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A Halftone Image Edge Enhancement Algorithm Based on Blue Noise

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Abstract— *Aiming at solving the problems, which are darkening of halftone image gradation and blurring of edges, caused by blue noise mask halftone algorithm, an algorithm with enhanced detail information is proposed. Firstly, the algorithm utilizes Laplacian operator to extract edge information, weighting the contour information detected and fusing with the original image. Then, screening parameters are determined through integrating the image grayscale information with edge information. Finally, multiple experiments show that the algorithm effectively solves the problems and the proposed algorithm is feasible. The work optimizes the classical blue noise mask halftone algorithm to improve the output quality of halftone images, which can better reproduce the background and contour information of halftone images.*

Keywords— *Blue noise; halftone; edge enhancement; image content matching.*

I. INTRODUCTION

The error diffusion, ordered dither, and iterative are the there most widely applied halftone processes. Because it is simple to implement and offers a better processing effect, error diffusion is frequently employed. The classical error diffusion algorithm [1] used an error diffusion filter to scan the image pixels for fixed direction diffusion quantization according to a set fixed order, which makes the average grayscale of the halftone image close to the original image to the maximum extent, but this algorithm is prone to problems such as blurred edges and worms in the generated halftone image. To address these problems, Stevenson, Stucki [2-3] proposed to increase the diffusion range of the error filter to eliminate the effect of worm phenomenon on the image. Eschbach R [4] designed a parameter-controlled edge enhancement error diffusion algorithm to improve the pseudo-contour problem. Kwak N J [5] proposed an edge enhancement algorithm based on the characteristics of the human visual system to enhance the image edges. Sarailidis G [6] determined the halftone processing order based on the image gray value and used a non-timing error filter to reduce the generation of directional textures and pseudo contours. Fung Y H et al. [7-9] enhanced the image edges by determining the minority point type in the image while improving the efficiency of the algorithm processing.

Ulichney [10] found that the halftone images processed by the error diffusion algorithm had the basic characteristics of blue noise during the completion of his Ph.D. dissertation, which inspired the blue noise mask algorithm. 1992 Mitsa and Parker [11] first proposed the blue noise mask halftone algorithm, which is similar in basic principle to the ordered dither algorithm, but its mask size is significantly larger than the dither matrix, and when the image size to be screened is larger than the mask size, the mask is combined and stitched in a way similar to tile tiling, so that it can be spread all over the effective range of the image. After this, Yu and Parker [12] proposed an adaptive color halftone algorithm that reduces the color error by applying 2 mutually exclusive blue noise masks on two different color planes and applying an adaptive scheme on the other planes. Lee and Park [13] proposed an edge enhancement error diffusion algorithm that uses blue noise masks to dither the threshold and improve the halftone image edge information. Garateguy, Arce, and Lau [14] proposed to improve the visual effect of blue-noise masked halftone images using the optimal properties of CVT and then optimized by Lloyd's algorithm. Georgiev and Fajardo [15] proposed to minimize the low-frequency content in the output noise by associating samples between masked pixels to significantly improve the visual fidelity. Most of the improvements in blue noise based mask algorithms have been constructed with the main goal of improving the processing performance of conventional mask halftones, which are more efficient than conventional methods. However, there are still problems such as uneven visual effects of processed halftone images, darkening of image tones and blurring of image edges.

The algorithm proposed in this paper combines image edge information and grayscale information to determine halftone mask screening parameters for halftone processing, which effectively improves the visual effect of halftone images, solves the problems of dark halftone tone information and blurred edges, optimizes the classical blue noise based screening algorithm, and improves the output quality of halftone image details.

II. ALGORITHM DESIGN

The work is designed to improve image details for issues such as image gradation darkening and image edge blurring caused by traditional blue noise halftone processing. Firstly, the original image is denoised. When edges are extracted, the algorithm boosts the image's noise signal, so the input signal needs to be pre-processed with a low-pass filter before using the operator. Next, the algorithm utilizes Laplacian operator to extract edge information, weighting the contour information detected and fusing with the original image. Then, a dither array and a prototype binary pattern are constructed based on the edge-enhanced image, and on this basis, a blue noise mask is constructed. Finally, an improved halftone mask is applied to the image to obtain an edge-enhanced blue-noise halftone image. The flow chart of the algorithm is shown in Figure 1.

