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Cluster-Dot Halftoning based on the Error Diffusion with no Directional Characteristic

Hidemasa Nakai and Koji Nakano *

Abstract —**Digital halftoning is a process to convert a continuous-tone image into a binary image with black and white dots. This process is necessary to print a continuous-tone image using printers. The Error Diffusion is one of the most popular methods of digital halftoning, because it can generates high quality output images with relatively low computing time. Binary images generated by the Error Diffusion are fine grained in the sense that they have a lot of isolated small black and white dots. However, fine binary images are not appropriate for practical printing, because isolated black and white dots may disappear by dot-gain or dot-loss. Hence cluster-dot halftoning, which generates binary images has no isolated black and white dots are important. It is known that the Error Diffusion with some feedback operation can generate clustered-dot binary images. However, the resulting binary images have strong directional characteristic, which spoils the printing results. The main contribution of this paper is to presents new filters of the Error Diffusion for cluster-dot halftoning with no directional characteristic. Quite surprisingly, it can generate cluster-dot binary images with no directional characteristic using our new filter. Also, the size of cluster can be adjusted by an additional feedback operation. The experimental results show that the Error Diffusion using our new filter can generate better quality binary images than the previously published know results.**
Keywords: Digital halftoning, Error Diffusion, Cluster-dot, Green-noise halftoning

1 Introduction

A gray scale image is a two dimensional matrix of pixels taking a real number in the range $[0, 1]$. Usually a gray scale image has 8-bit depth, that is, each pixel takes one of the real numbers $\frac{0}{255}, \frac{1}{255}, \ldots, \frac{255}{255}$, which correspond to pixel intensities. *A binary image* is also a two dimensional matrix of pixels taking a binary value 0 (black) or 1(white). *Halftoning* is an important process to convert a gray scale image into a binary image [1, 2, 3]. This process is necessary when a monochrome or color image is printed by a printer with limited number of ink colors.

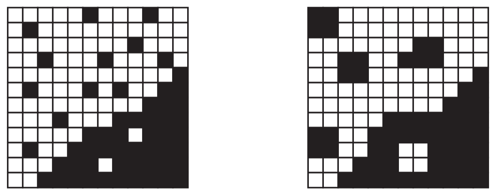

Figure 1: The binary images generated by regular halftoning and cluster-dot halftoning

One of the most popular halftoning algorithms is Error Diffusion [4] that propagates quantize errors to unprocessed neighboring pixels according to some fixed ratios. The Error Diffusion preserves the average intensity level between the original input image and the binary output image. Further, the Error Diffusion produces good halftone images despite relatively low cost. However, since the Error Diffusion may generate worm artifacts especially in the image areas of flat intensity, various modification are proposed [5, 6, 7].

When we print digital images using printers, *dot-gain* and *dot-loss* are very important issue that we need to consider. In ink-jet printers, a small isolated black dot (pixel) gains a lot by the ink blur (i.e. dot-gain), and isolated white dots may also disappear. In laser printers, small isolated black dots may not be printed because toner is not transfered for minimum-size dot (i.e. dot-loss). Therefore, it is desirable that dots in a binary image are *clustered*, that is, it has no isolated pixels and two or more same pixels with the same color are adjacent [8] as illustrated in Figure 1.

Although the Error Diffusion generates good halftone images, they have many isolated dots and it has no tolerance both for dot-gain and for dot-loss. There are several previously published works for cluster-dot halftoning based on the Error Diffusion technique. Levien [9] developed *Error Diffusion with Output Dependent Feedback* (EDODF), Velho and Gomez [10] are using halftoning on space filling curves. In particular, the EDODF, which is one of the most popular algorithms in cluster-dot Er-

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ror Diffusion, modifies the threshold process based on the output at previous locations. However, the EDODF generates structured worm-like artifacts in midtones and has strong directional characteristics.

The main contribution of this paper is to propose a new cluster-dot Error Diffusion using a *cluster-dot error filter*. The filter does not diffuse the quantization error to neighboring pixels and decide the filter weights by experimental evaluation. Quite surprisingly, it can generate cluster-dot halftone images using our new filter instead of the Floyd and Steinberg filter. Since we just use new filters for the Error Diffusion, our halftoning algorithm is simple and low computational complexity. Also, the size of cluster can be adjusted by the feedback operation. The experimental results show that the Error Diffusion using our new filter can generate better quality binary images with no directional characteristics than the EDODF.

