Error-Diffusion Robust to Mis-Registration in Multi-Pass Printing

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Abstract

Error-diffusion and its variants are commonly used halftoning techniques that produce dispersed dot (FM) halftones, which are often preferred because they are free from low-frequency structure. Since the isolated dots resulting from error diffusion are reproduced well on inkjet printers, error diffusion is commonly employed in these devices. Inkjet printers often print a page in two passes in order to allow for better drying of inks and to minimize appearance of a head signature. Any potential mis-registration between the passes is typically not comprehended in the error-diffusion halftoning process. The mis-registration between the passes can therefore cause significantly increased graininess (low-frequency structure) in printed error diffusion images even though the electronic bitmaps generated by error diffusion are free from low-frequency structure. In this paper, we propose modifications to the error-diffusion halftoning process that take the two pass printing into account and produce halftones that are robust to inter-pass mis-registration errors. This allows reduced tolerances and alignment requirements in manufacturing that translate to lower cost. The proposed technique works by suitably biasing the error diffusion process to ensure that a majority of the minority pixels are concentrated in a single pass, which provides improved robustness to mis-registration between the passes. Experimental results demonstrate that the modified error-diffusion technique performs significantly better than regular error diffusion in the presence of mis-registration errors.

1. Introduction

Error diffusion is an important technique for digital halftoning.[1,2] Error-diffusion and its variants are commonly used halftoning techniques that produce dispersed dot (FM) halftones, which are often preferred because they are free from low-frequency structure. Since the isolated dots resulting from error diffusion are reproduced well on inkjet printers, error diffusion is commonly employed in these devices. Inkjet printers often use a print mode with two passes in order to reduce the visibility of head signature and to allow better drying of inks. The pixels on the page are spatially partitioned into two sets with one set being printed in each pass (often, one pass is printed in the forward direction of head traversal and the other in the reverse direction). For the rest of this paper, the partition is assumed to be a "checker-board" partition, the ideas and algorithms developed are, however, equally applicable to other partitions that may be chosen (for example, an alternate line partition or a stochastic partition). The checkerboard partition, which is commonly used in practice, is shown graphically in Figure 1, where each of the black/white squares correspond to a pixel. The white pixels correspond to one partition, which we will refer to as Partition 1, and the black ones to the other partition, referred to as Partition 2 in this paper.

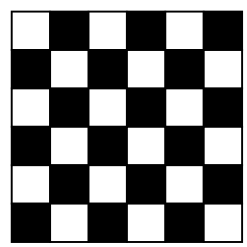

Figure 1. Checkerboard Partition

In printing an image on the page, the printer prints the pixels corresponding to (say) partition 1 in the first pass and to partition 2 in the second pass. If the registration between the passes is perfect, the graininess of the resulting images is largely unchanged in comparison with a printer that prints the entire image in a single pass. However, if there is mis-registration between the two passes, undesired textures may be generated that result in considerably increased graininess in the print. Examples of this problem are demonstrated in Figures 5 and 6. Figure 5 is a halftone image obtained using error-diffusion where there is no mis-registration between the checkerboard partitions and Figure 6 is a simulation of the ($\Delta x = 1$ pixel, $\Delta y = 1$ pixel) mis-regisration. Note the increased graininess and undesirable textures in Figure 6 in comparison to Figure 5.

For the above images, the mis-registration was simulated electronically. In actual inkjet printers, the mis-registration arises from mechanical positioning errors between the two passes. While increased precision in mechanical positioning would mitigate the problem, it could involve significant cost due to the tight tolerances required particularly at high resolutions. If the mis-registration is identical from page to page and over the life of the printer, it can be detected a priori and can be compensated for electronically. However, electronic compensation of each individual printer adds cost to these low-end devices and cannot correct registration errors under half a pixel (without excessive computation).

