A Negative Multiscale Error Diffusion Technique for Digital Halftoning

Nihar Ranjan Panda, Ajit Kumar Sahoo, Sananda Kumar

Department of Electronics and Communications
National Institute of Technology Rourkela,Orissa,India
(niharranjanpanda1@gmail.com,ajitsahoo@nitrkl.ac.in,sananda4u@gmail.com)

Abstract—**An innovative digital halftoning procedure is established on multiscale error diffusion is studied in this paper. In this research a negative multiscale error diffusion technique is proposed having more practical significance. The prominent features of the algorithm are (1) Application of image quadtree (2) Selection of the darkest pixel based on minimum intensity guidance theorem (5) Non causal diffusion of error. The quality of the halftoned image is evaluated both through subjective and objective evaluations. For the objective evaluation feature similarity index is adopted in this paper. The proposed technique provides enhanced result both visually and in terms of feature similarity index.**

Keywords—Digital halftoning; Error diffusion; FSIM; Multiscale error diffusion; Negative multiscale error diffusion

I. INTRODUCTION

Digital halftoning simulates a grey scale image by using only black and white tones. In today's modern world a key role was played by digital halftoning in field of printing and displaying like printing of books and magazine.

A good quality halftoning technique not only reproduces the original image but also replicate the full range of grey scale values, keeping the spatial resolution and quality. With the advancement of new generation of computers and its application to the printing industry many halftoning techniques are developed in due course of time. Based on the techniques of all the halftoning methods, they are broadly divided into three key classes. 1. Dithering [1-4] 2. Error Diffusion [5-7] 3. Optimization techniques [8-11]. In dithering either we add random noise (white noise) or deterministic noise (ordered dithering) prior to the quantization of the input image. If we add random noise the halftone image looks too noisy and if we add deterministic noise repetitive patterns occur in the output image. Though it is the simplest and cheapest in terms of mathematical complexity, the resemblance of the output halftone image to input image is poor in comparison to error diffusion. The error diffusion is based on the principle that the error generated because of the quantization of the pixel should be the diffused into the neighborhood pixels; mean the input pixel that is to be quantized is nothing but the summation of input pixel along with the diffused quantization error. This is mathematically simpler and gives fairly good results but because of the usage of the causal filter and deterministic scanning path it gives visual artifacts of directional hysteresis in the halftones image. In the optimization based methods a cost function is devised and by minimizing the cost function using standard techniques (LMS, RLS), the halftone becomes a optimization problem i.e. either we can optimize the output halftone image from input grey scale image or we can make the diffusion filter adaptive. Since this is an optimization problem it is computationally expensive.

In 1997 a new types of error diffusion technique [12-13] has been proposed known as Multiscale Error Diffusion technique (MED) based on the idea of multi-resolution. Traditionally error diffusion is applied to pixel in a predefined order. In MED, it finds the epicenter of the brightest point of the image in a deterministic way known as "maximum intensity guidance theorem". A non-causal filter is then applied to diffuse quantization error to neighborhood pixels of the pixel quantized.

A new halftoning procedure established on MED is presented in this paper. In this technique the epicenter of the darkest part of the image is found through the "minimum intensity guidance theorem" considering the practical application of printer where we have to put black ink on a white piece of paper for printing. A non-causal filter is used to spread the quantization error to the neighborhood of the quantized pixel.

II. REVIEW OF EXISTING DIGITAL HALFTONING TECHNIQUES

A. Error Diffusion

$x[m,n]$ = Input grey scale image

$u[m,n]$ = Updated input image

$g[m,n]$ = Output halftone image

$t[m,n]$ = Threshold value

$e[m,n]$ = Quantization error

$h[k,l]$ = Error diffusion filter

Error diffusion is one of the techniques which provide quality halftones having similarity with input grey scale image. In error diffusion the pixels are processed in raster scan approach, i.e., pixels will be calculated from left to right while moving downward row wise. The output pixel of the error diffusion is calculated using the quantizer value $t[m,n]$. i.e.

$$g[m,n] = \begin{cases} 1 & \text{if } u[m,n] \geq t[m,n] \\ 0 & otherwise \end{cases} \quad (1)$$

The quantization error is the difference of input pixel value from the output value,

$$e[m,n] = g[m,n] - u[m,n] \quad (2)$$

The quantization error is then distributed to the set of future pixels using the error diffusion filter.

