Data Hiding in Halftone Images Using Error Diffusion Halftoning Method with Adaptive Thresholding

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Abstract: *DHSED is a watermarking algorithm to embed hidden binary visual patterns in two error diffused halftone images such that the hidden patterns can be visually inspected when the images are overlaid. A drawback of the DHSED method is that if the image has large areas of the same grey-level, hiding data causes some edge effects which may reveal the hidden data. In this paper we propose an improvement to the DHSED which fairly reduces the edge effects.*

Keywords: Watermarking, Halftoning, Error Diffusion, Adaptive Thresholding.

1 Introduction

Digital halftoning is the technique used to display an image with a few immiscible colors discretely applied to paper. Examples of digital halftoning methods are ordered dither [1], error diffusion [2], dot diffusion [3], neural-net based methods [4], and direct binary search (DBS) [5]. Among these methods, error diffusion offers good visual quality and reasonable computational complexity, and the dot diffusion attempts to retain advantages of error diffusion while offering substantial parallelism.

Image data hiding is the hiding or embedding of invisible data in an image without affecting its perceptual quality so that the hidden data can be extracted with some appropriate algorithms. The study of data hiding technique is commonly called watermarking [6] or steganography [7].

Data hiding in halftone image can be used for printing security document such as ID card, currency as well as confidential documents to prevent from illegal duplication and forgery by further scanning documents to digital forms.

Halftone image data hiding can be divided into two classes. One class embeds digital data into halftone image such that the data is invisible but can be read by applying some extraction process on the halftone image. One of them incorporate hide data at pseudo-random locations in ordered dither and error diffused images by self toggling or pair toggling [8, 9] of the halftone values. Some other techniques make use of circularly asymmetric halftone dot patterns to embed data [10]. The second class of halftone image steganography techniques is applied to hide visual pattern into more than one picture such that when these images are overlaid, the hidden image can be viewed directly on the halftone images [11, 12].

Data Hiding by Stochastic Error Diffusion (DHSED) [13] is an algorithm to embed hidden binary visual patterns in two or more error diffused halftone images such that the hidden patterns can be visually inspected when the images are overlaid. This algorithm show good results when applied to crowded images. But DHSED has a poor performance for images with large areas of the same grey-level.

In this paper we propose a modification to DHSED which show better results for both crowded and uniform images. Section 2 devotes to introduction of Error diffusion halftoning and DHSED algorithms. In section 3 we present the Adaptive Thresholding method to improve the performance of DHSED for images with large areas of the same grey-level. Section 4 contains some simulation results and section 5 concludes the paper.

2 Error Diffusion and DHSED algorithms

In this section we first introduce the Error Diffusion halftoning algorithm, and then DHSED algorithm is completely described. We then show poor performance of DHSED algorithm over images with large areas of the same grey-level.

2.1 Error Diffusion Halftoning Algorithm

As stated in the introduction, there are several image halftoning techniques. Among these methods Error Diffusion and Dot Diffusion show pretty good performance. In Error Diffusion halftoning, the quantization error at each pixel is filtered and fed back to the input in order to diffuse the error among neighbouring greyscale pixels. In this paper the Floyd-Steinberg kernel is used to diffuse the error to neighbouring pixels. The Floyd-Steinberg error diffusion filter is shown in figure 1, in which *X* denotes the current pixel.

0	0	0
0	X	7/16
3/16	5/16	1/16

Figure 1: Floyd-Steinberg error diffusion filter

Let the input multi-tone image be *X*, with pixel values *x(i,j)* and let *Y* be the output halftoned image. The algorithm can be described in the following steps:

1- Compute the feed-forward error $a(i,j)$.

$$a(i,j) = \frac{1}{16}\sum_{k,l=-1}^{1} e(i-k, j-l)\ker(k,l) \quad (1)$$

Where *e(i,j)* is the halftoning error and ker(*k,l*) denotes the Floyd-Steinberg filter coefficients as shown in figure 1.

2- Update the pixel value $x(i,j)$

$$f(i,j) = x(i,j) + a(i,j) \quad (2)$$

3- Compare the updated multi-tone pixel value $f(i,j)$ with a threshold *T* (*T=128*) and specify the output halftoned pixel $y(i,j)$.

$$y(i,j) = \begin{cases} 0 & f(i,j) < T \\ 255 & f(i,j) \geq T \end{cases} \quad (3)$$

4- Compute the halftoning error.

$$e(i,j) = f(i,j) - y(i,j) \quad (4)$$

2.2 Data Hiding by Stochastic Error Diffusion (DHSED) Algorithm

Suppose that we want to hide the binary image *H* in a halftone image based on *X*. Instead of hiding data in just one halftone image, DHSED is an algorithm to hide invisible watermarking data or patterns in a halftone image Y_1 and simultaneously relevant to it another halftone image Y_0 is made so that the hidden data can be detected when Y_0 and Y_1 are overlaid.

In the following discussion all the matrices are supposed to be *M×N*. We will use $x(i,j)$ and $y_k(i,j)$, k=0, 1, to represent the pixels at location (i,j) of *X* and Y_k respectively.