2 Error Diffusion and EDODF

The main purpose of this section is to review the Error Diffusion method [4], and the Error Diffusion with Output Dependent Feedback (EDODF) [9]. A gray scale image $G = g(i,j)$ is an $N \times N$ two dimensional matrix of pixels taking real intensities number in the range $[0,1]$ $(0 \leq i,j \leq N-1)$. For simplicity, we assume that images in this paper is square. A binary image $B = b(i,j)$ is the two dimensional matrix of pixels taking a binary value 0 (black) or 1 (white). The Error Diffusion algorithm is designed to preserve the average intensity level between input and output images by propagating the quantization errors to unprocessed neighboring pixels according to some fixed ratios.

In the Error Diffusion algorithm, the pixel values $b(i,j)$ of binary image is determined in raster scan order (Figure 5 (a)). The value of $b(i,j)$ is determined by simply thresholding as follows:

$$b(i,j) = \begin{cases} 1 & \text{if } g(i,j) > \frac{1}{2}, \\ 0 & \text{if } g(i,j) \leq \frac{1}{2}. \end{cases} \tag{1}$$

Clearly, the quantizer error $e(i,j)$ is computed by

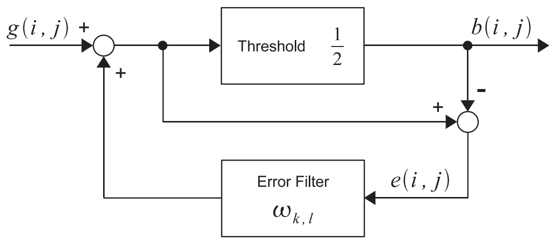
$$e(i,j) = g(i,j) - b(i,j). \tag{2}$$

Note that the Error Diffusion select the pixel values of binary image which minimize the absolute value of error $|e(i,j)|$. We then distributed the weighted error to a set of unprocessed pixels.

$$g(i+k, j+l) \quad \leftarrow \quad g(i+k, j+l) + \omega_{k,l} \cdot e(i,j), \tag{3}$$

where $\omega_{k,l}$ is the the error filter.

Figure 2 shows the block diagram of the Error Diffusion algorithm and the Floyd and Steinberg error filter.



	●	7/16
3/16	5/16	1/16

Figure 2: The block diagram of the Error Diffusion and its error filter

Levien [9] developed the EDODF that modifies the threshold based on the output at previous locations. This feedback encourages the output at the current location to be the same as the outputs at past locations. Equivalently, this method can be realized by modifying the quantization process in the conventional Error Diffusion as follows:

$$b(i,j) = \begin{cases} 1 & \text{if } g(i,j) + h(i,j) > \frac{1}{2}, \\ 0 & \text{if } g(i,j) + h(i,j) \leq \frac{1}{2}. \end{cases} \tag{4}$$

The output feedback $h(i,j)$ can be represented as

$$h(i,j) = H \cdot \sum_{p,q} \eta_{p,q} \cdot b(i-p, j-q), \tag{5}$$

where H is the *hysteresis constant*, and $\eta_{p,q}$ is the hysteresis weights filter. Large values of H leads to larger clusters. Figure 3 shows the block diagram of the EDODF and its error filter.

3 Our New Cluster-Dot Error Filters

This section is devoted to show our new cluster-dot Error Diffusion. The key idea of our Error Diffusion based halftoning method is using the *cluster-dot error filter*. Conventional error filters distribute the quantization error to neighboring pixels (Figure 4 (a)). On the other hand, cluster-dot error filter does not distribute the quantization error to neighboring pixels (Figure 4 (b)). Neighboring pixels have the nearly intensity level with the current pixel intensity level. Therefore, neighboring pixels may be quantized to the same color with the current pixel as the quantization error is not distributed.

