38.2: Adaptive Filtering for Error-Diffusion Quality Improvement

J. Shu
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ABSTRACT

A novel adaptive filtering approach to improve error diffusion halftone quality is presented. This technique employs a set of error filters having different sizes and/or associated weighted coefficients for diffusing quantization errors among neighboring pixels in predetermined tonal areas of an image. Both "worm" and "graininess" artifacts in halftone images were reduced to achieve high-quality smooth halftone images.

Introduction

A halftone image is a binary image whose pixel value is either 1 or O corresponding to black and white; however the image looks as though it has intermediate tones ranging from black to white due to varying halftone dot sizes or densities. Conversely, a continuous-tone image (e.g., a photograph) contains pixel values ranging from O to a positive number (e.g., 255) which corresponds to the image gray tones. Halftoning is a process to convert a continuous-tone image into a halftone image. For color halftoning, 24 bit/pixel continuous tone images may convert into 3 or 4 bit/pixel for CMY or CMYK (i.e., Cyan, Magenta, Yellow, blacK) colors (1 bit/pixel per color). Halftonig has been widely used for hardcopies such as ink jet, laser printers and printing press. Many halftoning algorithms and techniques were developed [1, 2]. Among them, error diffusion approach usually produces better halftone quality than ordered dithering but slower in performance.

In error diffusion approach, "worm" and "graininess" artifacts are common and difficult to be simultaneously eliminated. Reducing worms normally result heavier graininess; on the other hand, maintaining low graininess may result worms at certain tones. In order to reduce worm artifacts, previous arts added noise into images, threshold values, or weighted coefficients of error filters. Or, it selects an error filter randomly from a bank of error filters. However, all these approaches may increase halftone graininess levels while reducing worms.

It is the objective of this research to develop an improved error diffusion technique without worm artifact but with smooth halftone structure (i.e., reduced graininess).

Error Diffusion

Standard Error Diffusion

In a standard error diffusion, as illustrated in Fig. 1, each image pixel is processed by comparing its pixel value to a fixed threshold value where the pixel value is the original image pixel value plus error adjustments resulting from the previous processing of other pixels. If the pixel value exceeds the threshold value, then a "1" or dot is output. Alternatively, if the pixel value is less than the threshold value, then a "0" or no dot is output. A quantization error value is then determined by subtracting the output value from the input value. This error is then diffused, based on a predefined error filter, to unprocessed neighboring pixels. Fig. 2 shows the Floyd-Steinberg error filter.

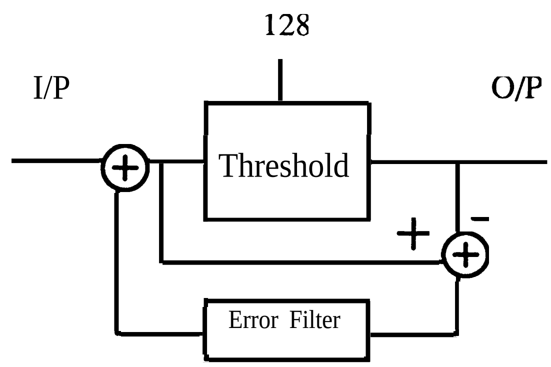


Fig. 1 Standard Error Diffusion

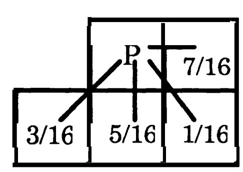


Fig. 2 Floyd Steinberg Error Filter

AFT Error Diffusion

Fig. 3 illustrates the presented technique (Adaptive Filtering and Thresholding error diffusion) in which the threshold value and error filter are no longer freed but adaptive according to the original image pixel values. As shown in Fig. 3, the threshold value is determined by a "Noise Generator" which is modulated by the original image pixel value. The output for the processing pixel can, therefore, be determined using this threshold value. Quantization error can, then, be calculated as the standard error diffusion. "Filter Selector" in Fig. 3 selects an error filter from a bank of error filters, depending on the original image pixel value, in order to diffuse the quantization error to the neighboring unprocessed pixels [4]. Except the adaptive threshold values and adaptive error filters, the rest part of the processing is same as the standard error diffusion as described above.

