

# Linking inkjet printing to a common source

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This study shows how the particular properties of the error-diffusion raster method can be used to link documents to a common digital source. It demonstrates that minimal changes in the electronic source will change the error diffusion dot pattern completely. The error diffusion method is commonly used for inkjet printing.

Keywords: Digital halftoning, dithering

## Introduction

In this paper we will give a short overview of digital halftoning methods that are used by commonly encountered printers in the home and office environment. The impact of minimal changes in the digital source of the printed image on an error diffusion dot pattern is studied with simulations and with an experiment. Finally, the results will be applied to the problem of linking two inkjet printed documents in a case.

## Methods

Most printers create the illusion of a full color (or gray scale) image with a very limited number of colors (or just black) at their disposal. They use a large variety of digital halftoning methods (Kang, 1999) to accomplish this, and the particular method chosen depends on the type of printer (see Figure 1).

The common principle of digital halftoning or dithering methods is that they trade spatial resolution for the illusion (impression) of continuous tones.

These methods can be divided into two main categories:

- threshold array methods
- error diffusion methods

The following discussion of these categories will be limited to grayscale images for clarity's sake, but the extension to full color images is straightforward.

### *Threshold array dithering*

Thresholding an image is the most direct way to convert a continuous tone image to a halftone image, but it completely removes the continuous tone quality of the source image. A much better result can be achieved by threshold array dithering methods. Although implementations vary, the most general way of looking at these methods is to see them as a multiplication with a threshold mask, followed by thresholding. These masks generally consist of a repeating pattern, the unit cells of which are the threshold array, which is carefully chosen to obtain a perceptually pleasing end result. Figure 2 shows a number of possibilities for the threshold arrays, such as:

- (i) noise (the pattern does not repeat itself, this method is computationally intensive and rarely used)
- (ii) a line pattern with a sinusoidal variation in intensity (compare Fig. 1b)
- (iii) a two dimensional sinusoidal pattern (compare Fig. 1a)
- (iv) an 4×4 ordered dither thresholding array (see Fig. 3).

These halftoning methods are commonly used with laser printers. Patterns (ii) and (iii) are sometimes referred to as AM (Amplitude Modulation) techniques, since the frequency of the pattern is fixed but the size or amplitude of its elements varies.

### *Error diffusion halftoning*

Error diffusion methods are commonly used with inkjet printers. They are sometimes referred to as FM (Frequency Modulation) techniques, because in this case the size of the elements (dots) is fixed while their frequency of placement varies.

In error diffusion dithering the first pixel of the image (e.g. in the upper left corner) is approximated by a black or a white pixel. Subsequently, the difference between the original value and the approximation (the error) is diffused to neighboring (following) pixels. The whole procedure is repeated for all the pixels in the image.

For example, if a pixel is dark gray and approximated by a black pixel, neighboring pixels in the source image will be made brighter by a certain fraction of the error made in the approximation (to compensate for the error in the subsequent steps of the procedure). Some possibilities for these fractions are illustrated in Figure 4.

## **Results and discussion**

### *Simulations*

Simulations were carried out on digital images, using Adobe® Photoshop® for halftoning of images with different methods. Then, minimal changes were introduced to the original images, after which once again, images were generated with different dithering methods. Finally it was shown to which extent the dither patterns were influenced by the introduction of minimal changes in the original image.

For threshold array dithering small changes in the original image will usually cause small changes in the result. In Figure 5 some results are shown for error diffusion dithering. In this case even a small change in the source image causes drastic changes in the placement of the dots in the dithered image. This effect is clearly visible in Figure 5d.

### *Experiment*

To verify the results of the simulations, we printed the original image as well as the image with the modified pixel on an inkjet printer (HP DeskJet 895C). The error diffusion dot pattern of the printed image was analyzed, and Figure 6 shows the magenta component of a portion of the right side of the printed image. No significant differences between multiple prints of the same source image are observed. But the dithered version of the slightly modified image (as in Figure 5a) has a different placement of the dots, starting below the ear (much like in the simulation).

