HIDING DATA IN COLOR HALFTONE IMAGES USING DOT DIFFUSION WITH NONLINEAR THRESHOLDING

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ABSTRACT

Image data hiding is the hiding of invisible patterns in an image without degrading its visual quality. This hidden pattern can be visualized by overlaying the original image with watermarked ones. Also it can be visualized using a simple XNOR operation. In this paper we propose a method called Dot Diffusion with Nonlinear Thresholding (DDNT) to embed hidden data in halftone images and its modification to color halftone images which will be called CDDNT. The main advantage of this method is that the hidden pattern's intensity can be adjusted by three parameters. Also it utilizes the inherent parallelism in dot diffusion halftoning method, although it suffers from its lower visual quality than some other halftoning methods such as error diffusion.

***Index Terms*—** Data hiding, Halftoning, Dot diffusion, Errot diffusion

1. INTRODUCTION

Halftoning is a technique to represent multi-tone images with binary images [1]. There have been several proposed methods to halftone gray-scale images such as ordered dithering [2], error diffusion [3], dot diffusion [4, 5, 6], neural-net based methods [7], and direct binary search (DBS) algorithm [8]. Among these methods, error diffusion offers good visual quality and reasonable computational complexity, and the dot diffusion method attempts to retain advantages of error diffusion while offering substantial parallelism. In this paper, dot diffusion is employed as the halftoning method.

Data hiding is the procedure to hide or embed data in an image without affecting its visual quality. Data hiding in halftone images can be used for printing security documents such as currency and confidential documents to prevent from illegal duplication and forgery by further scanning them to digital forms. Some data hiding schemes hide data in such a way that, when the watermarked and original images are overlaid, the hidden pattern or data can be visually detected [9, 10]. In addition to the overlaying method, the hidden pattern can be extracted by a simple XNOR operation on the two halftone images (the original and the watermarked images). Some other data hiding methods hide data in two or more visually different images where the hidden pattern can be extracted by overlaying these watermarked images. There are several proposed methods to hide data in halftone images. For example, some used noise balanced error diffusion [9] and stochastic error diffusion [10] to hide binary patterns in error diffused images.

In this paper, we propose a method called CDDNT to embed hidden data in color halftone images using the well known dot diffusion halftoning method with nonlinear thresholding. In order to halftone a pixel instead of comparing its value with the threshold 128, it is passed through a nonlinear function and then will be compared with that threshold. Hence the name nonlinear thresholding is adopted for this method. 8×8 parabolic or HVS class matrices are used as the class matrix of the dot diffusion method [6]. As mentioned before, there are three parameters which adjust the intensity of the extracted pattern, which is the main advantage of this method.

Rest of the paper is organized as follows. The dot diffusion halftoning method is briefly introduced in section 2. Section 3 introduces the DDNT algorithm for black and white halftone images. In section 4, the DDNT algorithm is generalized to color halftone images. Simulation results are given in section 5 and section 6 concludes the paper.

2. DOT DIFFUSION HALFTONING METHOD

The dot diffusion halftoning method is introduced in this section which was first introduced by Knuth [4]. Most essential works in this field are carried out by Mese and Vaidyanathan [5, 6]. Dot diffusion is an attractive method which attempts to retain the good features of error diffusion while offering substantial parallelism.

In dot diffusion method, a class matrix C is defined to determine the order in which the pixels are halftoned. Let (m, n) denote pixel positions of the image. C is an $M \times N$ matrix, where M and N are constant integers. The pixel positions of an image are divided into MN classes. So all pixels which have the same $m \bmod M$ and $n \bmod N$ belong to a common class. One example of a dot diffusion class matrix that obtained by parabolic weighting function is shown in the following figure [6].

59	12	46	60	28	14	32	3
21	25	44	11	58	45	43	30
24	20	13	42	33	5	54	8
64	52	55	40	63	47	7	18
35	57	9	15	50	48	4	36
41	17	6	61	22	49	62	34
2	53	19	56	39	23	26	51
16	37	1	31	29	27	38	10

Fig.1 The parabolic class matrix

In the class matrix shown in figure 1 there are 64 class numbers. Let $X(n_1, n_2)$ be the multi-tone image which has pixel values with a maximum of 255. Starting from class k=1, the pixels are processed for increasing values of k. For a fixed k, we take all pixel locations (n_1, n_2) belonging to class k and define the halftone pixels to be:

$$h(n_1,n_2)=\begin{cases}1 & if \quad x(n_1,n_2)\geq 128\\ 0 & if \quad x(n_1,n_2)<128\end{cases} \tag{1}$$

The error is defined to be:

$$e(n_1, n_2) = X(n_1, n_2) - h(n_1, n_2) \tag{2}$$

Then looking at eight neighbors of (n_1, n_2) the value of pixels with a higher class number is adjusted. These are the pixels which are not halftoned yet. To be specific, neighbors with higher class numbers are replaced with:

$$\begin{cases}x(n_1,n_2)+2e(n_1,n_2)/w & \textbf{for orthogonal neighbors}\\ x(n_1,n_2)+e(n_1,n_2)/w & \textbf{for diagonal neighbors}\end{cases} \tag{3}$$

where w is chosen such that sum of errors added to all the neighbors is exactly $e(n_1, n_2)$. The factor of two for orthogonal neighbors is because vertically or horizontally oriented error patterns are more perceptible than diagonal patterns. The multi-tone pixels $X(n_1, n_2)$ which have the next class number k+1 are then similarly processed. When the algorithm terminates, the signal $h(n_1, n_2)$ is the desired halftone image.