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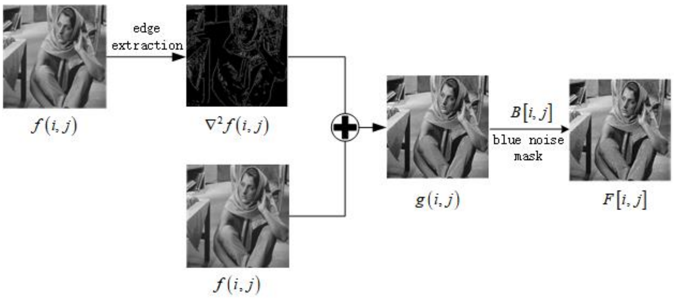

Fig. 1. Flow chart of the algorithm

A. *Edge Extraction Process*

In the picture structure, various frequency information plays diverse roles. The image contains both target and background information, with the predominant component being low frequency information, or background information, which produces the image's basic gray level. The high frequency information forms the edges and details of the image, which is a further enhancement of the image content on the medium frequency information, generally the target feature information. The Laplacian operator is needed to detect the target with high frequency information and extract its edge information. For two-dimensional images $f(i,j)$, the Laplacian operator is a second order linear differential operator that is defined as follows [16]:

$$\nabla^2 f = \frac{\partial^2 f}{\partial i^2} + \frac{\partial^2 f}{\partial j^2} \tag{1}$$

where,

$$\frac{\partial^2 f}{\partial i^2} = f(i+1, j) + f(i-1, j) - 2f(i, j) \tag{2}$$

$$\frac{\partial^2 f}{\partial j^2} = f(i, j+1) + f(i, j-1) - 2f(i, j) \tag{3}$$

The equations (2) and (3) indicate that the Laplacian is a linear transformation. For the discrete image, it can be expressed as:

$$\nabla^2 f(i, j) = f(i+1, j) + f(i-1, j) + f(i, j-1) - 4f(i, j) \tag{4}$$

B. *Enhancement of Image Edges*

The detects contour information and the original input image are weighted and fused to compensate for the lost edge information, and the calculation formula for edge information enhancement is:

$$g(i, j) = f(i, j) + c\left[\nabla^2 f(i, j)\right] \tag{5}$$

In equation (5), $g(i, j)$ is the output image information and c is the coefficient. The output image is processed by Laplacian template, and then the parameters of Laplacian operator are adjusted and the previous step is repeated until the optimal edge-enhanced image information is obtained.

C. *Prototype Binary Patterns and Dither Array*

A prototype binary pattern and a dither array are required for making a blue noise mask. The value of each element in the dither array corresponds to the value at that place in the input image in order, and in value, for example, if the mask size is $M \times N$, then the value is an integer from 0 to $(M*N-1)$, also known as rank. The prototype binary pattern is a matrix of the same size as the dither array, and for the convenience of sorting the elements in the dither array, the values are only 1 and 0. Suppose there are R 1s in the prototype binary pattern, then it means that the gray value distribution of the input image is $L = R/M*N$.

a). The Void-and-Cluster Finding Filter

Since the dither array is periodic, the corresponding prototype binary pattern will tile all the two spaces. To achieve uniform distribution, a few pixels are removed from the cluster or a few pixels are inserted into the void. Where void represents a region with a sparse distribution of a few points in the prototype binary pattern, and cluster represents a region with a dense distribution. In each iteration, the maximum cluster is first found and then the value of that cluster is set to 0. Next, the maximum void is found and the value of that void is set to 1. The iteration stops on the condition that when the value of the maximum cluster is set to 0, it itself becomes the maximum void.

A fundamental property of the void-and-cluster finding filter is the wrap-around property, defined as in equation (6):

$$D(i, j) = \sum_{p=-M/2}^{M/2} \sum_{q=-M/2}^{M/2} P(p', q')h(p, q) \tag{6}$$

where , $p' = (M+i-p) \bmod uloM$, $q' = (M+j-p) \bmod uloM$, $D(i, j)$ is the dither array, $P(i, j)$ is the prototype binary mode, and $h(i, j)$ is the Gaussian filter.

b). Constructing Prototype Binary Patterns and Dither Array

After selecting the edge-enhanced image as the initial prototype binary pattern, the ranking process begins. The values of the ranking constitute the dither array matrix, and the prototype binary pattern and the dither array are operated in parallel. The rank finding process is divided into three steps.

(a)Add 1 to the initial prototype binary pattern ($M \times N$), and when the number of 1 reaches $(M*N)/2$, set the rank of the corresponding position of the dither array to the total number of 1 in the current pattern minus one, and the processing steps are described in Table I.