## *Case*

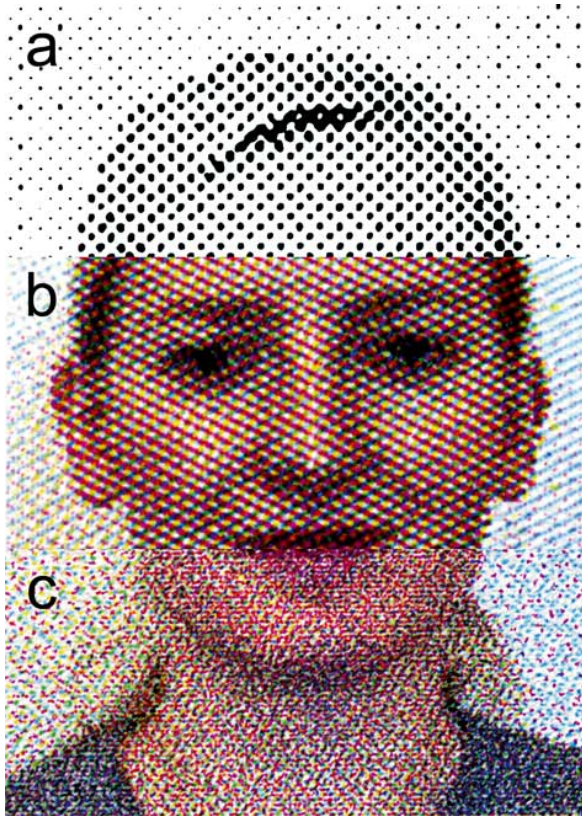
In a so-called rip-deal case, inkjet printed (forged) money had been found at two scenes of shootings. The purpose of the document examination was to see whether the shootings could have been connected by linking the forged money to the same source. No blemishes were found that could have made linking the documents easy. But applying the results of the study in this paper, the details of the dot pattern were studied and they were found to be identical (see Figure 7).

## **Conclusion**

Detailed analysis of an error diffusion inkjet dot pattern can link two prints to a common source because even two images with a minimal difference (one pixel) will generate a different dot pattern. When a different dot pattern is found, the images might still have a common source. For example: for an identical image in an otherwise different word-processing document the dot pattern can be different, even when printing software and hardware are identical.

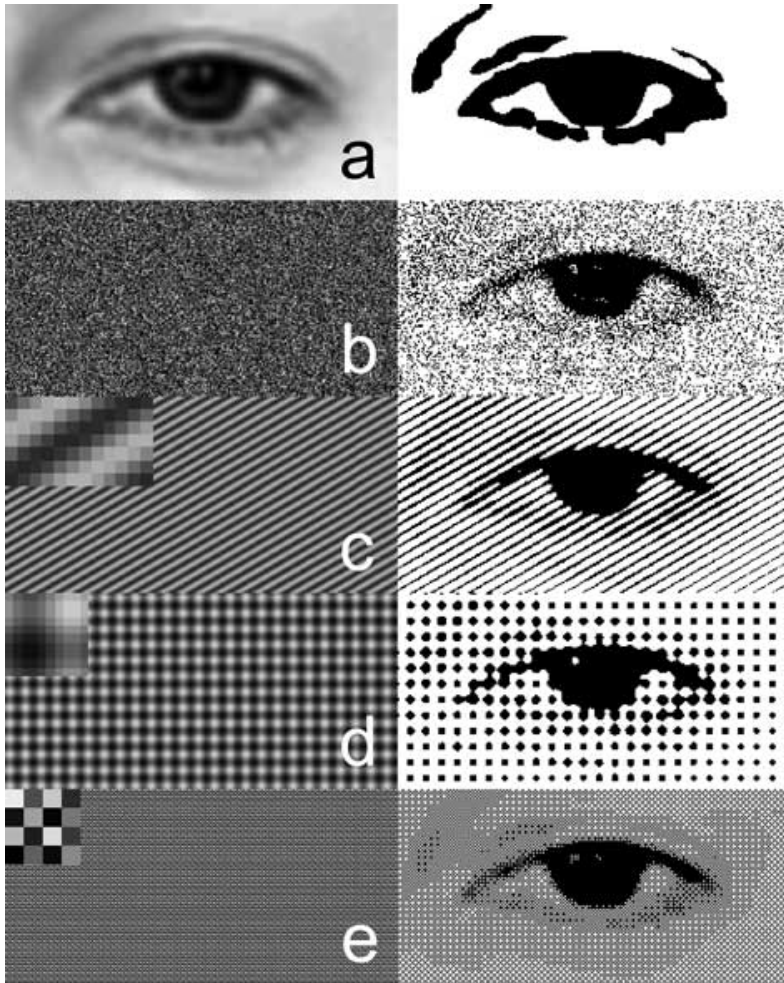
## **References**

Kang, H.R. (1999). *Digital Color Halftoning*, Bellingham, Washington: SPIE Optical Engineering Press.