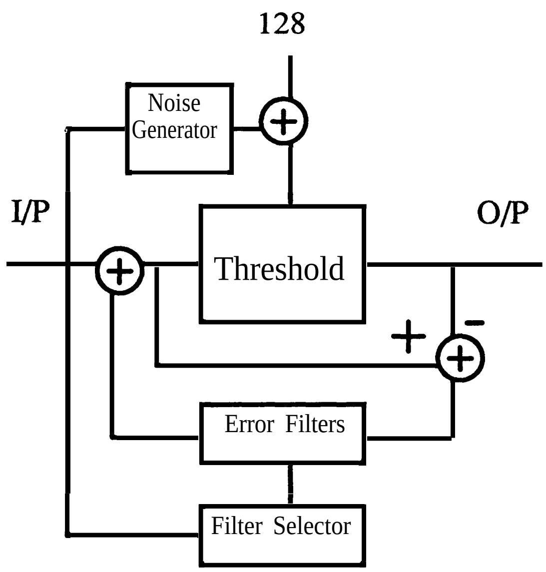


Fig. 3 AFT Error Diffusion

The adaptive tresholding and filtering rearrangement improves the quality of halftone images by minimizing artifacts due to standard error diffusion halftoning operation.

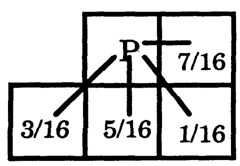
Adaptive Filtering

In accordance with an aspect of the adaptive filtering arrangement, a set of error filters having different sizes and/or proportional weighting coefficients are provided for diffusing quantization errors among neighboring pixels in predetermined tonal areas of an image.

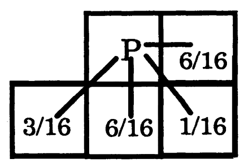
These error filters are selectively applied to input image pixels depending upon the gray tone of those pixels. It was found that single error filter cannot provides uniform, smooth high-quality halftones along the entire tone range. Given an error filter, high-quality halftones appear at certain tones but poor quality appear at the rest tones in the full-dynamic tone range, e.g., O to 255. This suggests to use multiple error filters each of which works on different tones with high-quality output. The union of the working tones from each of error filter forms the entire tone range.

In order to avoid visible junctions between tones caused by the difference of two neighboring error filters, we make small change between each pair of neighboring error filters. (e.g., An error filter only changes its two weights by +1 and -1 from its adjacent error filter.)

Fig. 4 shows a set of such error filters for the adaptive filtering process. As shown, for scan direction from left to right, Filter A is for tones within [0,188], i.e., input image value from O to 188; Filter B is for tones in [189,212]; Filter C is for tones in [213,220]; Filter D is for tones in [221,233]; and Filter E is for tones [234,255]. For scan direction from right to left, Filter F is for tones in [0,188]; Filter G is for tones in [189,212]; Filter H is for tones in [213,220]; Filter I is for tones in [221,233]; and Filter J is for tones [234,255]. These 10 error filters are used in serpentine scan, i.e., even (or odd) scan line is processed from left to right and odd (or even) scan line is processed from right to left.



Filter A, [0,188]



Filter B, [189,212]

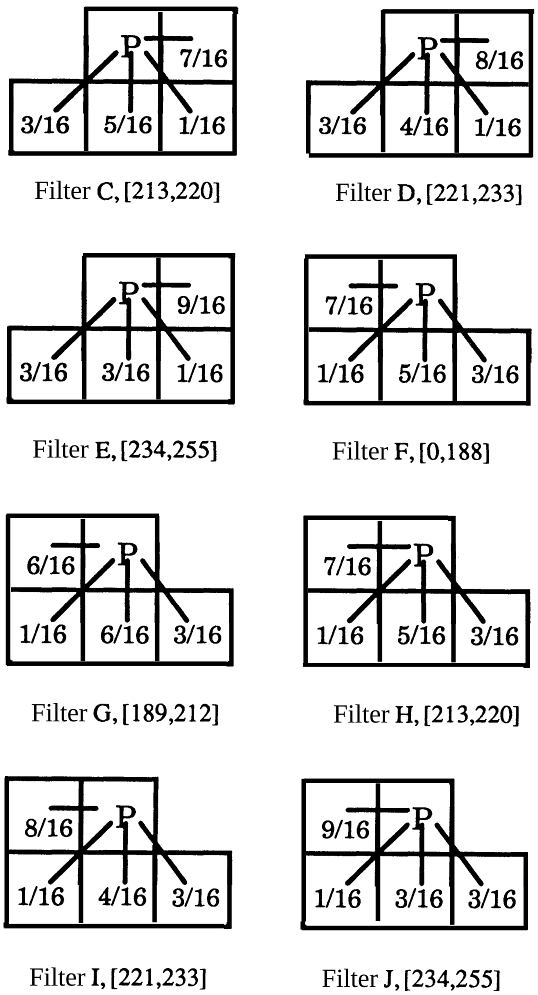


Fig. 4 AFT Error Filters

Adaptive Thresholding

Although this adaptive filtering approach reduces the graininess of halftone images over a full-tone range, visible pattern distortion may arise at certain input image tones, more particularly, at the intersection of two widely dis-alike filters. Or when we enforce the similarity of two adjacent error filters in order to avoid the visible junctions, it limits the selection of filters to cause visible worms at certain tones.