In our cluster-dot Error Diffusion, the error filter in Figure 6 (a) is used for the conventional Error Diffusion. Sometimes, the resulting binary image by just using our error filter in Figure 6 (b) is sufficient. Also, if we need to adjust the size of cluster dots, we use the error filter

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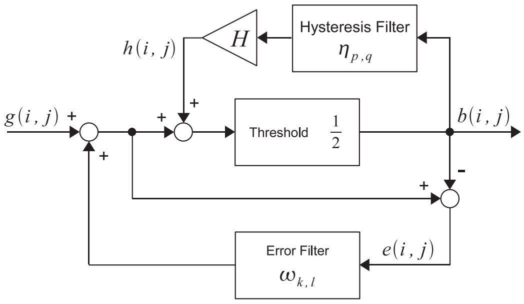
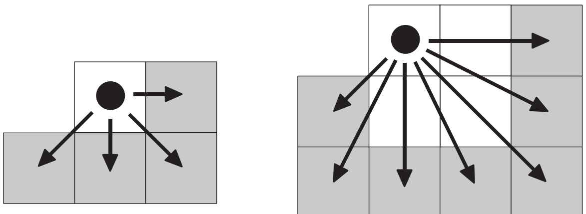


hysteresis

	1/16	5/16	3/16	
	7/16	●	8/42	4/42
2/42	4/42	8/42	4/42	2/42
1/42	2/42	4/42	2/42	1/42

error

Figure 3: The block diagram of the EDODF and its error filter



(a) Conventional error filter

(b) Cluster-dot error filter

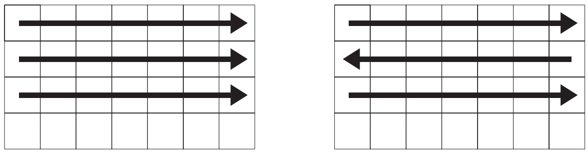
Figure 4: Conventional and cluster-dot error filters

with feedback in Figure 6 (b). By adjusting the hysteresis coefficient H, we can change the size of cluster dots. We also use a serpentine scan illustrated in Figure 5 (b), which can generate better quality of binary images.

We discuss how we find a new cluster-dot error filter illustrated in Figure 6. We have three important points to design this filter that we have considered as follows:

1. No error diffuse area
   The filter does not distribute 2×2 area including the current pixel (indicated by $\bullet$). The size of this area can affect the cluster-dot size of the halftone images directly. However, when the area is larger than 2×2, the halftoning decrease the image quality due to increasing the isolation dots. Therefore, we decide the size of this area to 2×2.

2. Symmetric error filter weights
   We divide the cluster-dot error filter in five areas which is illustrated by bold lines in Figure 6 (a). The sums of the error weights in the left-bottom and in the right-bottom area are equal. The sums of the error weights of the bottom and right area are also equal, because, if the two sums are not equal, then the resulting binary images will have artifacts.



(a) raster scan

(b) serpentine scan

Figure 5: Two commonly used scanning path for the Error Diffusion

		●	0	6/64	4/64
1/64	6/64	0	0	5/64	3/64
	4/64	7/64	3/64	5/64	3/64
	3/64	5/64	3/64	4/64	2/64

(a) cluster-dot error filter

hysteresis

	1/16	5/16	3/16		
	7/16	●	0	6/64	4/64
1/64	6/64	0	0	5/64	3/64
	4/64	7/64	3/64	5/64	3/64
	3/64	5/64	3/64	4/64	2/64

error

(b) cluster-dot error filter with feedbacks

Figure 6: Our new cluster-dot error filter

3. Ratio of the error filter weights
   We also consider the ratios of the five areas in cluster-dot error filter illustrated by bold lines. The ratio of sum of the error weights between right area and bottom area is $9 : 7$. This ratio can affect the form of the cluster-dot. Figure 7 shows examples of various halftone images by the difference of the ratio. (top) is $ratio = 2 : 1$. The cluster-dots forms diagonal clusters. (bottom) is $ratio = 1 : 1$. The image appear the artifact in the midtone. (middle) is $ratio = 4 : 3$. The experiment shows that this ratio $4 : 3$ can generate the best halftone images. To reduce the computational complexity, the weighs of the filter are denominated by a power of two numbers, because the division by a power of two can be simply implemented by the bit shift operation. Thus, we construct our cluster-dot error filter such that their elements are multiple of $\frac{1}{64}$, and the ratio is $9 : 7$ which is close to $4 : 3$.

4 Experimental Results

This section shows the experimental results of our new error diffusion filter and compares the resulting images with binary images obtained by the EDODF.

