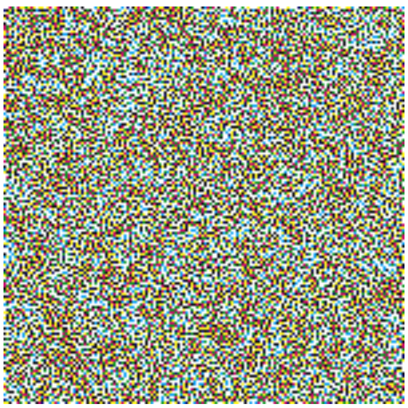


b

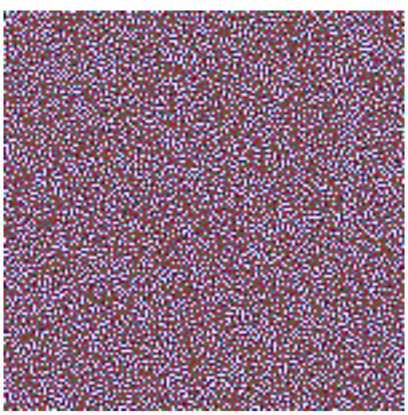
*Figure 3. A colour image with 20% and 30% and 40% coverage in its C, M and Y separations is halftoned with Near-optimal halftoning. In **a** the separations are halftoned independently. In **b** the separations are halftoned dependently as explained in the text.*

Table 3. The ratio (in percent) of the number of the dots in images shown in Fig. 4 that are placed on top of each other to the maximum number of the dots that can be placed on top of each other.

	Independent	dependent
C & M	49.8	34
C & Y	60	40.43
M & Y	60.18	40.42
C & M &Y	30.1	0



a



b

*Figure 4. A colour image with 40% and 50% and 60% coverage in its C, M and Y separations is halftoned with Near-optimal halftoning. In **a** the separations are halftoned independently. In **b** the separations are halftoned dependently as explained in the text.*

This type of dot placement, which is called negatively correlated dot placement or dot-off-dot, yields a larger colour gamut compared to the dot-on-dot case.[9,14]

Dot Gain

One of the most important concerns in the process of printing is how to deal with dot gain. While it is sometimes regarded as an unwanted distortion it can also be seen as a possibility of producing more grey levels in the monochromatic printing.[15] It has also been shown that a large dot gain expands the colour gamut quite considerably in halftone colour reproduction.[16] The effect of dot gain is normally taken into account before the halftoning process is applied. Due to the sequential rendering nature of the algorithm presented in this paper, this effect can be taken into consideration within the algorithm by using proper models for physical and optical dot gain.[8,13] The dot gain models are applied when a dot is rendered and before the feedback process is performed, see Figure 5. The image after the application of the dot gain models should represent the image that would be obtained if we had printed the halftoned image on a substrate and viewed it. The physical dot gain model is dependent e.g. on the printer and the paper or the substrate. The optical dot gain model can be designed by studying the diffusion of light within the substrate.

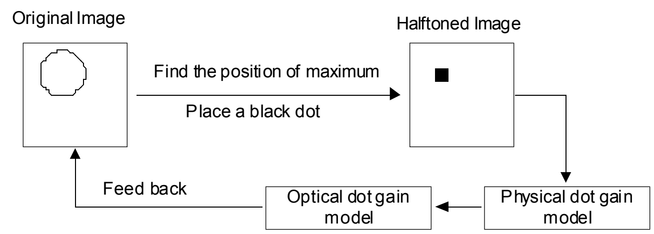


Figure 5. The physical and optical dot gain models are used within the Near-optimal halftoning. The image achieved after applying the models to the halftoned image should represent the image that would be obtained if we had printed the halftoned image on a substrate and viewed it.

Nothing prevents us from utilising the advantage of considering the effect of dot gain within the process of halftoning in our colour halftoning method as well. The principle is almost the same as before. The model for physical dot gain can most probably be the same for all separations. The model for optical dot gain on the other hand is dependent on the wavelength. Therefore different optical dot gain models should be used for different separations.

Conclusions

An extension of *Near-optimal halftoning* is explained in this paper. The extended algorithm is called *Near-optimal colour halftoning* and halftones the separations of the colour image dependently. By using a properly designed distribution function we can control the dot placement in all separations in relation to that in the others. Three examples are given to illustrate that a detailed control of the dot placement in each colour plane in relation to that in the other planes can lead to results of high quality.