TABLE I. Find the first stage of rank

Step	Algorithm Content
Input:prototype binary pattern image	
Output:rank_num in mask	
Step.1	the maximum cluster point s in the image
Step.2	read initial binary pattern image
Step.3	one_num←number(image(i,j)==1)
Step.4	rank_num←one_num-1
Step.5	**for** cluster in image:
Step.6	find s(max(image.cluster))
Step.7	**if** rank_num<0
Step.8	rank_num←one_num
Step.9	**else**
Step.10	0←s(cluster.position)
Step.11	rank_num←rank_num-1
Step.12	**end for**

(b) Remove 1s from the maximum void position from the initial prototype binary pattern until the number of 1s is zero,

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while setting the rank of the corresponding position in the jitter array to the total number of 1s of the current pattern plus one.

(c) Add 1s to the prototype binary pattern with the number of 1s being (M*N)/2 until the number of 1s is M*N-1, and set the rank of the corresponding positions in the jitter array to the total number of 1s in the current pattern plus one.

Each step of the algorithm writes the rank num value to the dither array's corresponding position, and in the conclusion, all positions in the dither array are written to the corresponding value, which is between 0 and $(M*N)$.

D. Normalize the Dither Array to Get a Blue Noise Mask

Suppose the order level of the input continuous tone image is K and the dither array is $D[i,j]$, then there is:

$$B[i,j]=\text{int}\left(\frac{D[i,j]}{MN}K\right) \tag{7}$$

where $B[i,j]$ is the requested blue noise mask.

E. Load a Blue Noise Mask onto an Edge-Enhanced Image

The blue noise mask is loaded to the edge-enhanced image using the bilinear interpolation, and the improved blue noise halftone image is obtained after processing by the algorithm in this paper, which is $F(i,j)$.

III. EXPERIMENTAL RESULTS AND ANALYSIS

A. Subjective Evaluation

The experimental test results are shown in Figure 2. Barbara image with mainly smooth regions, Boat image with rich high-frequency components and Tree image including components of low-frequency regions and high-frequency regions are mainly used for halftone processing with the classic blue noise mask algorithm and the edge-enhanced blue noise based algorithm, respectively.

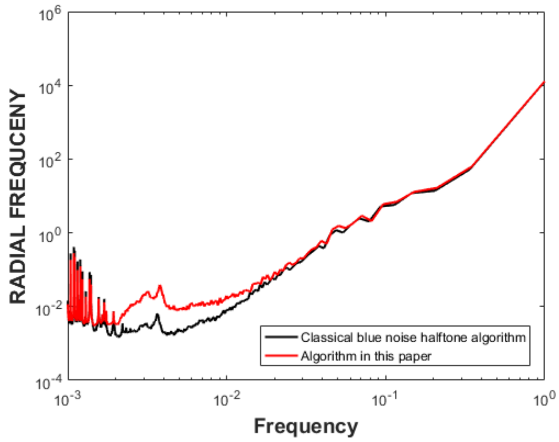
(a) (b) (c)

Fig. 2. Comparison of halftone results of Barbara, Boat and Tree. (a)Original image(b)Image generated by classical blue noise algorithm(c)Image generated by algorithm in this paper

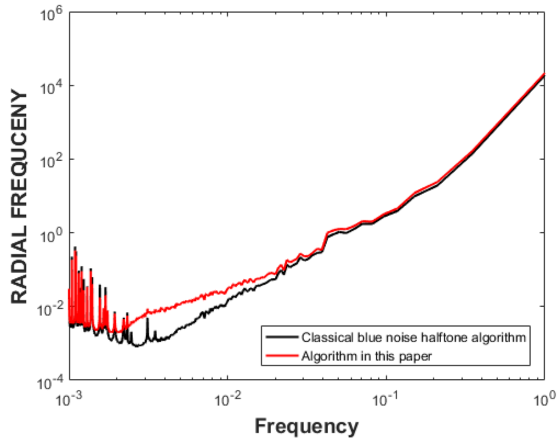
As seen in Figure 2(b) and Figure 2(c), the halftone image with darkening order and blurring edges is well improved with clearer and more uniform visual effect.