3. DOT DIFFUSION WITH NONLINEAR THRESHOLDING

In this section, we describe the Dot Diffusion with Nonlinear Thresholding (DDNT) algorithm [11] to hide data in halftone images. Let X denote the original gray-level image, H the hidden binary image, TDD the halftoned image obtained by traditional dot diffusion method and WDD the watermarked halftone image obtained by DDNT algorithm. Let H_B and H_W represent the set of black and white pixels in H respectively. Also, (i, j) is defined to be position of the pixel that is being processed. TDD is a halftoned version of X using the dot diffusion algorithm with the parabolic or HVS class matrices [6]. The image WDD is obtained in the following manner:

1- If the current pixel belongs to white pixels of H i.e. $(i,j) \in H_W$, $WDD(i,j)$ and $e(i,j)$ is calculated as follows:

$$\begin{aligned}&WDD(i,j)=TDD(i,j)\\ &e(i,j)=\max(\min(X'(i,j)-TDD(i,j),127),-127)\end{aligned} \tag{4}$$

Where $e(i, j)$ denotes the error in halftoning this pixel. Previous processed pixels of $X(i, j)$ update this pixel to $X'(i, j)$ through the diffusion error. In equation (4) the minimum and maximum operations are used to limit the error between -127 and 127.

2- If the current pixel belongs to black pixels of H and white pixels of TDD i.e. $(i, j) \in H_B$ and $(i, j) \in TDD_W$, $WDD(i,j)$ is obtained by the following equation:

$$\begin{cases}WDD(i,j)=0 & if \quad M_l \times X'(i,j)-N<128\\ WDD(i,j)=255 & otherwise\end{cases} \tag{5}$$

Where M_l is a constant less than one, and N is a positive constant. So the error is computed by:

$$e(i,j)=\max(\min(M_u(X'(i,j)-TDD(i,j))+N,127),-127) \tag{6}$$

Where M_u is a constant higher than one. This allows a number of white pixels of TDD to become black in WDD. Therefore, when TDD and WDD are overlaid the hidden pattern can be visualized.

3- If the current pixel belongs to black pixels of H and TDD i.e. $(i, j) \in H_B$ and $(i, j) \in TDD_B$, $WDD(i, j)$ can be computed by:

$$\begin{cases}WDD(i,j)=255 & if \quad M_u \times X'(i,j)+N>128\\ WDD(i,j)=0 & otherwise\end{cases} \tag{7}$$

In this case error is calculated as follows:

$$e(i,j)=\max(\min(M_l(X'(i,j)-TDD(i,j))-N,127),-127) \tag{8}$$

This makes a number of black pixels of TDD become white in WDD, which has no effect on the intensity of the hidden pattern when the images are overlaid. But if the XNOR operation is used to extract the hidden pattern instead of overlaying, the intensity of the extracted pattern will be improved by making black pixels of TDD white in WDD.

4. GENERALIZING DDNT TO COLOR HALFTONE IMAGES

In order to generalize the DDNT algorithm to color halftone images which will be called color DDNT or CDDNT, First the dot diffusion algorithm must be generalized to perform on color images. In this paper, we use the RGB components of an image to represent it. Let represent a color image C by a vector $C = [C_R\ C_G\ C_B]$ where C_R, C_G and C_B are the red, green and blue components of the multi-tone color image C. Let the vector $C^h=\begin{bmatrix}C_R^h & C_G^h & C_B^h\end{bmatrix}$ representing the halftoned version of C. The three components of this vector C_R^h, C_G^h and C_B^h are binary matrices. Therefore the color at each pixel of the image C^h is specified by three bits. The halftoning process can be thought as effect of a function f on the vector C such that $C^h = f(C)$. For simplicity we assume that this function is separable so $C^h = \begin{bmatrix} C_R^h & C_G^h & C_B^h \end{bmatrix} = \begin{bmatrix} f(C_R) & f(C_G) & f(C_B) \end{bmatrix}$. Hence to produce the halftoned version of C, first it is decomposed to its RGB components, then every component is halftoned with the dot diffusion algorithm and at last the three components are combined. In this way every component of the original color image is treated as a single image and it is halftoned separately.

