Improved Color Error Diffusion

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Abstract

We present a novel error-diffusion technique for halftoning color-separated images. The method correlates the different ink planes in a pixelwise manner and minimizes the overlap of dots from different colors to optimize the color halftone with respect to graininess.

It is a two-step error diffusion: in a first step it is determined how many ink drops should be placed at a particular pixel without specifying the color of these drops. In a second step the color of these ink drops is determined.

Introduction

Error diffusion is a well-established halftoning technique, especially fit for printers that are able to produce dispersed dots, like inkjet printers. The error-diffusion algorithm consists of quantizing a modified pixel value and diffusing the thus made quantization error to neighboring, yet unprocessed pixels. The modified pixel value is the original pixel value + the error collected from pixels processed earlier on. The feedback of the quantization error guarantees a correct average tint.[1]

Error diffusion algorithms exist for both gray-level images and color images. The simplest way to extend the algorithm from gray scale to color is to perform the gray-scale algorithm independently on each color plane of the color-separated image (e.g. Cyan, Magenta, Yellow for a 3-ink device or Cyan, Magenta, Yellow, Black for a 4-ink device). This technique gives us no control on the overlap of dots of the different colors. Controlling the overlap is important to improve the visual quality of the halftone. Supposing an ideal spatial distribution of the dots, the visibility of the halftone dot pattern is governed by the contrast of the dots with respect to their surround as well as by the sparseness of the dots [2]. A same tint of light gray can be reproduced by overprinting cyan, magenta, and yellow dots in a sparse configuration, but also by printing the cyan, magenta, and yellow dots in between each other in a less sparse configuration. This last option produces a less grainy and thus more pleasing halftone.

The algorithm presented here minimizes overprinting of dots from different colors. It is inspired by the method of Klassen et al.[3] where a guiding ink-error-diffusion process is used to assist the color-error diffusion. This ink-error diffusion is a bilevel process. In addition, a distorted color space is used for the color-error diffusion. In contrast to the Klassen method, the current method uses a multilevel guiding error-diffusion, which is the total ink-drop count.

Outline of the Method

In short, the present method is a two-step error diffusion. In a first step it is determined how many ink drops should be placed at a particular pixel. In a second step the color of these ink drops is determined. This way of working is schematized in Figure 1.

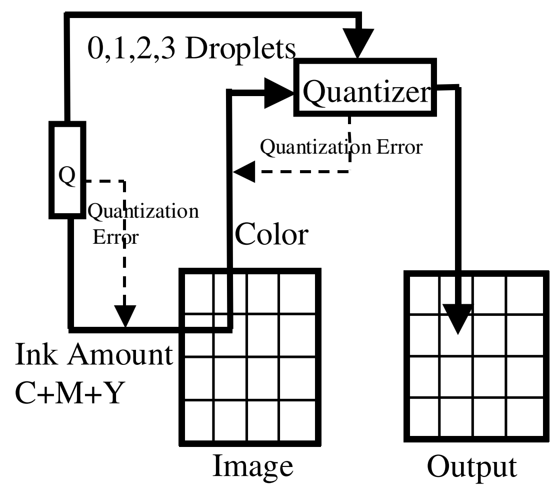

Figure 1. Scheme of the method

For a binary CMY printer we can deposit either 0,1,2,3 ink drops on a pixel. The output total drop count can take on 4 possible values. Therefore we halftone the contone total drop count C+M+Y with a 4-level error-diffusion process. In that way, we determine for each pixel how many drops it will receive, without specifying the exact color of these drops.
Let us denote this quantized total drop count by T.

T=0 means no drop will be printed on the pixel.
T=1 means a drop of C, or M, or Y can be printed.
T=2 means an overprint of CM, CY, or MY.
T=3 means an overprint of CMY.

The color of the drops is then decided by sorting the modified pixel values for C, M, and Y in descending order, and printing a drop of the T inks corresponding to the T largest modified pixel values. This is illustrated in Figure 2.