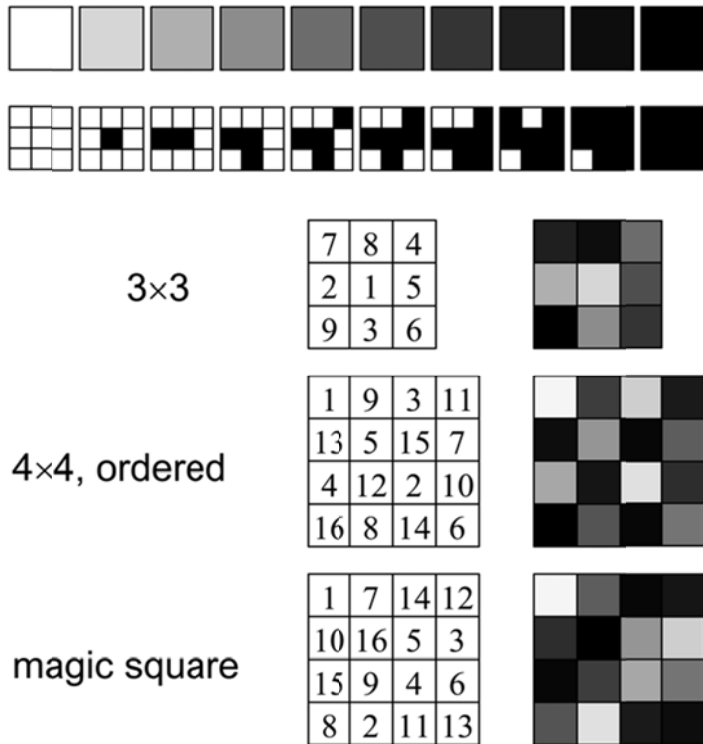
**Figure 1**

Examples of screens encountered in common printers such as (a) black-and-white laser printer (b) color laser printer, and (c) color inkjet printer.



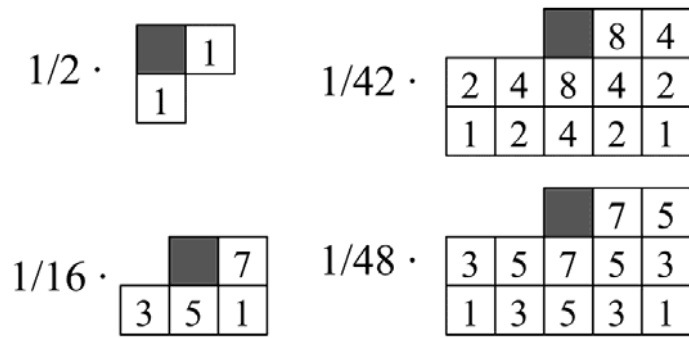
**Figure 2**

The original image (a) is shown together with a thresholded version. The halftone images on the right below this were generated by multiplication with the mask on the left, followed by thresholding. The masks used were: (b) noise, (c) line mask, (d) sine mask, and (e) ordered dither mask (4×4). The unit cells of the masks (threshold arrays) in (c), (d), and (e) are shown in insets on the left.



**Figure 3**

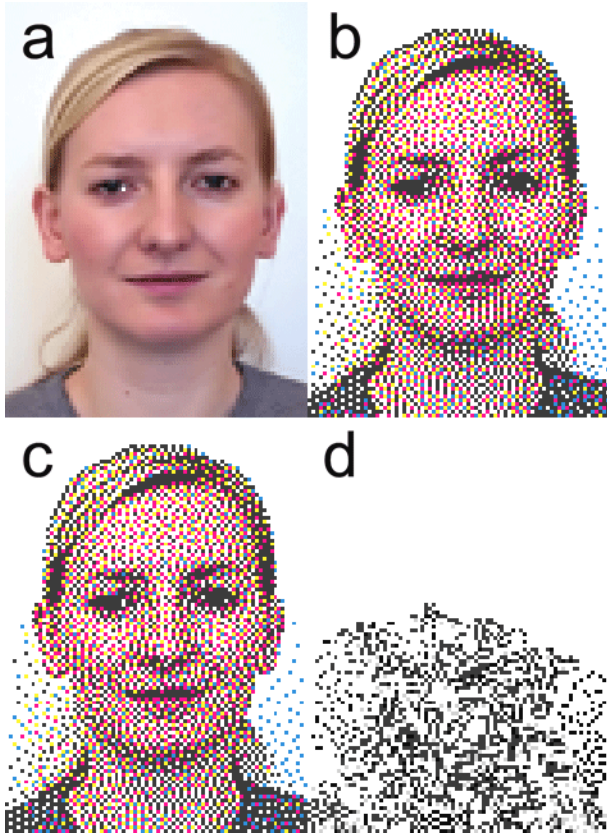
The top part shows how a 3x3 threshold array suggests gray levels by switching pixels on, one by one. The order in which this takes place is shown in numbers as well as gray levels in the matrices in the middle. The latter can be used as the unit cell of the mask to multiply the image with before thresholding. Different sizes and orders can be chosen.