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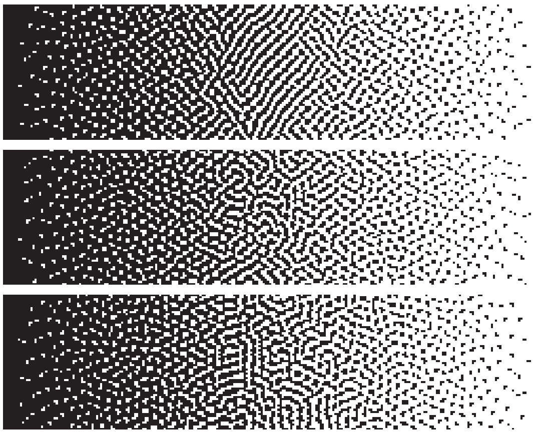

Figure 7: Variation the output images: (top) the weights ratio is 2 : 1, (middle) the weights ratio is 4 : 3, and (bottom) the weights ratio is 1 : 1.

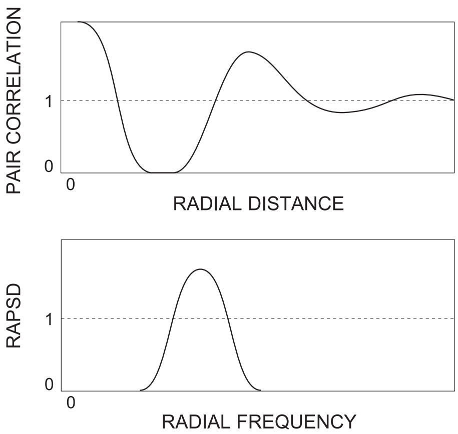

Figure 8: The pair-correlation (top) and the RAPSD (bottom) of the ideal binary image.

We first evaluate the resulting image using the spatial and the spectral statistics. *The pair-correlation* [11] is used as a spatial statistics within the halftone image, and *The Radially Averaged Power Spectrum Density* (RAPSD) [12] is used as a spectral statistics within the halftone pattern. Due to the stringent page limitation, we omit the details of the explanation of the pair-correlation and the RAPSD. The ideal cluster-dot halftone image has the pair-correlation and the RAPSD shown in Figure 8. In general, good halftoning algorithms generate binary images with the pair-correlation and the RAPSD close to those in Figure 8. In particular, the pair-correlation converges to 1.

We compare the cluster-dot error filter Error Diffusion with the EDODF by the actual halftone images, the pair-correlation, and the RAPSD. Figure 9 shows the results by each of the methods for a solid patch with $g = \frac{1}{2}$. The EDODF images (Figures 9 (a) and (b)) generated by the hysteresis parameter $H = 0.5$ and 0.75 have strong horizontally directional characteristic. Furthermore, the pair-correlation does not converge to 1, and the RAPSD is too sharp. Figure 9 (c) show the resulting binary image by our cluster-dot Error Diffusion using the cluster-dot error filter. Figures 9 (d) and (e) are the results by the cluster-dot Error Diffusion with feedback with hysteresis parameter $H = 0.1$ and 0.15. All of the three images have the pair-correlation and the RAPSD close to the ideal one. Also, the image Figure 9 (c) has no directional characteristic. Further, we can confirm that the size of cluster dots can be changed with small variance of the hysteresis H. Therefore, images in Figures 9 (d) and (e) have few horizontally directional characteristics. Consequently, our new Error diffusion filter can generate better binary images.

Figure 10 shows the results by the EDODF and the our cluster-dot Error Diffusion for a ramp image. We can see strong horizontally directional characteristic in the binary images by the EDODF (Figure 10 (a) and (b)) On the other hand, by using our new cluster-dot error filter, we can generate binary images with no directional characteristic and no artifacts.

Figure 11 shows the resulting binary images by our cluster-dot Error Diffusion and the EDODF for a woman image. Clearly, our cluster-dot Error Diffusion generates better quality halftone images compared than the EDODF. The binary images generated by our cluster-dot Error Diffusion reproduces more details and tones of the original image and have no or few directional characteristic and artifacts.

5 Conclusions

We have presented a cluster-dot Error Diffusion methods using the cluster-dot error filter. The key idea of our error filter is not to diffuse the quantization error to neighboring pixels. Also, the coefficient of the filter is decided such that the resulting binary image has no directiona characteristics and no artifacts. The experimental results show that our new filter based Error Diffusion can generate better quality binary images than the EDODF.

References

[1] T. Asano, "Digital halftoning: Algorithm engineering challenges," *IEICE transactions on information and systems*, vol. 86, pp. 159–178, Feb. 2003.

[2] K. Nakano, "Various screening methods," *Convertech*, vol. 36, no. 1, pp. 72–77, 2008.