In the first example of Figure 2, 1 drop of ink needs to be chosen (T=1). Magenta is chosen because it has the largest modified pixel value. When T=2, Magenta and Yellow will be chosen.

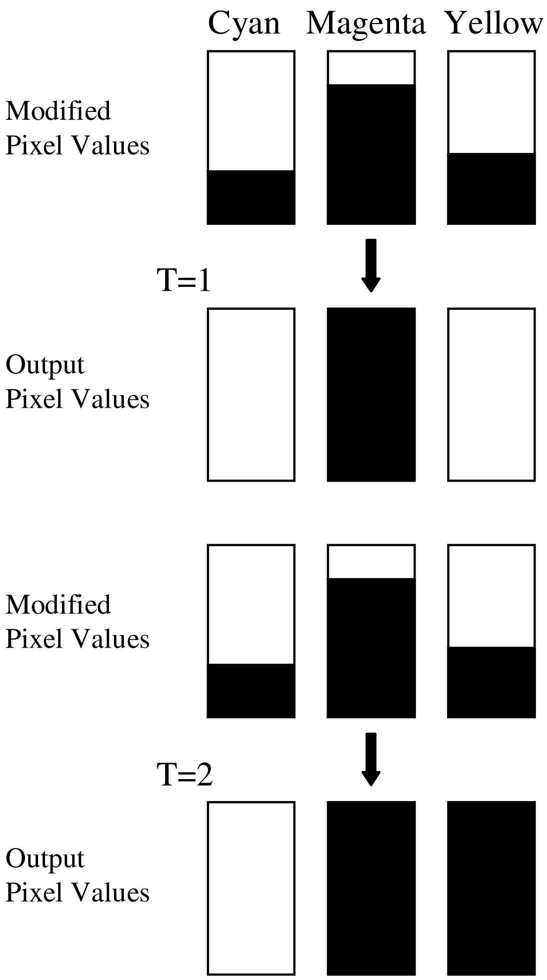

Figure 2. Drop-color decision

It should be clear that the algorithm is not restricted to CMY printing, but can be implemented for any multi-ink printing procedure, from duotones (printing with 2 inks), to 3,4,5,6 and even more inks.

For example in CMYK printing the total drop count C+M+Y+K can take values from 0 to 4 and is halftoned with a 5-level error-diffusion process.
T=0 means no drop will be printed on the pixel
T=1 means a drop of C, or M, or Y, or K can be printed
T=2 means an overprint of CM, CY, MY, CK, MK, or YK.
T=3 means an overprint of CMY, CMK, CYK, or MYK.
T=4 means an overprint of CMYK.

If the ink limit in the separation is set to 300% or less, then a total drop count of 4 will never be selected by the algorithm and a pixel will never receive more than 3 drops of ink. The ink limit is not guaranteed in a pixelwise manner when halftoning the color planes independently, but only in a macroscopic manner.

The inks do not necessarily need to have different colors. The algorithm can be used to print gray-scale images with multiple gray inks of different densities. Also in this case it is advantageous to prevent unnecessary overprinting of dots of the different inks to reduce the graininess of the printed image.

The method can also be extended to multi-level error diffusion for printers capable of recording multi-level images (by using multiple drop-sizes, multiple inks, or a combination of both). As an example we consider a 5-ink printer, with Cyan, Magenta, Yellow, light Cyan, and light Magenta inks. We identify light Cyan with drop count 1 for Cyan, dark Cyan with drop count 2 for Cyan, and the same for Magenta. Cyan and Magenta thus have three drop-count levels {0,1,2} and Yellow takes only two drop-count levels {0,1}. This naturally divides the color cube up into 4 subcubes, as shown in Figure 3. Any point in cube 2 can be mapped onto a point in cube 1, having the same position in cube 1 as it had in cube 2, by subtracting the corner point of cube 2 with smallest total drop count from it. For example, the point (C=1.3,M=0.9,Y=0.7) in cube 2 is mapped to (C=0.3,M=0.9,Y=0.7) in cube 1 by subtracting the point (C=1,M=0,Y=0). The same holds for cubes 3 and 4. By making this subtraction for every color of the input image, we reduce the multi-level case to the binary case discussed above. After quantization, the corner point that was subtracted is added again to produce the correct output.