B. Objective Evaluation

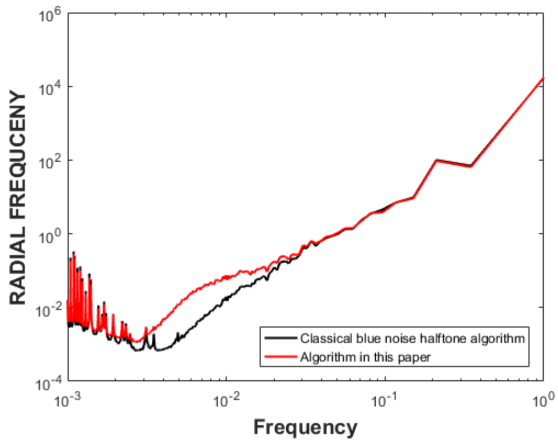
(a)The corresponding radial average power spectra are plotted for the halftone processing of the above images as shown in Figure 3.



(a) Barbara



(b) Boat



(c) Tree

Fig. 3. Comparison of radial average power spectra of Barbara, Boat and Tree

From the objective evaluation indexes in Figure 3, the halftone images obtain using both the classical blue noise mask algorithm and the algorithm in the paper have good blue noise characteristics, and the algorithm in the paper has more uniformity.

(b)The structural similarity-based approach of evaluating image quality SSIM (Structural Similarity Index) [17] is a method for reflecting an image's quality characteristics from three aspects of image brightness, image contrast, and image structural similarity, and comparing with PSNR, SSIM is more consistent with the human eye's judgment of image quality in the measurement of image quality.

SSIM takes the value range [0,1], the larger the value, the smaller the image distortion and the better the quality of halftone image reproduction. Let the original image is $M(i,j)$, the image after halftone is $N(i,j)$, L is the maximum number of gray levels of the image, which is defined as shown in equation 8.

$$SSIM=\frac{\left(\overline{M}\,\overline{N}+k_1L\right)\left(2\sigma_{MN}+k_2L\right)}{\left(\overline{M}^2+\overline{N}^2+k_1L\right)\left(\sigma_M^2+\sigma_N^2+k_2L\right)} \quad (8)$$

where, σ_M,σ_N are the standard deviations of M and N, respectively, and σ_{MN} are covariances, k_1,k_2 both of which are constants.

(c)The quality factor FOM (Pratt's Figure of Merit) [18] for image quality evaluation is a method that calculates the deviation of the detect edge point from the ideal edge, defined as shown in Equation 9.

$$FOM=\frac{1}{\max\{N_d,N_t\}}\sum_{k=1}^{N_d}\frac{1}{1+\lambda d^2(k)} \quad (9)$$

Where, N_t is the number of edge points on the ideal edge image, N_d is the number of detecting edge points, $d(k)$ represents the distance between the detecting kth edge pixel and the corresponding ideal edge pixel, and is the metric constant. The value range of FOM is [0,1],1 means the detected edge pixel matches the ideal edge pixel exactly.

TABLE II . Objective quality evaluation results of halftone images

Test Chart	Evaluation Indicators	SSIM	FOM
Barbara	Classical blue noise algorithm	0.2841	0.8937
	Edge enhancement algorithm	0.3751	0.9427
Boat	Classical blue noise algorithm	0.3762	0.9545
	Edge enhancement algorithm	0.4267	0.9637
Tree	Classical blue noise algorithm	0.2056	0.8152
	Edge enhancement algorithm	0.2688	0.9568

From the objective evaluation indexes in TABLE II, comparing with the classical blue noise algorithm, the algorithm proposed in this paper obtained the highest SSIM and FOM values of halftone images from the processing of Barbara, Boat and Tree maps, maintained the order and structure information of the original image during the processing, and the overall information has the highest similarity with the original image, and the halftone processing algorithm can best reproduce the original image. The objective evaluation results are consistent with the subjective evaluation results. It further indicates that the algorithm proposed in the paper improves the halftone image effect.

IV. Conclusion

The work design a algorithm with enhanced detail information to address the problem that the blue noise mask halftone algorithm leads to darkening of halftone image tones and blurring of edges. The algorithm uses Laplacian operator to extract edge information, then combines the image edge information with grayscale information to determine the parameters of the halftone mask for halftone processing. The results of the experiments reveal that the halftone images processed with this optimized algorithm have good blue noise characteristics, and the resulting images have good visual effects and can better reproduce halftone image features. Optimized classical blue noise based screening algorithm effectively improves the output quality of halftone images printed with higher definition and more complete edge detail under the same printing equipment or printing art conditions.

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