[3] D. Lau and G. Arce, *Modern Digital Halftoning.* CRC Press, 2nd ed., 2008.

[4] R. Floyd and L. Steinberg, "An adaptive algorithm for spatial gray scale," *SID 75 Digest, Society for information display*, pp. 36–37, 1975.

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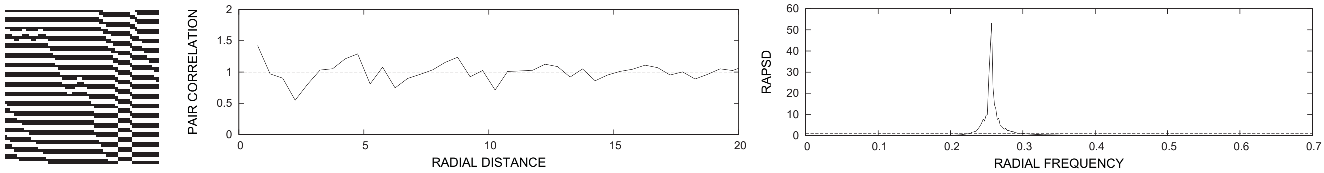
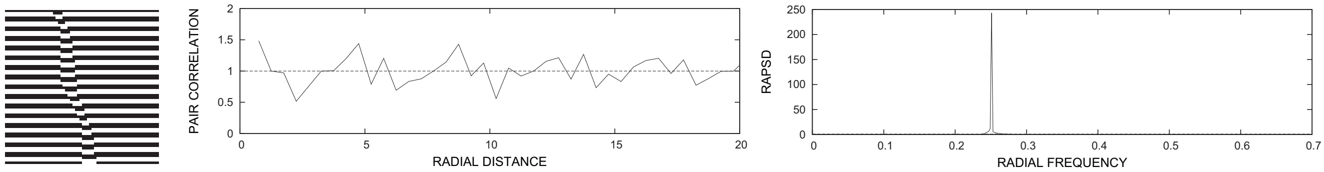
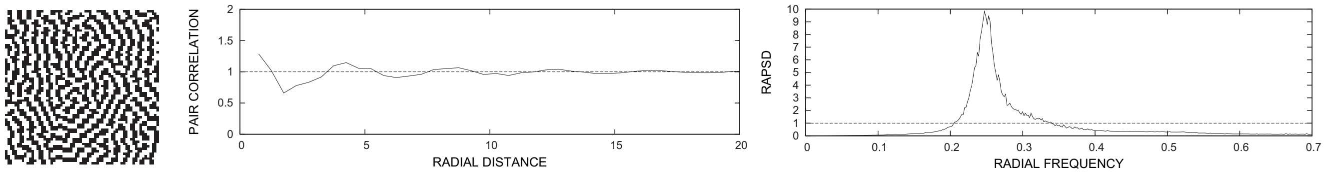


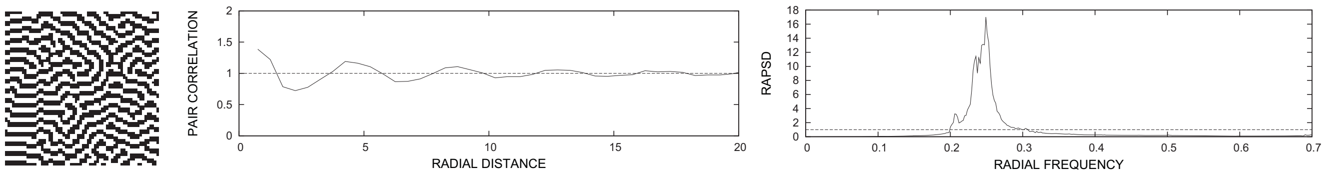
(a) EDODF ($H = 0.5$)



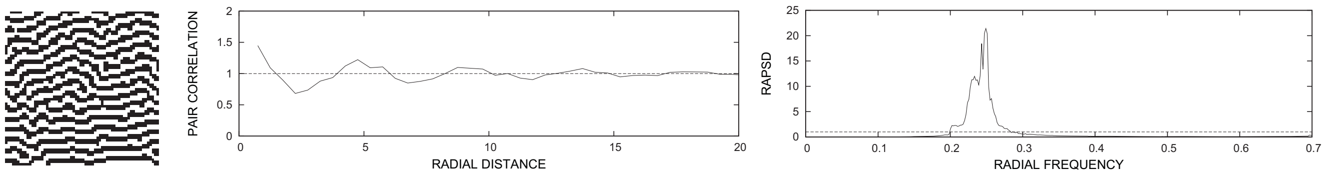
(b) EDODF ($H = 0.75$)