$$h[k,l].u[m+k,n+l] = u[m+k,n+l] - h[k,l] * e[m,n] \quad (3)$$

In order to avoid the error leakage and to preserve the local tone the error diffusion matrix $h[k,l]$ must satisfy the condition $\sum h[k,l] = 1$ (4)

The diffusion of the error works in a causal fashion, since the current location consists of the quantization of previous locations. For example, The Floyd Steinberg algorithm binarizes an image in raster scan order. The threshold of the quantizer value is set at 0.5 for all [m, n]. The quantizer threshold can be adaptive, but that is another open area of research. The error diffusion filter has four nonzero weights. $\left(\frac{1}{16}\right) * \begin{bmatrix} 0 & 0 & 7 \\ 3 & 5 & 1 \end{bmatrix}$

B. Multiscale Error Diffusion

Image Quadtree

Katsavounidis [12] devised a quadtree structure for X, B and E corresponding as input, output and error image. Each X, B, E are considered as square images of size $* N$, where $N = 2^r$. let X_k is the k th level of the input image of size $2^k \times 2^k$ for $k = 0,1,2,..r$.

Let X_r is of dimension $N * N$ and the dimension and the dimension is decreased with a factor of 2 with every reduction in the value of r. I.e. the X_{r-1} has the dimension $N/2 \times N/2$ and so on. Collection of all of the image arrays from X_r to X_0 i.e. the collection of different resolution image arrays from $N \times N$ to 1×1 is called as input image pyramid or input image quadtree.

Algorithm

Multiscale error diffusion is founded on the notion of error diffusion. MED follows the order of scanning based on “maximum intensity guidance” algorithm in contrast to the raster scanning of the Error Diffusion. Where the input image is successively partitioned and zoomed into the most luminous partition till we reach a single pixel or the illumination centre of the image.

In addition to the randomness to the scanning the application of non-causal error diffusion filters improves upon the suppression of unwanted textures results in low causality in the output image against the Floyd Steinberg’s method.

Let X, B, E denotes Input, Output and Error image respectively and all of have dimension$N \times N$ .Where $N = 2^k$. B The Output image is initialized as a dark image means all of its values are zero.

$$E = X - B \quad (5)$$

The error image matrix is initialized as the input image.

Let I stand for the total intensity of the error image.

$$I = \sum_{i=1}^{N} \sum_{j=1}^{N} E(i,j) \quad (6)$$

Stage -1 (determination of maximum intensity)

The error input image is segmented into four non-overlapped regions of dimension $N/2 \times N/2$ each. The total cumulative intensity is calculated for each sub-image and the sub-image of highest cumulative intensity is chosen. The chosen sub-image is again subdivided into four sub-images and the procedure of selection of sub-image of highest total intensity goes on till the size of sub-image becomes 1×1 or in other words a single pixel is selected after the end of the procedure. Let the location of the pixel is(i_k, j_k). Then a white dot or value 1 is placed at the corresponding location of the halftoned image.

Stage-2 (diffusion of quantization error)

From the stage 1 the output pixel $b(i_k, j_k)$ is assigned as one. $b(i_k, j_k) = 1$

Hence the quantization error is calculated as

$$eq = e(i_k, j_k) - 1 \quad (7)$$

And the quantization error is assigned to the corresponding pixel location of the error image .i.e.

$$e(i_k, j_k) = eq \quad (8)$$

The quantization error is diffused among the neighborhood using a 3×3 or 5×5 non causal diffusion filter.

$$\left(\frac{1}{12}\right) \begin{bmatrix} 1 & 2 & 1 \\ 2 & -12 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

$$\left(\frac{1}{9.1}\right) \begin{bmatrix} .125 & .2 & .25 & .2 & .125 \\ .2 & .5 & 1 & .5 & .2 \\ .25 & 1 & -9.1 & 1 & .25 \\ .2 & .5 & 1 & .5 & .2 \\ .125 & .2 & .25 & .2 & .125 \end{bmatrix}.$$

The filters should have zero mean, so that there will be no error leakage.

After the diffusion the Error image is updated and since the error is negative, it reduces the neighborhood pixel values according to the weight of the filters. Subsequent to the diffusion of the error filter the Error Input E is restructured and the total intensity I is calculated. This modus operandi goes on until the sum of the total intensity $I < .5$.

