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An Overview to various Digital Halftone Processing Techniques

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ABSTRACT

Digital halftoning is a technique to convert grayscale images into two-tone binary images for printing and display. An image having several bits for brightness levels is converted into a binary image consisting of black and white dots which looks similar to an input image. The similarity between two images is measured by the differences in the weighted sums of brightness levels of pixels in a neighborhood surrounding each pixel. The problem of producing halftoned image is to obtain an optimal binary image that retains the intensity information contained in the image. In this paper, we will study the various techniques for image halftoning and will analyze them for different parameters.

Keywords: Halftoning, Dithering Error-Diffusion, Block replacement, PSNR, WSNR, UQI.

INTRODUCTION

Halftoning is an application of image processing widely used in printing processes. With the evolution of computers and their use of typesetting, printing, and publishing, the field of halftoning that was previously limited in scope, called halftoning screen evolved into its successor digital halftoning. Today, digital halftoning plays a key role in almost every discipline that involves printing and displaying. [1] All newspapers, magazines, and books are printed with digital halftoning. It is used in image display devices capable of reproducing two-level outputs such as scientific workstations, laser printers, and digital typesetters. It is also important for facsimile transmission and compression. The grayscale digital image consists of 256 gray levels, while the black and white printers only have one colored ink. So, there is a need to replace wide range of grayscale pixels for printers. These 256 levels of gray have to be represented by placing black marks on white paper. Halftoning is a representation technique to transform the original continuous tone digital image into a binary image consisting only of 1's and 0's. The value 1 means a black dot in the current position and 0 means to keep the corresponding position empty. Since the human eyes have the low pass spatial-frequency property, human eyes perceive patches of black and white marks as some kind of average grey when viewed from sufficiently far distance. Our eyes cannot distinguish the small dots patterns and our eyes integrate the black dots and the non-printed areas as varying shades of gray. Figure 1(b) shows a typical half toning image.

(a) (b)

Figure 1: (a) The original image; (b) The halftone image

The various parameters for evaluating the figure of merit of the output halftone are briefly explained as under:
PSNR: - The simplest and most widely used pixel wise error based measures are mean squared error (MSE) and peak signal-to-noise ratio (PSNR). The MSE is the squared intensity differences between the reference and the test image pixels, which defined by:

$$MSE = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}[f(m,n) - f'(m,n)]^2$$

$$PSNR = 10\log_{10}\frac{255^2}{MSE}$$

UNIVERSAL IMAGE QUALITY INDEX (UQI):

Let $X = \{x_i \mid i = 1,2..N\}$ and $Y = \{y_i \mid i = 1,2,..N\}$ Be the original and test image signal respectively. $\bar{x}$ is the mean of x, σ_X^2 is the variance of x , σ_{XY} is covariance of x, y

$$UQI = \frac{4\sigma_{XY}\overline{xy}}{(\bar{x}^2 + \bar{y}^2)(\sigma_X^2 + \sigma_y^2)}$$

Where , $\bar{x} = \frac{1}{N}\sum_{i=1}^{N}x_i$; and $\bar{y} = \frac{1}{N}\sum_{i=1}^{N}y_i$

Weighted Signal-to-Noise Ratio (WSNR):

WSNR is calculated in the spatial frequency domain and is defined as follows:

$$WSNR = 10\log 10\frac{255^2}{\sum_{m=1}^{M}\sum_{n=1}^{N}[X(m,n) - B(m,n)]^2 .W(m,n)}$$

where, $W(m,n)$ is the is a weighting function represents the discrete Fourier transform (DFT) of a grayscale image with size M x N , and B(m, n) is the DFT of the bilevel halftone image

HALFTONE PROCESSING METHODS

There are a number of advanced halftoning methods. These methods can be categorized into three categories, based on their computational complexity and the simplest method is to operate on each pixel individually, [2] without considering neighbors. The second is region-based method, which quantifies each pixel using a neighborhood operation. The third is an iterative method that normally operates over the entire original image and iteratively tries to minimize the errors. In this section we briefly introduce some common halftoning.

CONSTANT THRESHOLD HALFTONING

The constant threshold method is the simplest method**.** Let $I = \{(i, j), i, j = 1,2,...255\}$, describe the pixel positions in the image. The pixel value at position (i, j) in I is compared with some threshold value T**.** If it is greater than or equal to the threshold, then 1 is set at the corresponding position in the halftoned image H. Figure 2 illustrates how this method works. Figure 3 shows the result. Obviously, the result is unsatisfactory. It produces a poor quality rendering of a continuous tone image, losing most of the details.