The effect of physical and optical dot gain can also be taken into account within the process of this halftoning method.

Future Works

It should be thoroughly investigated how to design the distribution function used in the algorithm. More experiments should be done on different colour images.

The optical and physical dot gain models that are going to be used within the algorithm should be closely investigated and tested.

Other possible ways of extending *Near-optimal halftoning* should be considered and examined.

Acknowledgements

I would like to thank Prof. Björn Kruse for his help and valuable comments and the Swedish forest industry research foundation for generous funding.

References

1. R. A. Ulichney, *Digital Halftoning*, MIT Press, 1987.
2. R. W. Floyd and L. Steinberg, *Adaptive algorithm for spatial grey scale*, Proc. SID, Vol. 17/2, 1976, pp. 36-37.
3. D. Anastassiou and S. Kollas, Visual Commun. Image Proc. 1001, (1988) 1062.
4. M. Broja, F. Wyrowski and O. Bryngdahl, Optics Comm. 69, (1989) 205.
5. M. Analoui and J. P. Allebach, *Model-based Halftoning using Direct Binary Search*, Proceedings of the 1992 SPIE/IS&T Symposium on Electronic Imaging Science and Technology, Vol. 1666, San Jose, CA, 1992, pp. 96-108.
6. F. Nilsson, *Pre-computed frequency modulated halftoning maps that meet the continuity criterion*, Proceedings of the IS&T International Conference on Digital Printing Technologies (NIP12), 1996, pp. 72-77.
7. S. Gooran, M. Österberg and B. Kruse, *Hybrid halftoning – A Novel Algorithm for Using Multiple Halftoning Technologies*, Proc. IS&T Int. Conf. On Digital Printing Technologies (NIP12), Oct. 1996, pp. 79-86.
8. S. Gooran and B. Kruse, *Near-optimal model-based halftoning technique with dot gain*, SPIE, Human Vision and Digital Display III, San Jose, Jan. 1998.
9. S. Gustavson, *The colour Gamut of Halftone Reproduction*, Proc. IS&T Int. Conf. On Digital Printing Technologies (NIP12), Oct. 1996, pp. 111-116.
10. J. R. Sullivan, R. L. Miller, T. J. Wetzel (inventors), *Colour Digital Halftoning with Vector Error Diffusion*, US Patent 5 070 413, issued Dec 3rd, 1991, filed Oct. 10, 1989.
11. V. Ostromoukhov, P. Emmel, N. Rudaz, I. Amidror and R. D. Hersch, *Mutli-Level Colour Halftoning Algorithms*, Int. Symposium on Advanced Imaging and Network Technologies, Conf. on Imaging Sciences and Display Technologies, Oct. 96, Berlin, SPIE Vol. 2949, 332-340.
12. M. Yao, K. J. Parker, *Color Halftoning with Blue Noise Masks*, Proc. IS&T Int. Conf. On Digital Printing Technologies (NIP11), 1995, pp. 466-468.
13. S. Gooran, *Hybrid and Frequency Modulated Halftoning*, Thesis LIU-TEK-LIC-1998: 61, Linköping Studies in Science and Technology, 1998, ISBN: 91-7219-307-7.
14. C. M. Hains, *The Influence of Halftone Orientation on Colour Gamut and Registration Sensitivity*, Proceedings of IS&T's 46th Annual Conference, Cambridge, May 1993.
15. T. N. Pappas and D. L. Neuhoff, *Model-based Halftoning*, Proceedings of SPIE, Human Vision, Visual Proc., Digital Display II, San Jose, CA, Vol. 1453, Feb. 1991, pp. 244-255.
16. S. Gustavson, *Dot Gain in Colour Halftones*, Dissertation No. 492, Linköping Studies in Science and Technology, Sept. 1997, ISBN: 91-7871-981-X.

Biography

Sasan Gooran received his MSc degree in Computer Science and Engineering from Linköping University, Sweden, in 1994. Since then and until November 1998, he was a Ph.D. student of the Image Processing Lab at the same university. Since he received his Licentiate degree in November 1998, he has been a Ph.D. student of the Department of Science and Technology, in the group of Media Technology, at Linköping University. His licentiate thesis is titled Hybrid and Frequency Modulated Halftoning.