The solution is to adaptively add noise to threshold values at these problem tones to break up the worm or visible junction artifacts. Unlike prior arts where noise is constantly added to the threshold value at each pixel of an image, this adaptive thresholding approach modulates the threshold value with random noise only at pre-selected input image tones. Moreover, the degree of the added noise varies depending upon the seriousness of the worm artifact at different tones. This adaptive thresholding avoids over and under noise addition to maintain halftone worm free and less graininess.

The bits of noise at different tones is shown in Fig. 5 for Epson Stylus color printers at 360 dpi mode. As illustrated in Fig. 5, there are 3 bit noise in [217,213), i.e., input image value <= 217 and > 213; 4 bit noise in [213,195); 5 bit noise in [195,186); 4 bit noise in [186,174); 5 bit noise in [174,166); 4 bit noise in [166,162); 3 bit noise [162,158); 3 bit noise in [141,137); 4 bit noise in [137,133); 5 bit noise in [133,120); 4 bit noise in [120,116); 3 bit noise in [116,112); and no noise in [255,217), [158,141), and [112,0]. The noise table may need adjustment for different printers.

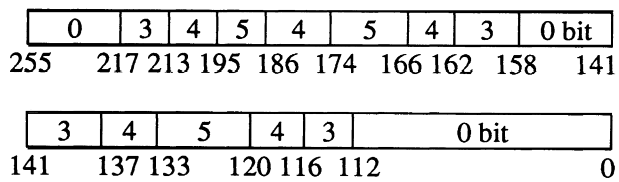


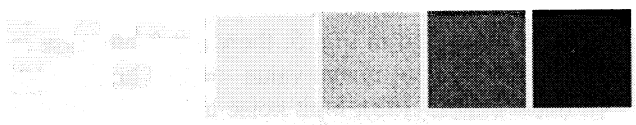
Fig. 5 Noise Bit for Adaptive Thresholding

Summary

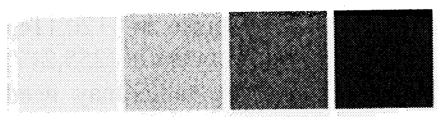
The AFT technique described here improves error diffusion image quality by reducing halftone worm and graininess artifacts.

Fig. 6 shows halftoned uniform gray patches of 2%, 5%, 20%, 40% 60%, 80% tones to compare different error diffusion techniques. Fig. 6(a) shows the result of standard FD (Floyd Steinberg) error diffusion. Fig. 6(b) shows the result of FDAN (Floyd Steinberg error diffusion with 50% Added Noise into its weighted coefficients) at serpentine scanning. Fig. 6(c) shows the AFT result. Fig. 7(a)(b)(c) show results of applying the three error diffusion techniques to a photographic image. All images were printed using an Epson Stylus color printer at 360 dpi mode.

As shown in the experimental results, FD has worm and graininess artifacts at certain tones. FDAN has no worm artifact but heavy graininess at light tones. The presented AFT produces overall low graininess and no worm artifacts. At some dark tones, FDAN is comparable to or slightly better than AFT in terms of low graininess. It is possible to extend AFT to include FDAN processing for dark tones. At light tones, AFT has significantly superior image quality to FDAN and FD.



(a)



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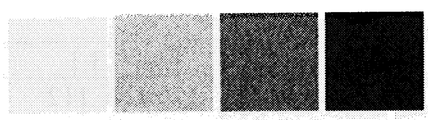

(c)

Fig. 6 uniform gray patches of 2%, 5%, 20%, 40%, 60%, and 80% tones: (a) processed by FD error diffusion, (b) processed by FDAN, and (c) processed by AFT.

(a)

(b)

(c)

Fig. 7 A photographic image halftoned by: (a) FD (b) FDAN, and (c) AFT error diffusion.

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1. R. Ulichney, Digital Halftoning, The MIT Press, Cambridge, MA., 1988.
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3. Floyd and L. Steinberg, " an adaptive algorithm for spatial gray scale," SID Dig., Vol. 36, 1975.
4. J. Shu, "improved adaptive filtering and tresholding arrangement for reducing graininess of images", US patent pending.