(c) Our cluster-dot error filter



(d) Our cluster-dot error filter with feedback ($H = 0.1$)



(e) Cluster-dot error filter with feedback ($H = 0.15$)

Figure 9: (left) The halftone images for $g = \frac{1}{2}$ (center) pair-correlation, and (right) RAPSD

[5] K. Knox and R. Eschbach, “Threshold modulation in error diffusion,” *Journal of Electronic Imaging*, vol. 2, pp. 185–192, July 1993.

[6] P. Li and J. Allebach, “Tone dependent error diffusion,” in *IS&T/SPIE Color Imaging: Device-Independent Color, Color Hardcopy, and Applications VII*, vol. 4663, pp. 310–321, Jan. 2002.

[7] V. Ostromoukhov, “A simple and efficient error-diffusion algorithm,” in *SIGGRAPH2001*, pp. 567–572, Aug. 2001.

[8] Y. Ito and K. Nakano, “A new FM screening method to generate cluster-dot binary images using the local exhaustive search with FPGA acceleration,” *International Journal on Foundations of Computer Science*, vol. 19, no. 6, pp. 1373–1386, 2008.

[9] R. Levien, “Output dependent feedback in error diffusion halftoning,” in *Proc. IS&T Imaging Science and Technology*, vol. 1, pp. 115–118, May 1992.

[10] L. Velho and J. Gomes, “Digital halftoning with space filling curves,” in *SIGGRAPH ’91: Proceedings of the 18th annual conference on Computer graphics and interactive techniques*, pp. 81–90, July 1991.

[11] D. Lau, G. Arce, and N. Gallagher, “Green noise digital halftoning,” *Image Processing, International Conference on*, vol. 2, pp. 39–43, Oct. 1998.

[12] R. Ulichney, “Dithering with blue noise,” *IEEE Transactions on Image Processing*, vol. 76, pp. 56–79, Jan. 1988.

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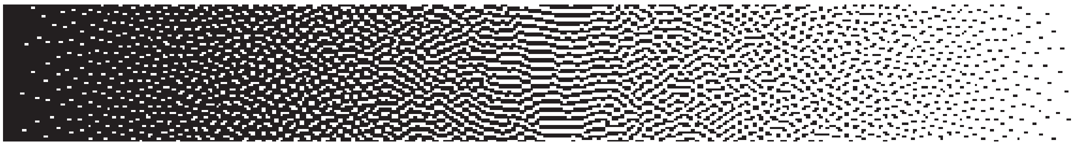
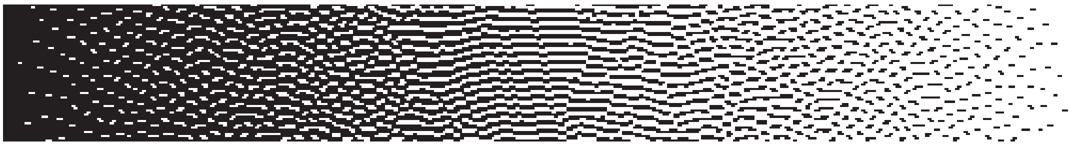
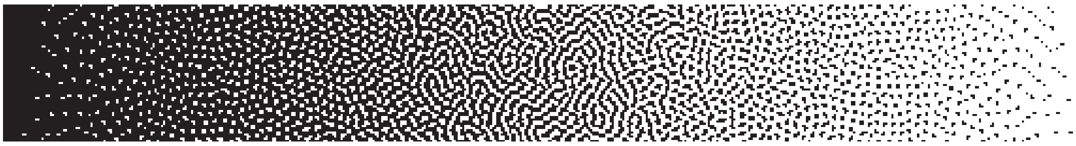


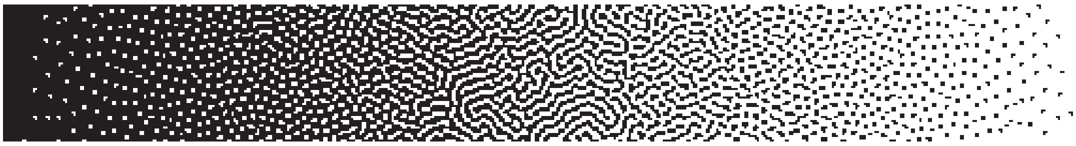
(a) EDODF ($H = 0.5$)



