Incorporating Edge Information in Digital Halftoning

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Abstract: Digital halftoning is the process of generating a binary image preserving gray shade information so as to make the binary image appears visually similar to gray image. It was used in printing machines and display devices to produce binary images having gray shades. Ordered dithering and error diffusion methods are two most popular methods to generate halftone image. Generally, in a halftone image, the edges become blurred or loses its sharpness. Edges carry significant information of the foreground objects in an image and increase visual clarity by distinguishing the objects from background. A method is proposed to generate edge sharpened halftone images using a strong unsharp masks. Such edge sharpened halftone images are visually more pleasing and informative as compared with the normal halftone images. The proposed method is found to be better than Xin-Li's edge-adaptive method of generating halftone images.

Keywords: Digital halftoning, edge enhancement, unsharp masking, error diffusion, Sierra's Filter

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1. Introduction

Digital Halftoning, also earlier referred to as dithering, is the process of converting a gray scale image to binary image having shade information. It is commonly used in printing and display devices to produce gray tone like effect in binary image. Digital halftoning is performed mainly by using two different methods, Ordered dithering and error diffusion. In ordered dithering where a small matrix known as mask is repeated to generate a threshold matrix which will be compared with gray level image pixel-wise to generate binary image having shade information. Bayer method [1] is the most popular dispersed dot method of ordered dithering. The problem of the Bayer's method is that the generated binary image is not visually smooth because the generated binary image consists of textured cross-hitches. To get around textured cross-hitches in dispersed dot dithering to generate smoother binary images with shade information, Floyd and Stein [4] suggested error diffusion methods as the improved method of halftoning. This method is popularly known as Floydstein method. The error-diffusion schemes compare a pixel value with mid-range value taken as threshold. If the pixel value is greater than the threshold, the pixel value is set to upper limit of the pixel range in the image. Otherwise, the pixel value is set to the lower limit of the pixel range. The difference between the current pixel value and the currently set pixel value is considered as error and is distributed to some of its neighboring pixels yet to be processed. This process works pixel by pixel, from left to right and from top to bottom and results in random dot patterns of black and white representing gray shades. However, in Floydstein method, worm like patterns appears in the halftone image. To reduce or eliminate worm like patterns, error is diffused to the larger number of unprocessed neighboring pixels [5, 12]. A better understanding on various halftoning methods can be obtained from the reviews provided in [13, 16]. Also, several researchers proposed different halftoning methods as alternative and improvement to Floydstein method [2, 3, 6, 7, 9, 10] to suugest a few. However, the halftone images generated by these methods lost most of the edge information and hence the clarity of the image is low. Moreover, edges and textures are appeared blurred in halftone images since they are constructed by broken lines of dots. Therefore, enhancing the edges in halftone images is a way to increasing the visual quality. Horng [17] and Li [8] suggested different methods to incorporate edges in halftone image. Horng uses Canny's method to extract edges of a gray image which is then combined with the halftone image produced by Stucki's method for error diffusion. Since Canny's methods results in distorted edges, the resulted halftone image appears to have distorted and unwanted edges. Li's method uses Sobel's method for edges detection and uses Floydstein method for error diffusion. The edge image generated by Sobel's edge detector is used to modify the weight matrix of Floydstein error diffusion method. But the method, although better than that of Horng's, fails to capture most of edges and also fails to produce smooth edge enhanced halftone images because of the wormlike distortion produced by Floydstein method of error diffusion.

In the proposed method, in order to generate a smoother edge enhanced halftone image, the gray image is edge enhanced using a strong unsharp mask. The edge enhanced image is then error diffused using Frankie Sierra's Filter Lite [16] to generate halftone image. Sierra's Filter-lite method is found to be the simplest and cost effective error diffusion method to generate smoother halftone images. In spite of its simplicity, the quality of halftone images generated by Sierra's Filter lite is much better than those generated by

Floydstein's method. As a result, the quality of the halftone image is much better than that produced by Li's method.

2. Enhancing Edges using unsharp masks

Edge caries significant images about the shapes of the objects in an image. Enhancing edges in image adds visual clarity of the foreground objects from the image background. The edges of objects in a halftone image gets blurred in order to make it visually appear as a gray tone image. As a result clarity or sharpness of image is reduced in a halftone image. It has been found that the edge information in a halftone image can be enhanced using unsharp masking. Edges are the high frequency components of an image, which can be extracted from the image using unsharp mask filter as in generating informative binarization [11]. First the gray image whose halftone is to be generated is filtered with a strong unsharp mask. The resulting unsharp filtered image will be gray image with edges enhanced. A portion of it is added to the original gray image and then halftoning is performed on the resulting image.

Let X be a gray level image, U be an unsharp mask. Then the edge enhanced halftone image Y is given by

$$Y=H(X + k(U\otimes X)),$$

where $\otimes$ denotes size preserving filtering operation, k is fractional number between 0 and 1 and H denotes the halftoning operation.