We propose modifications of the error diffusion to make it more robust to mis-registration between the two passes. The modified error diffusion provides increased robustness to inter-pass registration errors by primarily using the pixels from a single partition for printing in the highlight regions where graininess is the biggest problem. By concentrating the minority black pixels in a single pass, these methods ensure that the gap between these minority pixels is not affected by inter-pass mis-registration errors. For the proposed methods, a similar benefit is also obtained in the shadow regions by similarly ensuring that the minority white pixels are located in a single pass.

This paper is organized as follows. In Section 2, an introduction is presented to error diffusion. Section 3 describes the modified algorithm. Section 4 shows simulation results and a summary is given in Section 5.

2. Error Diffusion

Roughly speaking, error diffusion can be considered as a 2-D extension of sigma-delta modulation. The output of error diffusion is produced by quantizing the modified input, which is defined to be the input signal plus the sum of the weighted past quantization errors.

Let i(m,n) and b(m,n) denote the input and output for error diffusion at pixel (m,n) for a black and white image, respectively. It is assumed that b(m,n) has a binary value of 0 (white) or 1 (black), and i(m,n) has a value in the range of [0,1]. The error diffusion algorithm can be characterized by the following steps:

$$i^*(m,n) = i(m,n) + \Sigma_{s,t}\, e(m-s,n-t) \times a(s,t) \qquad (1)$$

$$b(m,n) = Q[i^*(m,n)] \qquad (2)$$

$$e(m,n) = i^*(m,n) - b(m,n), \qquad (3)$$

where $i^*(m,n)$ is the modified input, Q[.] is the quantization operation, e(m,n) is the quantization error, a(s, t) is the weight for error propagation in the (s, t) direction, and the summation in (1) is computed over a suitably defined causal neighborhood. The first step given in (1) calculates the modified input as the sum of the input and the errors diffused from neighboring pixels. In the second step, the output is produced by quantizing the modified input. Specifically, the output is set to 1 or 0, depending on whether the modified input is greater or less than 0.5. The quantization error is evaluated in the third step as the difference between the output and the modified input.

For color images, variables i(m,n), $i^*(m,n)$, b(m,n) and e(m,n) in equations (1)-(3) become vectors. In addition, there are a number of variations in the quantization step. A scalar quantization performs thresholding on each color component. On the contrary, a vector quantization considers the vector as a whole in decision making.[3-6]

3. Proposed Algorithm

We propose modifications of the error diffusion algorithm to make it more robust to mis-registration between the two passes. The basic principle for maximized robustness is what we call "**minority concentration**". Specifically, all the black pixels in highlights are printed in one partition, say Partition 1, and all the white pixels in shadows are assigned to another partition (Partition 2).

The features and advantages of the above scheme are:

1. For uniform (or slowly varying) regions where input $\leq$ 0.5, all the black pixels are located in Partition 1. Entire Partition 2 is white. As a result, there are no mis-registration artifacts as shown in Figure 2.
2. When the input reaches 0.5, the entire Partition 1 is black, and the entire Partition 2 is white. The combined output is a checkerboard.
3. When input exceeds 0.5, Partition 1 remains black. Partition starts to have black pixels. The combined image is a checkerboard with some of the while holes filled (Figure 3). Mis-registration does not produce significant texture changes. However, it may introduce a reduced density, since mis-alignment may cause black pixels in Partition 1 and Partition 2 overlapping. Nevertheless, considering the dot gain, the actual density reduction may not be very severe.

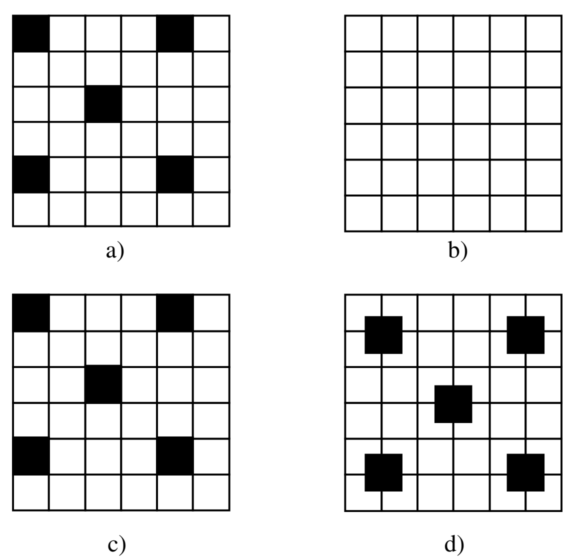

Figure 2. Output of proposed method for Input < 0.5. a) Partition 1; b) Partition 2; c) Combined output with no mis-registration; d) Combined output with mis-registration of (Δx = 0.5, Δy = 0.5)