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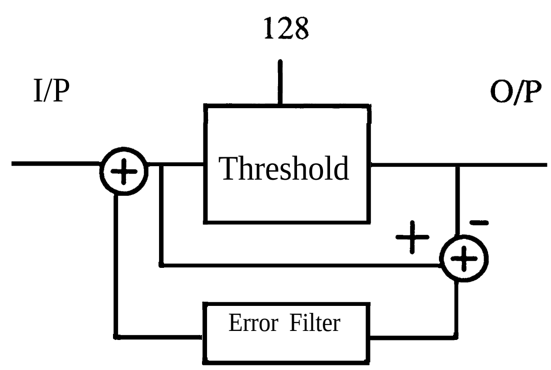

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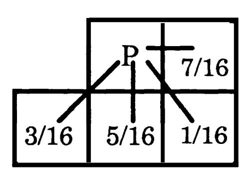

Fig. 2 Floyd Steinberg Error Filter

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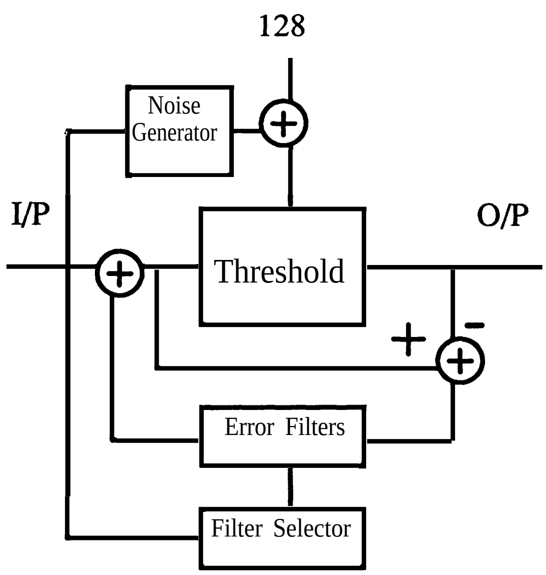

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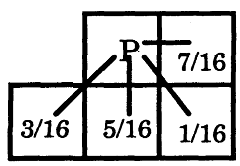
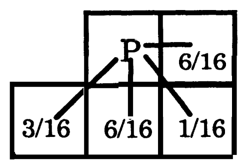


Filter A, [0,188]



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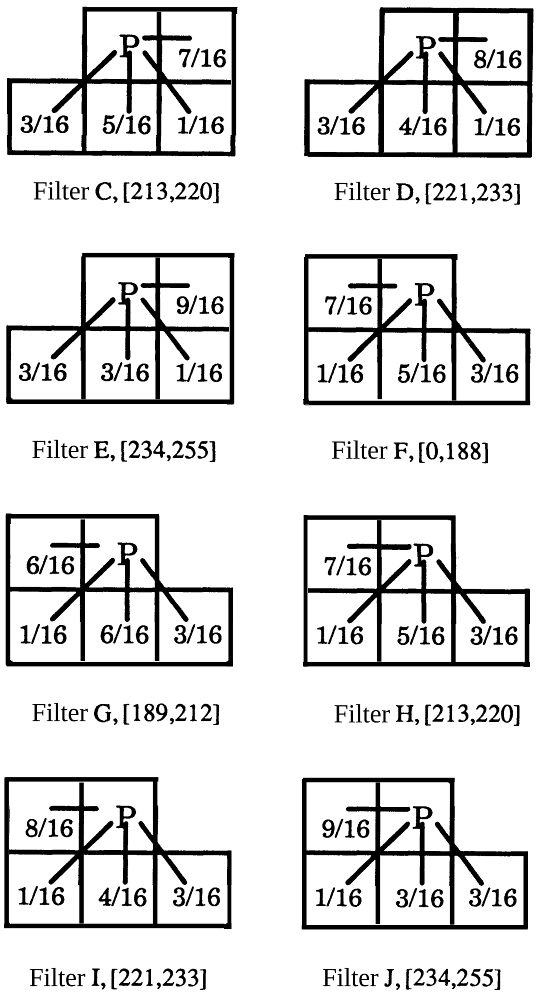

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0	3	4	5	4	5	4	3	*0* bit
255	217	213	195	186	174	166	162	158 141

3	4	5	4	3	*0* bit
141	137	133	120	116	112 … 0

Fig. 5 *Noise* Bit for Adaptive Thresholding

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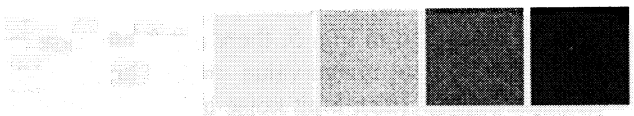
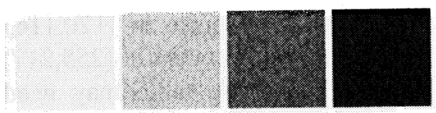


(a)



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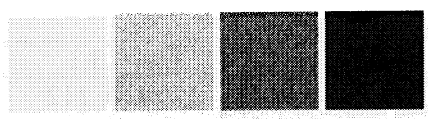

(c)

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(a)

(b)

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