The halftoning operation here we consider is the error diffusion method of Sierra Filter Lite. The reason for choosing this method is that it simplest but effective in generating good quality halftone image. The amount of edge information is controlled two parameters k and U. If k=0, the resulting halftone image is the ordinary halftone image. If $k \neq 0$, then for a given U, the more the value of k, the more edge-enhanced halftone image is obtained.

Also, for a fixed non-zero k, the quality of edge enhanced halftone image Y, depends on the unsharp mask U. To get a good quality edge-enhanced halftone image, a strong unsharp mark is required. It may be noted that the unsharp mask obtained from fspecial function in Matlab, is not suitable for this purpose. The following unsharp masks U1 and U2 are two strong unsharp masks. It has been found in [16] that the more the difference between the successive boundary elements in the mask, and the greater the value of the positive element at the middle, the stronger is the unsharp mask. So, U2 is much stronger unsharp mask than the unsharp mask U1.

$$U1 = \begin{bmatrix} -14.1667 & -10.8333 & -14.1667 \\ -10.8333 & 101.0000 & -10.8333 \\ -14.1667 & -10.8333 & -14.1667 \end{bmatrix}$$

$$U2 = \begin{bmatrix} -35.6250 & -14.3750 & -35.6250 \\ -14.3750 & 201.0000 & -14.3750 \\ -35.6250 & -14.3750 & -35.6250 \end{bmatrix}$$

The value of k must be smaller for strong unsharp masks. It has been found that the halftone image generated using the unsharp mask U1 at k=0.25 is similar to halftone image generated using U2 at around k=0.0625.

The quality of Y also depends on the size of unsharp masks used. Larger masks generate denser halftone images. Larger masks can be generated by convolution of the unsharp mask by a low pass filter.

The following unsharp masks of sizes 5x5 and 7x7 are generated from U1 by convolution of U1 by the low pass filter L, once and twice respectively.

$$L = \begin{bmatrix} 0.0667 & 0.1333 & 0.0667 \\ 0.1333 & 0.2000 & 0.1333 \\ 0.0667 & 0.1333 & 0.0667 \end{bmatrix}$$

$$U1\otimes L = \begin{bmatrix} -0.9444 & -2.6111 & -3.3333 & -2.6111 & -0.9444 \\ -2.6111 & 1.0111 & 6.0778 & 1.0111 & -2.6111 \\ -3.3333 & 6.0778 & 10.6444 & 6.0778 & -3.3333 \\ -2.6111 & 1.0111 & 6.0778 & 1.0111 & -2.6111 \\ -0.9444 & -2.6111 & -3.3333 & -2.6111 & -0.9444 \end{bmatrix}$$

$$U1\otimes L\otimes L = \begin{bmatrix} -0.0630 & -0.3000 & -0.6333 & -0.7926 & -0.6333 & -0.3000 & -0.0630 \\ -0.3000 & -0.8178 & -0.7267 & -0.4178 & -0.7267 & -0.8178 & -0.3000 \\ -0.6333 & -0.7267 & 1.3289 & 2.9222 & 1.3289 & -0.7267 & -0.6333 \\ -0.7926 & -0.4178 & 2.9222 & 5.6400 & 2.9222 & -0.4178 & -0.7926 \\ -0.6333 & -0.7267 & 1.3289 & 2.9222 & 1.3289 & -0.7267 & -0.6333 \\ -0.3000 & -0.8178 & -0.7267 & -0.4178 & -0.7267 & -0.8178 & -0.3000 \\ -0.0630 & -0.3000 & -0.6333 & -0.7926 & -0.6333 & -0.3000 & -0.0630 \end{bmatrix}$$

Similarly, larger unsharp masks may be generated by successively convolving repetitively a given unsharp mask with a low pass filter.

3. Halftoning using sierra's Filter lite

Frankie Sierra developed three different error diffusion methods for generating halftone image from a gray scale image. Filter-Lite is error diffusion method is the simplest and the most effective one. First normalize the intensity of the gray scale image. For each pixel, test whether it is greater than 0.5. If so the pixel of the corresponding halftone image is made 1, otherwise made 0. The difference between the pixel values of the gray image and the halftone being processed is considered as error and is distributed to its forward three neighboring pixels. If (i,j) is the location of the pixel being processed, the error is distributed to the three pixels corresponding to the location (i,j+1), (i+1, j-1) and (i+1,j) with respective weights 0.5, 0.25 and 0.25. This distribution of error is similar to adding the following matrix to the 8-neghborhood of the current pixel.

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0.5 \\ 0.25 & 0.25 & 0 \end{bmatrix} \times error$$

This matrix is the Sierra Filter Lite where error is the difference between the current pixel value and current pixel value in the halftone image. Assuming that Z is a normalized gray scale image of size $M\times N$. Then, the halftone image Y can be generated using Sierra Filter lite as

$$\text{FilterLite}=\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0.5 \\ 0.25 & 0.25 & 0 \end{bmatrix}$$

Z(i-1:i+1,j-1:j+1)=Z(i-1:i+1,j-1:j+1) + FilterLite*(Z(i,j)-double(Y(i,j)>0.5))

Where i=1, 2, …,M and j=1, 2, …, N and Z(i-1:i+1, j-1:j+1) denotes the 3×3 sub-matrix corresponding the 8-connected pixels at the neighborhood of Z(i,j).