Input: Image I ,threshold T =127
Output: Halftone image ***H****;* for each pixel (i, j) in *I*, set

$$H(i,j) = \begin{cases} 1 & \text{if } I(i,j) \geq T \\ 0 & \text{if } I(i,j) < T \end{cases}$$

(a) **(b)**

Figure 3 (a): original image (b) : Halftone image by constant threshold method

1. ORDERED DITHERING

Ordered dithering is an approach that provides an ordered pattern of turning the pixels on using a selected screen before thresholding to binary. [3] In this method the threshold matrix, which is also called screen, is tiled over the image using periodic replication. The pixel value at each position (i, j) in I is thresholded by the threshold matrix T. Figure 4 describes the dithering process.[4]. The ordered dithering techniques are mainly divided into two groups, clustered dot dithering and dispersed dot dithering [5].

Input: Image *I*, threshold matrix T of size R x C
Output: Halftone image ***H****;* for each pixel (i, j) in *I*, set

$$H(i,j) = \begin{cases} 1 & \text{if } I(i,j) \geq T(i \bmod R, j \bmod C); \\ 0 & \text{otherwise.} \end{cases}$$

Figure 4: The Dithering Algorithm

In clustered dot dithering, the consecutive thresholds are located in spatial proximity. In this method pixels adjacent to one another are turned on thus forming a cluster The final halftoning images using two different threshold matrices in Figure 5 are shown in Figure 6.

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Comparing the two images in Figure 6, the larger threshold matrix has worse resolution Due to the dot-center criterion and the limited gray levels; the final halftoning image has poor detail rendition and obvious contouring artifact. On the other hand, there is no additive spot overlap. This method efficiently decreases the effect of ink spreads to neighboring pixels.

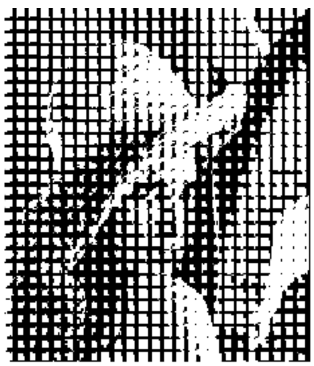
$$\begin{pmatrix} 62 & 57 & 48 & 36 & 37 & 49 & 58 & 63 \\ 56 & 47 & 35 & 21 & 22 & 38 & 50 & 59 \\ 46 & 34 & 20 & 10 & 11 & 23 & 39 & 51 \\ 33 & 19 & 9 & 3 & 0 & 4 & 12 & 24 \\ 32 & 18 & 8 & 2 & 1 & 5 & 13 & 25 \\ 45 & 31 & 17 & 7 & 6 & 14 & 26 & 40 \\ 55 & 44 & 30 & 16 & 15 & 27 & 41 & 52 \\ 61 & 54 & 43 & 29 & 28 & 72 & 53 & 60 \end{pmatrix}$$

5(a)

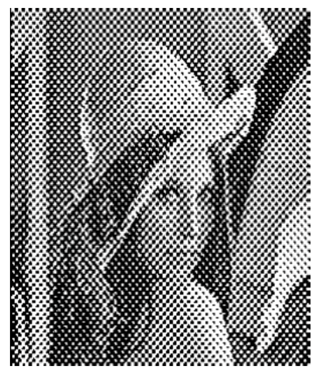
$$\begin{pmatrix} 14 & 10 & 11 & 15 \\ 9 & 3 & 0 & 4 \\ 8 & 2 & 1 & 5 \\ 13 & 7 & 6 & 12 \end{pmatrix}$$

5(b)

Figure 5: Two threshold matrices, (a) represent 64grey levels (b) represent 16 grey levels



(a)



(b)

Figure 6: Halftone Image by Clustered dot order dithering
(a) Using threshold matrix 5(a) (b) Using threshold matrix 5(b)

Figure	PSNR(dB)	WSNR(dB)	UQI
6(a)	6.75058	21.2792	0.068768
6(b)	6.68929	23.9478	0.0672133

Figure of merit for clustered dot ordered dithering

In the dispersed dot dithering method, the threshold matrices are arranged in a way that the values of threshold grow separately. Figure 7 shows an example of an 8x8 threshold matrix. In this method the pixels are turned on individually without being grouped into cluster, hence make the final halftone dots disperse in each screen. Figure 8 shows the halftoning images resulting from the threshold matrix shown in Figure 7. The 4x4 case does not look much different from the 8 x 8 case. There is no need to consider the tradeoff between the number of gray levels and the resolution. Compared with clustered dot dithering, this method has improved detail rendition.