This objective of minority concentration can be achieved by many different methods. A simple scheme is to add a bi-level zero mean bias "image" signal which takes a positive value +D over one partition and a negative value –D over the other partition to either the threshold or the input image. For the case of the common checker-board partition shown in Figure 1, this "image" signal is shown graphically in Figure 4. The addition of this signal to the input image to be halftoned causes the minority pixels in the highlights and the shadows to be localized to a single one of the partitions. Since the added "image" signal is zero mean, the added signal does not influence the overall controls the degree to which the minority pixels are coerced towards a single partition. Empirically, a value of D between 1/8 and 1/4 was found to provide satisfactory results when added to the input image. As an alternate scheme, the spatially varying bias may be added to the thresholds in the quantization process. Visually, there are no noticeable differences in image quality whether the bias is added to the input or to the threshhold.

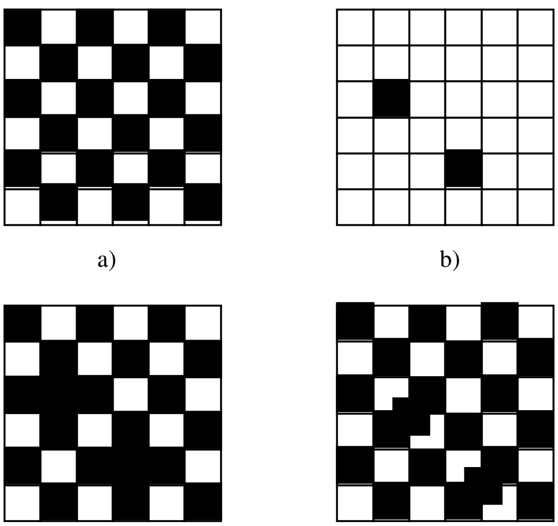

Figure 3. Output of proposed method for Input > 0.5. a) Partition 1; b) Partition 2; c) Combined output with no mis-registration; d) Combined output with mis-registration of (Δx = 1, Δy = 1)

+D	-D	+D	-D	+D	-D
-D	+D	-D	+D	-D	+D
+D	-D	+D	-D	+D	-D
-D	+D	-D	+D	-D	+D
+D	-D	+D	-D	+D	-D
-D	+D	-D	+D	-D	+D

Figure 4. Image signal added to input image for error diffusion robust to inter-pass registration.

The techniques can also be extended to the printing of color images. If the bias image is added to the input, no modification of the algorithm is needed. The identical bias image may be applied to three color channels. On the other hand, if the bias is introduced to the thresholds, modification may be needed, depending on the quantization algorithms used. For scalar quantization, the technique can be directly applied on a separation by separation basis. For vector quantization or its variations[3-6] a simple modification of the quantization step is required.