III. Negative Multiscale Error Diffusion(NMED)

Multiscale error diffusion is founded on the idea of putting a white dot in a blank image; where as in practical application of printing black ink is printed upon a white sheet. Negative MED followed the order of scanning based on “minimum intensity guidance” algorithm in contrast to the raster scanning of the Error Diffusion. Here we successively break the input image into four parts and zoom into least luminous partition till we reach a single pixel or the centre of the darkest part of the image.

Let X, B denotes Input Image and Output Image respectively having dimension $N \times N$. Where, $N = 2^k$. B The Output Image is initialized as a white image means it's all values as one.

Let F is denoted as a blank image having the dimension $N \times N$ and it is initialized as input image. $F = X$

Let I stand for the subtraction of the total intensity of the output image to the input image X.

$$I = \sum_{i=1}^{N} \sum_{j=1}^{N} B(i,j) - \sum_{i=1}^{N} \sum_{j=1}^{N} X(i,j) \quad (9)$$

Stage -1 (determination of minimum intensity)

The error input image F is segmented into four non-overlapped regions of dimension $N/2 \times N/2$ each. The total intensity for each sub-image is calculated and the sub-image of lowest total intensity is selected. The selected sub-image is further subdivided into four sub-images and the procedure of selection of sub-image of lowest total intensity goes on till the size of sub-image becomes 1×1 or in other words a single pixel is selected. Let the location of the pixel is(i_k, j_k). Then a black dot or value 0 is placed at the corresponding location of the output halftoned image.

Stage-2 (diffusion of quantization error)

From the stage 1 the output pixel $b(i_k, j_k)$ is assigned as zero. $b(i_k, j_k) = 0$

Hence the quantization error is calculated as

$$eq = e(i_k, j_k) - 0 \quad (10)$$

And the quantization error is assigned to the corresponding pixel location of the error image .i.e.

$$e(i_k, j_k) = eq \quad (11)$$

The quantization error is diffused among the neighborhood using a 3×3 or 5×5 non causal diffusion filter.

Assign $F(i_k, j_k) = 1$ (12)

After the diffusion the output pixel is updated as zero and since the error value is positive it increases the neighborhood pixel values according to the weight of the filters. Subsequent to the diffusion image F is restructured and the total intensity I is calculated till $I < .5$. I.e. the difference of the intensity between output image and the input image should fall below 0.5.

IV. Results

Results are presented in table I for halftoning using test images Lena, baboon and boat. All the test images are taken of 8-bit grey scale image having the dimension 512×512 for the comparison of algorithms. No preprocessing steps have been considered for the algorithms. Tie breaker concept is used for both the case of MED and negative MED. For the diffusion of the error non causal filters have been used in both the algorithms. Fig. 1 shows the subjective results for the Lena image and it is visible that both the MED and negative MED are free from visual artifacts. And from the objective results it was found that both NMED and MED performs similarly in the case of MSE but the negative MED performs better in case of FSIM.

TABLE I. Objecive Quality comparision for MSE and FSIM

Image	ED		MED		NMED	
	MSE	*FSIM*	*MSE*	*FSIM*	*MSE*	*FSIM*
Lena	0.213	0.966	0.207	0.969	0.207	0.971
Boat	0.213	0.975	0.204	0.976	0.204	0.976
Man	0.209	0.976	0.201	0.978	0.201	0.979