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$$\begin{pmatrix} 21 & 37 & 25 & 41 & 22 & 38 & 26 & 42 \\ 53 & 5 & 57 & 9 & 54 & 6 & 58 & 10 \\ 29 & 45 & 17 & 33 & 30 & 46 & 18 & 34 \\ 61 & 13 & 49 & 1 & 62 & 14 & 50 & 2 \\ 23 & 39 & 27 & 43 & 20 & 36 & 24 & 40 \\ 55 & 7 & 59 & 11 & 52 & 4 & 56 & 8 \\ 31 & 47 & 19 & 35 & 28 & 44 & 16 & 32 \\ 51 & 6 & 23 & 4 & 17 & 61 & 19 & 30 \end{pmatrix}$$

7(a)

$$\begin{pmatrix} 5 & 9 & 6 & 10 \\ 13 & 1 & 14 & 2 \\ 7 & 11 & 4 & 8 \\ 15 & 3 & 12 & 0 \end{pmatrix}$$

7(b)

Figure 7: Two threshold matrices,(a) Represent 64grey levels (b) Represent 16grey levels

(a)

(b)

Figure 8: Halftone Image by Dispersed dot dithering (a) Using threshold matrix 7(a) (b)Using threshold matrix 7(b)

Figure	PSNR(dB)	WSNR(dB)	UQI
8(a)	6.70681	23.9032	0.067013
8(b)	6.77697	23.54	0.0713384

Figure of merit for Dispersed dot ordered dithering

2. BLOCK REPLACEMENT

Block replacement is a commonly used halftoning technique in which each pixel in the original image is replaced by one of a predetermined set of binary patterns (i.e. matrices). The dimension of the patterns is determined by screen frequency and the print resolution. For simplicity, assume that each pixel is replaced by a 2 x 2 matrix in which only five different gray levels can be represented as in Figure 9.

The pixel belong to one of the five gray level regions is replaced by the corresponding predetermined candidate. Figure 9 illustrates how this method works. for the first and the last pixel are shown. The same is done for the rest of the original image.

Figure 10(a) is the image halftoned by a 2-by-2 block replacement and 10 (b) is by a 3-by-3 block replacement. The 3-by-3 block replacement can represent ten different gray levels Comparing the two images (a) and (b), the 3-by-3 block replacement can keep more details than 2-by-2 replacement, the bigger number of gray levels, the higher resolution.

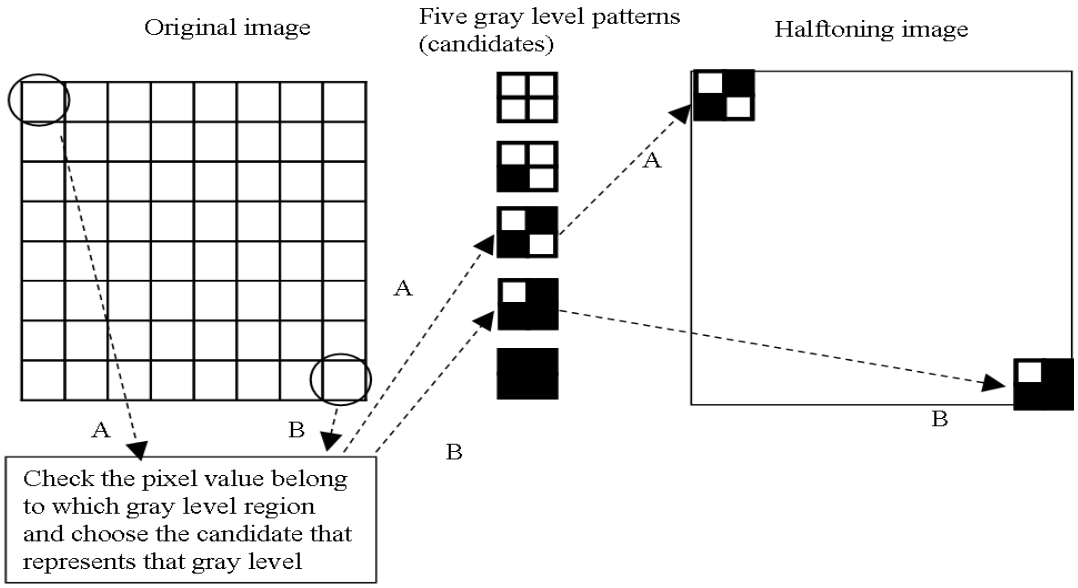

Figure 9: Block replacement halftoning. Each pixel in the original image is replaced by a 2 x 2 matrix

Due to the low-pass spatial frequency property of the human eye the same gray level can be represented by two different patterns, each of them can be arranged as a clustered dot or as a dispersed dot. The choice of the patterns has an impact on the characteristics of the final halftoning image

(a) **(b)**

Figure 10: Halftone images by block replacement. (a) The candidates are 2 x 2, i.e. 5 gray levels (b) The candidates are 3 x 3, i.e. 10 gray levels.