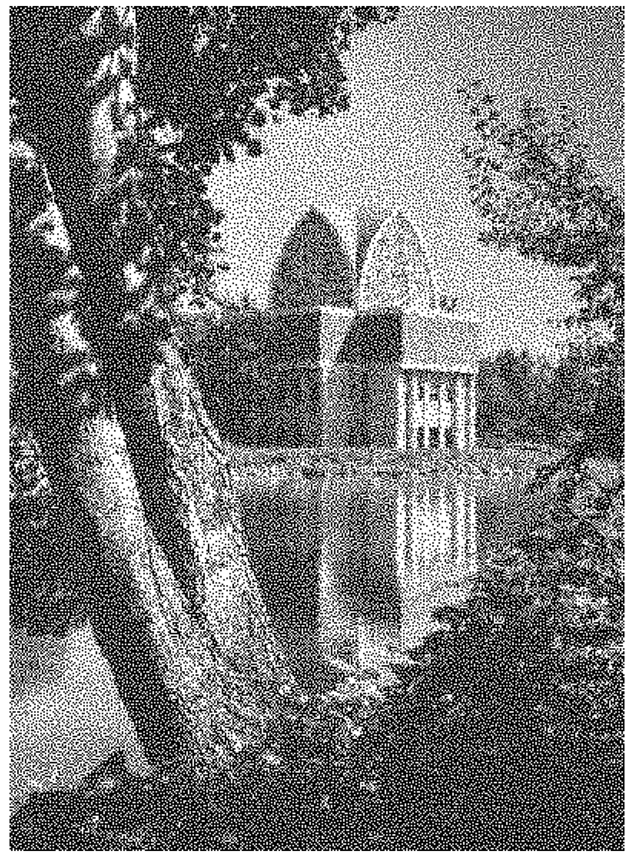

Figure 5. Conventional method with no mis-registration.

4. Simulation

The results of using the above mentioned modified error diffusion method are demonstrated in Figures 5-8. Figure 7 shows the halftone image obtained with the modified error diffusion method described above for the case of no inter-pass mis-registration and Figure 8 shows the corresponding image for a simulated mis-registration of (Δx = 1, Δy = 1). Note that increase in image graininess as from Figure 7 to Figure 8 (if any) is much smaller than the drastic increase in graininess seen from Figure 5 to Figure 6 for conventional error diffusion. This clearly demonstrates that the modified error diffusion method of this paper is significantly more robust to inter-pass mis-registration than conventional error diffusion. Similar results can be found for other mis-registration values.

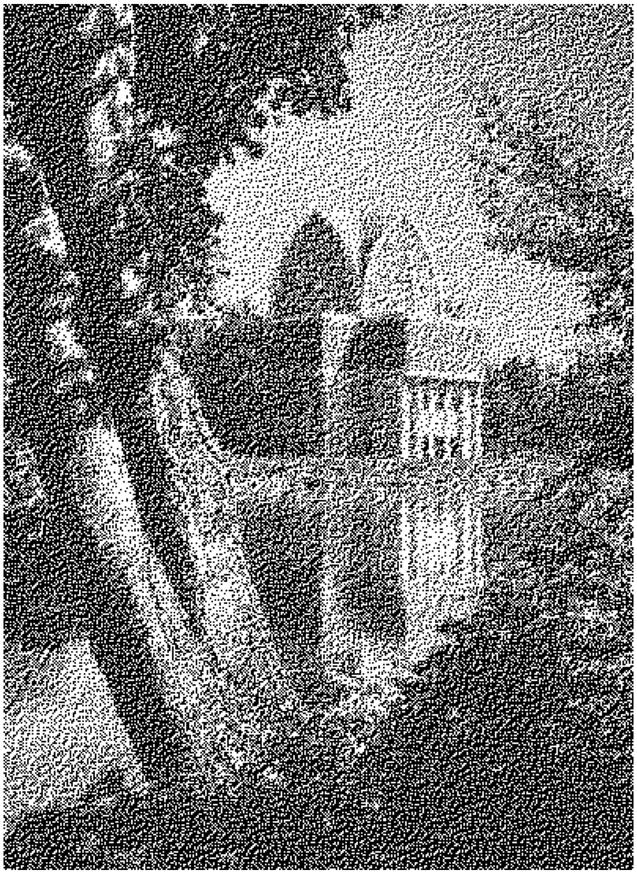

Figure 6. Conventional method with mis-registration of ($\Delta x = 1$, $\Delta y = 1$).