The halftone image is then simply the binary image Y generated by thresholding at 0.5 as

Y=Z>0.5;

The working of this error diffusion method is that when the current pixel is higher than the 0.5, it reduces the pixel values of the left-buttom, down and right pixels so that these neighboring pixels less than 0.5 on subsequent processing. Similarly if the current pixel value is less than 0.5, it increases the values of the three neighboring pixels so that these pixels becomes greater than 0.5 on the subsequent processing. Thus, this method tries avoid white or black patches in the resulting halftone image.

Using the same proposed method, edge-enhanced color halftone can be generated from a color image by halftoning the separate color planes. Other methods for generating normal color halftones are suggested in [14, 15].

4. Experimental Results

For experimentation purpose, we used a gray image (Lena image) and a color image (Peppers.tif available in Matlab) shown in Figure-1. The edge enhancement in halftoning can be controlled by varying amount of unsharp filtered image added to the original image and then performing halftoning operation. It is found that the more fraction of the unsharp filtered image is added, the more conspicuous edges appears in the resulting halftone image. This can be easily seen from the Figure-2. The left-top image corresponds to the normal halftone image obtained by applying Filter-lite directly on the original image. The remaining three images, Figure-2(b)-2(d) i.e., top right, bottom left and bottom right are halftone images obtained by applying Filter lite on the original image plus 25, 50 and 75 percent of the unsharp filtered image using 5x5 mask. That is, the top right image of Figure-2(b) is the halftone image obtained by applying halftone operation on the image Z which is given by Z=X+0.25Y, where X is the Lena image and Y is the unsharp filtered image of it. We see that top-right image has more edge information than the top-left image. Also, we see that bottom right image contains more edges than the rest of images in Figure-2. This is because, the halftone image is generated from an image on which 75 percent of the unsharp filtered image has been added.

For comparison with Xin Li's method of halftoning, the halftone images generated by Li's edge-stop and edge-adaptive approaches are respectively shown in Figure-3 (a) and (b). From Figure-3, it is clearly visible that the halftone image in Figure-3(a) is somewhat distorted. Figure-3(b) is better compared to Figure-3(a) as it is less distorted and smoother. In both images, most of the finer edges in the original image are missing which can be easily noticed by looking at hair region of the halftone images. However, halftone image in any of the Figure 2(b), 2(c) and 2(d), the finer edge details in the original image is appropriately represented and is visually more appealing than the halftone image in Figure-3(b).

The proposed halftoning approach is then applied to color images and is found that the edge enhanced color halftones can also be produced by this approach. Figure-4 shows the halftone images of Peppers image of Figure-1, obtained by adding 50 % of the edge-enhanced image using unsharp mask of varying sizes 3x3, 5x5 and 7x7. From the figure, it can be seen that finer details in the original image are also represented appropriately in the color halftones.

Next, a study on the influence of unsharp filter size for generating edge enhanced halftone images has been made. It has been found that with the increase in filter size, more and more noise are suppressed and also at the same time edges get blurred losing finer details. So, in order to generate halftone image with proper edge information, proper sized unsharp filter must be chosen. It can be seen that unsharp filters of size 5x5 to 13x13 is found appropriate.

5. Conclusions

A simple, fast and effective method for enhancing edges in halftone image is suggested. This method based on Sierra's Filter lite and unsharp mask, can be used to incorporate undistorted edge and shade information of the original images in halftone images to increase visual clarity. It is flexible in the sense that the quality of halftone images can be controlled by either varying the size of the unsharp mask or by varying the percentage of the edge-enhanced filtered image to be added to the original image before applying halftoning operation. The proposed method has been extensively tested to several images of various textures and colors and is found to generate much better edge-enhanced binary and color halftone images as compared to the existing halftoning methods.

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Figure-1: Original Images

(Top: Lena Image, bottom: Peppers)

Figure-2: Halftone images of Lena image using proposed method.(a-top left, b-top right, c-bottom left, d-bottom right)
a: Nomral Halftone using Sierra's method b: Halftone image after adding 25% of unsharped filtered image (UFI)
c: Halftone image after adding 50% UFI d: Halftone image after adding 75 % of UFI.

Figure -3: Half tone images of Lena image using Xin-Li's method (a- top left, b-top right)
a: Halftone image uisng edge-stop approach, b: Halftone image using edge-adaptive approach

Figure-4: Color halftones of Peppers image (a- top left, b-top right, c-bottom left, d-bottom right)
a:. Color halftone using Sierra’s Filter lite, b: Color halftone using 3x3 unsharp mask
c: Color halftone using 5x5 unsharp mask, d: Color halftone using 7x7 unsharp mask

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