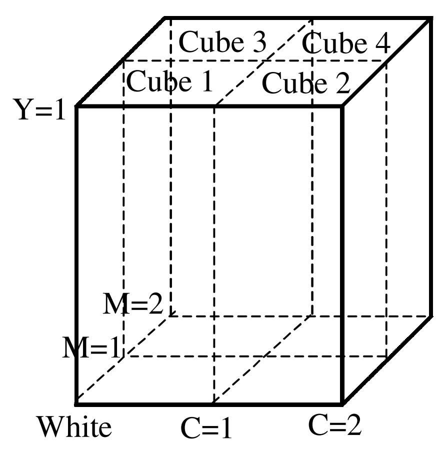

Figure 3. Division of color cube into subcubes

Conclusion

We have outlined a new error-diffusion method for halftoning ink-separated images. The method minimizes overlaps of dots of different inks. This results in less grainy images, compared to halftoning the ink planes independently. An example is shown in Figure 4.

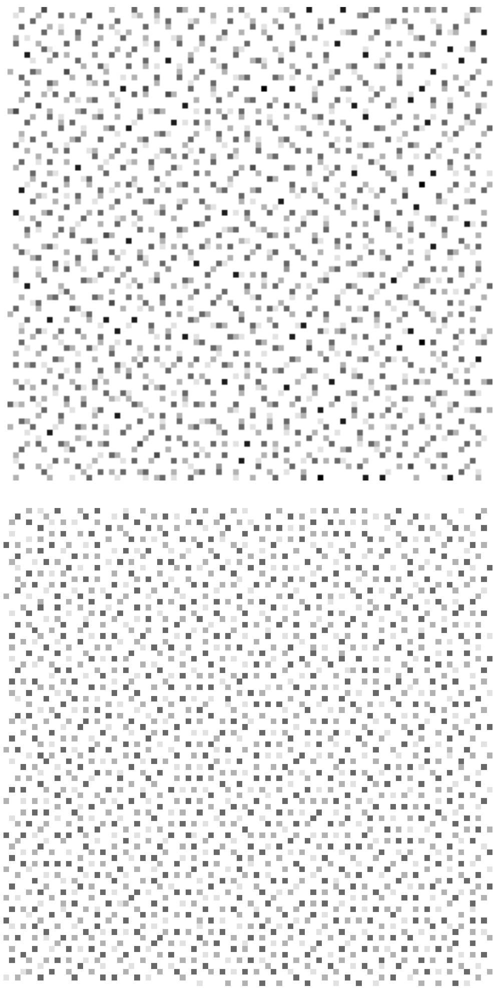

Figure 4. Independent error diffusion (above) versus the improved color error diffusion (below)

References

1. R.W. Floyd and L. Steinberg, *An adaptive algorithm for spatial grey-scale*, Proc. Soc. Inf. Disp. **17**, 75-77 (1976).
2. P.A. Delabastita, L. Minnebo, K. Vande Velde, *Graininess in inkjet printing*, IS&T's PICS2000 conference.
3. R.V. Klassen, R. Eschbach, K. Bharat, *Vector error diffusion in a distorted colour space,* IS&T annual meeting 1994.

Biography

Koen Vande Velde has a PhD in physics and is working as a researcher on image processing at the Research Center for Electronic Imaging of Agfa. His current research is directed towards halftoning and color management for ink-jet devices. Before he joined Agfa in 2000, he was working at the Medical Image Computing group of the Catholic University of Leuven. He has published several patents in the field of digital image processing.

Paul A. Delabastita manages the digital image processing group of the Research Center for Electronic Imaging at Agfa. He developed Agfa's key screening technologies and has published several papers and patents in the field of digital image processing.