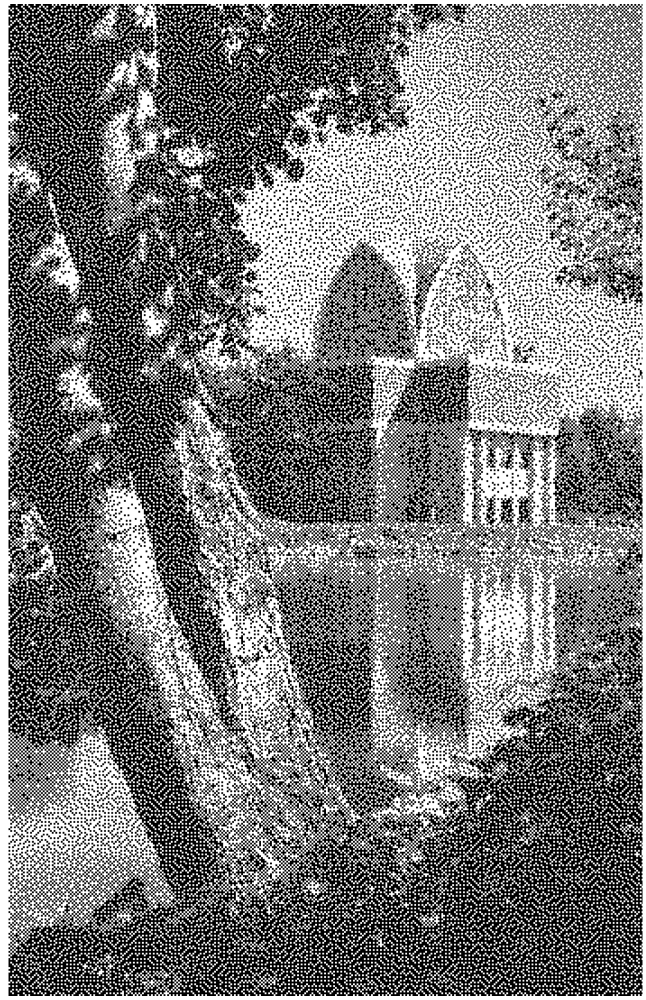

Figure 7. Proposed method with no mis-registration.

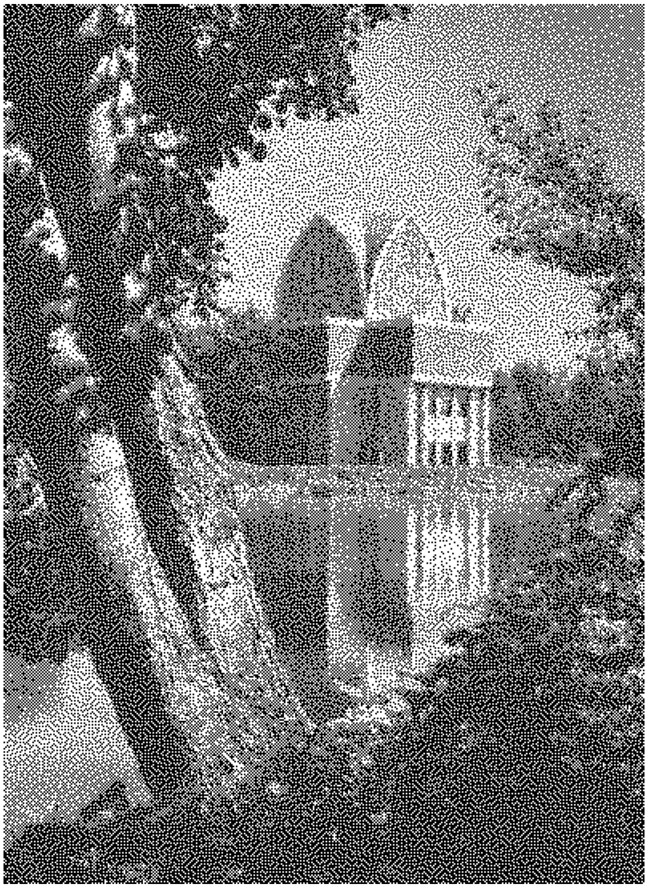

Figure 8. Proposed method with mis-registration of (Δx=1, Δy=1).

References

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