**Figure 4**

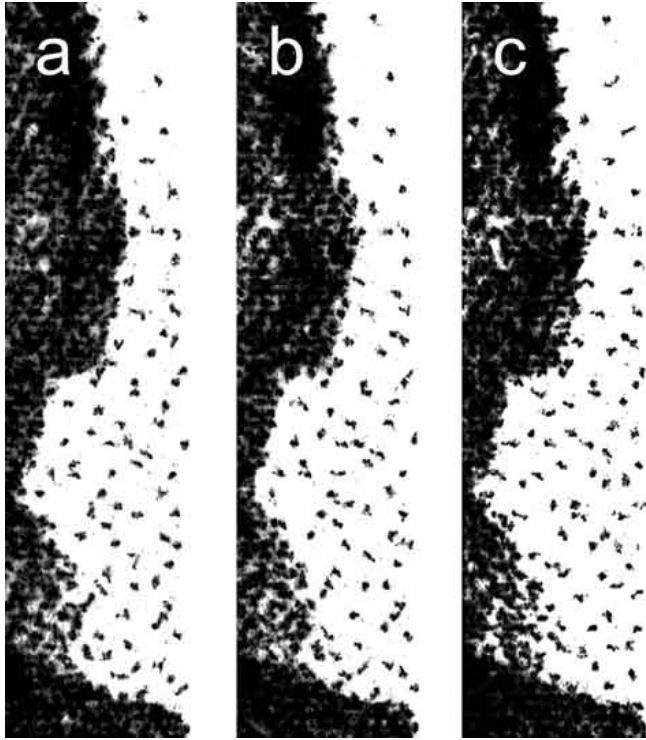
Different schemes for error diffusion, showing how the difference between the intended gray level and its approximation is spread over neighboring pixels for subsequent compensation.





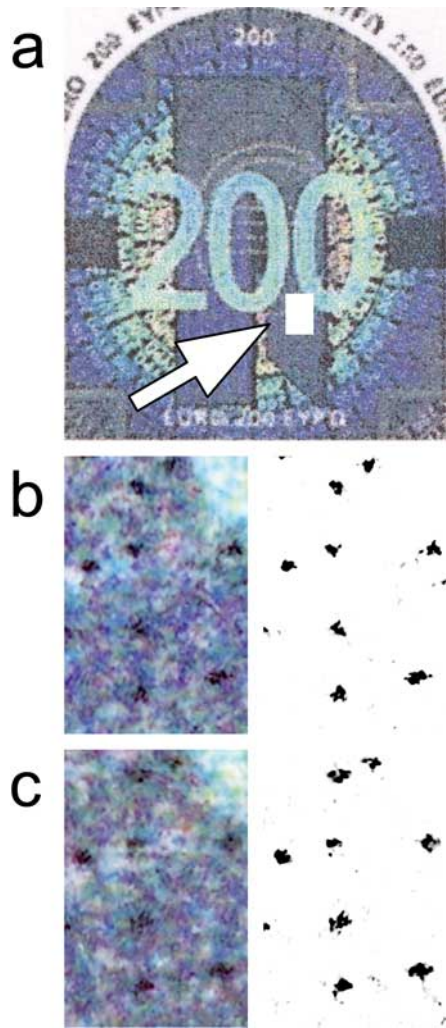
**Figure 5**

Illustration of the impact of a small change in an image on its error diffusion halftone version: (a) original image with 1 pixel in the eye turned to white, (b) halftoned original image, (c) halftoned modified image, and (d) the difference between (b) and (c).



**Figure 6**

Details of the inkjet-printed versions of the original and modified image: (a) and (b) show the magenta dots for 2 prints of the original image, (c) shows the magenta dots for the printed modified image. As in the simulation, differences are apparent in (c) below the ear.



**Figure 7**

An analysis of a detail (a) in the inkjet-printed forgeries showing the same distribution of black dots (b)(c) in the area analyzed.