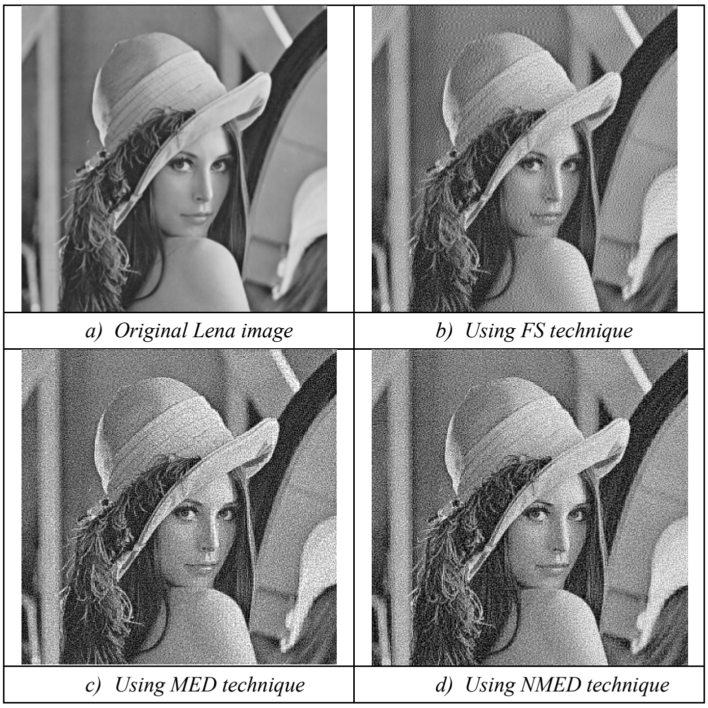

Fig. 1. Results of different error diffusion halftoning techniques on LENA a) Original Image b) Using FS technique c) Using MED Technique d) Using NMED technique

V. Conclusion

In this paper, a new halftoning procedure founded on MED is presented. The algorithm negative multiscale error diffusion serves more practical purpose in terms of the application of printing and properly places the black dots in the halftoned image. Though it provides similar results in terms of MSE it performs better in terms of FSIM. It removes the visual artifacts of worm like effects from the halftoned image. The algorithm can be further implemented for multitoning and color image.

REFERENCES

[1] R. A. Ulichney, “The void-and-cluster method for dither array generation,”Proc. SPIE, Human Vision, Visual Processing and Digital Display IV, vol. 1913, pp. 332–343, 1993.

[2] R. W. Floyd and L. Steinberg, “An adaptive algorithm for spatial grey scale,” in Proc. SID Int. Symp. Digest of Technical Papers. New York, 1975, pp. 36–37.

[3] T. Mitsa and K. Parker, “Digital halftoning using a blue-noise mask,” in Proc. SPIE, Image Processing Algorithms and Techniques II, 1991, vol. 1452, pp. 47–56.

[4] R. A. Ulichney, “The void-and-cluster method for dither array generation,”Proc. SPIE, Human Vision, Visual Processing and Digital Display IV, vol. 1913, pp. 332–343, 1993.

[5] J. F. Jarvis, C. N. Judice, and W. H. Ninke, “A survey of techniques for the display of continuous-tone pictures on bilevel display,” Comput. Graphics Image Processing, vol. 5, pp. 13–40, 1976.

[6] P. Stucki, “Mecca—A multiple-error correcting computation algorithm for bilevel image hardcopy reproduction,” IBM Res. Lab., Res. Rep. RZ1060, 1981.

[7] T. N. Pappas and D. L. Neuhoff, “Least-square model-based halftoning,” in Proc. SPIE, Feb. 1992, vol. 1666, pp. 165-176.

[8] M. Analoui and J. Allebach, “Model-based halftoning using direct binary search,” in Proc. SPIE, vol. 1666, pp. 96-108, Feb. 1992.

[9] D. A. Carrara, M. Analoui, and J. P. Allebach, “Recent progress in digital halftoning,” in Proc. IS&T’s Int. Congress Adv. Non-impact Printing Technol., Williamsburg, VA, Oct. 1992, pp. 265-270.

[10] R. A. Vander Kam, P. A. Chou, and R. M. Grey, “Combined halftoning and entropy-constrained vector quantization,” in Proc. SID Int. Symp. ,Dig. Tech. Papers, Seattle, WA, May 1993, pp. 223-226.

[11] A. Zakhor, S. Lin, and F. Eskafi, “A new class of B/W halftoning algorithms,” IEEE Trans. Image Processing, vol. 2, pp. 499-509, Oct. 1993.

[12] Ioannis Katsavounidis and C.-C. Jay Kuo” A Multiscale Error Diffusion Technique for Digital Halftoning” IEEE Trans. Image Processing, vol. 6, no. 3, pp. 483-490 ,March 1997.

[13] Giorgos Sarailidis and Ioannis Katsavounidis” A Multiscale Error Diffusion Technique for Digital Multitoning” IEEE Trans. Image Processing, vol. 21, No. 5, pp. 2693-2705, May 2012.