Suppose that X is the original color image. Let TDD denote the color halftoned image obtained by the color dot diffusion method described in the previous paragraph. Also, let WDD be the watermarked color halftone image obtained by CDDNT algorithm. H, H_B and H_W are as defined in section 2. The image WDD is obtained by applying DDNT to every component of X and then combining the halftoned components into a single color image.

As mentioned before the main advantage of the CDDNT method is that the intensity of the extracted pattern can be adjusted by three parameters of M_u, M_l and N. As can be seen from equation (5), by increasing N a larger number of white pixels in TDD become black in WDD. Also increasing M_u and decreasing M_l has the same effect. From equation (7) it is obvious that increasing N will make more black pixels of TDD become white in WDD. Again increasing M_u and decreasing M_l will help this process. But as N increases the visual quality of the watermarked image will reduce effectively in a way that the hidden pattern can be visually extracted using the watermarked image itself. It must be noted that in every data hiding method for halftone images, increasing the intensity of the extracted pattern will result in reducing the PSNR as well as the visual quality of the watermarked image. So there is a tradeoff between the intensity of the extracted pattern and the visual quality of the watermarked image. Simulation results have shown that the intensity of the extracted pattern is more sensitive to changes in N rather than M_u and M_l.

5. SIMULATION RESULTS

The proposed CDDNT algorithm has been implemented and simulated on the LENA color image. Figures 2 and 3 respectively show the original color image X and the hidden binary pattern H. Figure 4 is the image TDD which is the halftoned version of X by applying dot diffusion to RGB (Red, Green and Blue) components of it separately and then combining the three binary matrices into a single color image. The image WDD is shown figure 5 which is the halftoned version of X using the proposed CDDNT algorithm with parameters $M_u = 1.05$, $M_l = 0.95$ and $N = 30$. Figure 6 shows the result of overlaying figures 4 and 5. To generate figure 7 the three components of figures 4 and 5 are XNORed and then they are combined in a single color image. To generate the halftone images we have used 8×8 parabolic class matrix [6]. The dot diffusion algorithm works on square sub-matrices of the original multi-tone image. This feature can be readily seen in figures 6 and 7. For example in figure 7 the pixels which are not white can be grouped in square sub-matrices of the same size as the class matrix in the dot diffusion algorithm. This feature fairly distorts the boundaries of the hidden pattern. To reduce this distortion smaller class matrices can be used in the dot diffusion algorithm.

6. CONCLUSION

In this paper we introduced a data hiding method for color halftone images called CDDNT. As discussed in the paper the intensity of the extracted pattern can be adjusted by three variable parameters in the algorithm which is the main advantage in comparison with other methods such as that in [9]. As the simulation results show the visual quality of the watermarked image is very good and the hidden pattern can be extracted by overlaying the original and watermarked images as well as by a simple XNOR operation.

7. REFERENCES

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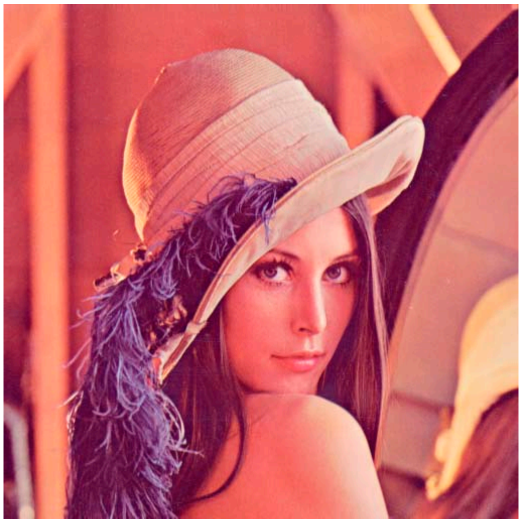

Fig.2 Lena Color Image

Fig.3 Hidden Binary pattern

Fig.4 Halftone Image by Traditional Dot Diffusion

Fig.5 Watermarked Image by CDDNT algorithm

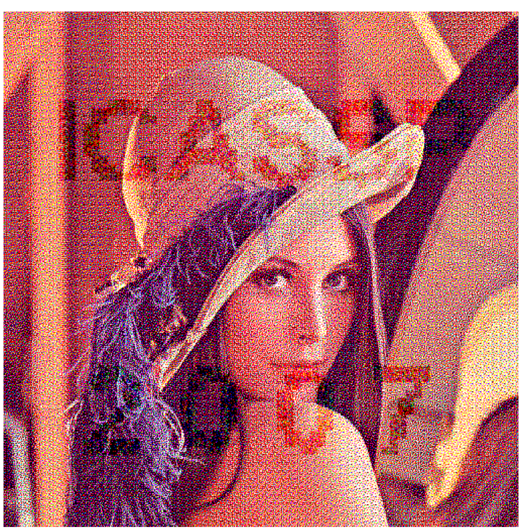

Fig.6 Overlaid Version of Figures 4 and 5

Fig.7 Result of XNORing Figures 4 and 5