3. ERROR DIFFUSION

The block replacement and ordered dithering methods, treats each pixel individually, error diffusion quantifies each pixel using a neighborhood operation. In this case, the value of each output point does not depend only on the value of the corresponding input point. A schematic diagram of error diffusion method is given in Figure 11. In this figure, H and I denote the final halftoning image and the original image, respectively. This method moves through the original image in raster order, normally starting from the pixel up to the left (i.e. the first element of the matrix) and then goes through all pixels from left to right until the end. The value of each pixel in I is quantified by the constant threshold method.

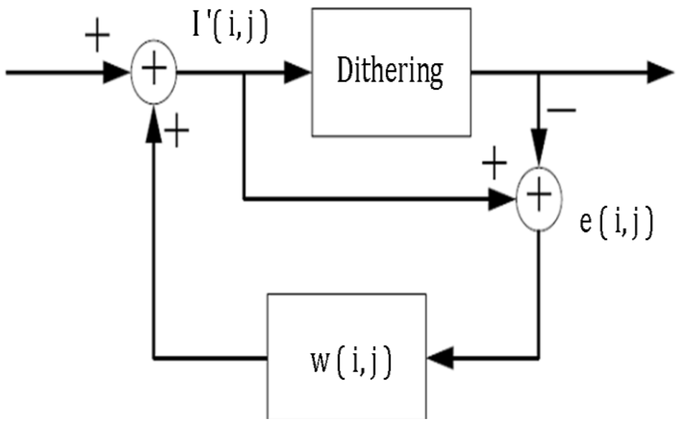

Figure 11: Error Diffusion halftoning method

One or zero is set at the corresponding position in H. Since the pixel value in I is replaced by 0 or 1 in H, there is a difference between the pixel value in I and H at the position (i, j).

After computing the difference, we obtain an error **e.** And then this error is pushed forward to the neighborhoods. To which neighborhoods and how this error is pushed is decided by a error diffusion weight matrix, i.e. a error filter w.

In Figure 12 shows the two common different error diffusion weight matrices In the Floyd and Steinberg matrix, the error occurred at the position (i,j) is weighted by 7/16 and added to the neighborhood pixel at (i+1, j). , same error is also weighted by 1/16 and added to the neighborhood at (i+1, j+1) and so on. After the error has been diffused, we get the new input image I'. The same process moves to the pixel at the next position and performs the above described steps until all pixels have been preceded.

			7/48	5/48
3/48	5/48	7/48	5/48	3/48
1/48	3/48	5/48	3/48	1/48

		7/16
3/16	5/16	1/16

(a) **(b)**

Figure 12: Error diffusion weight matrixes (a) Jarvis, Judice, and Ninke (b) Floyd and Steinberg

Figure 13 shows two images being halftoned by error diffusion with different error diffusion weight matrices. Using a larger weight matrix, the final halftoning image has sharper details and reduces some of the artifacts. In general, error diffusion shapes the error to make the most of the noise energy concentrated in the high frequencies, so that the low-frequency artifacts are minimized made not visible for the eyes. [6,7] However, since error diffusion accomplishes good resolution by spreading the dots, the final halftoning images are normally darker than the images using other methods presented so far. It is, thus, very sensitive to ink spreading.

(a) (b)

Figure 13: Halftoning image by Error Diffusion. (a) Using weight matrix 12(a). (b) Using weight matrix 12(b)

Figure	PSNR(dB)	WSNR(dB)	UQI
13(a)	6.89729	24.5358	0.106034
13(b)	6.75054	30.1316	0.0783243

Figure of merit for Error Diffusion Halftoning

CONCLUSION

In this paper, we review the various existing techniques for digital halftone processing. The constant threshold halftoning method gives unsatisfactory results. It produces a poor quality rendering of a continuous tone image, losing most of the details. In ordered dithering, the clustered dot dithering method requires a trade-off between the number of gray levels and the resolution, but it efficiently decreases the ink spreads to neighboring pixels. The dispersed dot dithering method has improved detail rendition. In block replacement, the choice of the patterns has an impact on the characteristics of the final halftoning image. Error diffusion accomplishes good resolution by spreading the dots, the final halftoning images are normally darker than the images using other methods presented so far and is very sensitive to ink spreading.

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