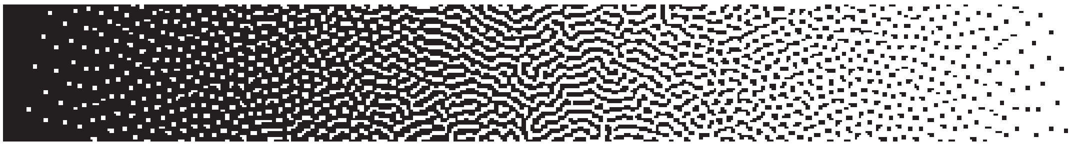
(a) EDODF ($H = 0.75$)



(c) Cluster-dot error filter

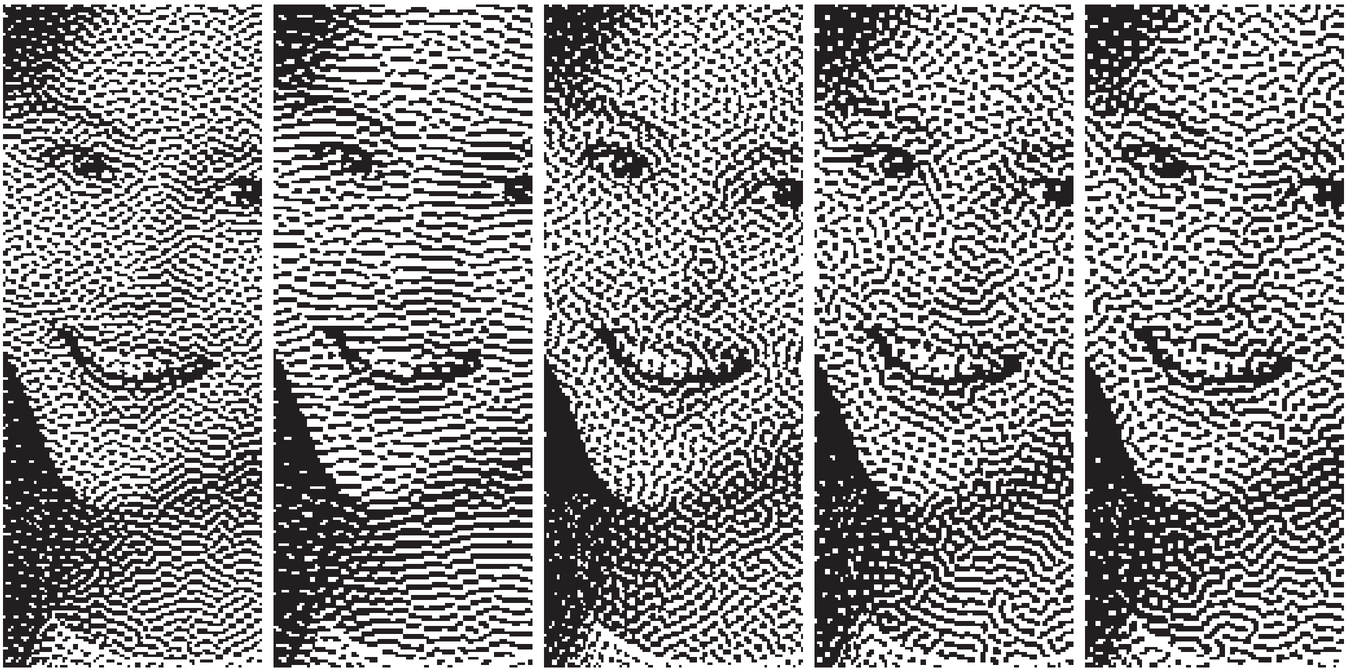


(d) Cluster-dot error filter with feedback ($H = 0.1$)



(e) Cluster-dot error filter with feedback ($H = 0.15$)

Figure 10: The resulting bianry images for a ramp image.



(a) (b) (c) (d) (e)

Figure 11: The resulting binary images for a woman image, (a) EDODF ($H = 0.5$), (b) EDODF ($H = 0.75$), (c) Cluster-dot error filter, (d) Cluster-dot error filter with feedback ($H = 0.1$), and (e) Cluster-dot error filter with feedback ($H = 0.15$)

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