The first image Y_0 is generated by applying Floyd-Steinberg error diffusion method to the image *X*. Let H_W and H_B be the collection of white and black pixels in *H* respectively. DHSED applies a morphological dilation to H_B with a structuring element *S*. Let *D* be the dilated version of H_B. We can partition the pixels of image *X* into three groups as follows:

1- The pixels belonging to H_B $(:P_1)$.

2- The pixels belong to $D \cap H_W$ $(:P_2)$. (Note that P_2 corresponds to the narrow strip added around H_B to construct *D*).

3- The pixels not belonging to *D* $(:P_3)$.

To generate Y_1 with respect to the hidden data *H*, DHSED begin to halftone *X* by Error Diffusion algorithm but modifies the algorithm for pixel groups belonging to one of the sets P_1, P_2 and P_3 respectively. If the pixel (i,j) belongs to P_1 the traditional Error Diffusion method is applied. If the pixel (i,j) belongs to P_2, equations 1 and 2 are used to compute $a_1(i,j)$ and $f_1(i,j)$. Instead of equation 3 we use $y_1(i,j) = y_0(i,j)$ and instead of equation 4 we apply the following equation:

$$e_1(i,j) = \max(\min(f_1(i,j) - y_1(i,j), 127), -127) \qquad (5)$$

Finally, if the pixel (i,j) belongs to P_3, $y_1(i,j) = y_0(i,j)$ and $e_1(i,j) = 0$.

To make the above discussion clearer we present an example of DHSED. Figure 2 shows the picture *H* which is to be hided.

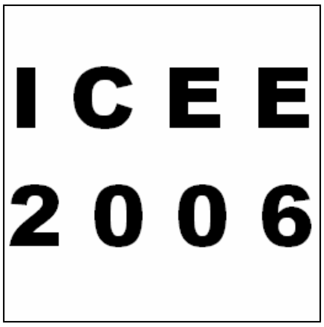

Figure 2: The hidden picture *H*

Figure 3 shows the original greyscale image *X*. figures 4 and 5 are Y_0 and Y_1 respectively and figure 6 shows the overlaid image.

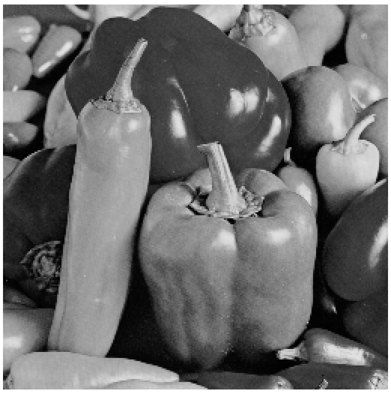

Figure 3: The original greyscale image *X*

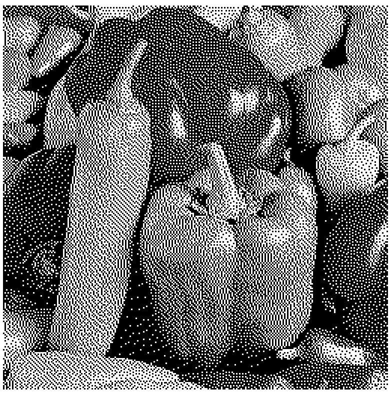

Figure 4: The image Y_0 (With no hidden data)

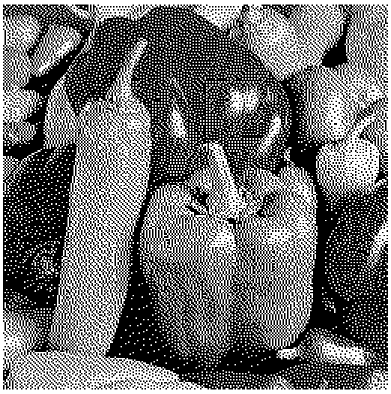

Figure 5: The image Y_1 (With hidden data)

Figure 6: Result of overlaying Y_0 and Y_1

To show the short coming of the above algorithm we make use of an image X which is divided into two parts with different brightness. The hidden text is a 'T' character. Figure 7 is the output halftoned image Y_1. Note that the edges of the hidden text character are detectable in figure 7, and perhaps by some processing it can be extracted. In the following section we propose an Adaptive Thresholding method to reduce this effect.

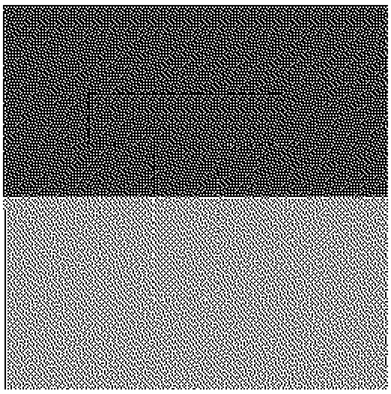

Figure 7: The edge effect in Y_1 for a hidden 'T' character

3 DHSED with Adaptive Thresholding

In this section we propose a method to reduce the above mentioned drawback of DHSED. These edge effects occur for the pixels in set P_1, because the pixels in P_2 and P_3 in image Y_1 have the same grey-level as image Y_0 but the error $e_1(i,j)$ of these pixels in Y_1 is different from $e_0(i,j)$ in Y_0. Although this is the key point in DHSED, by which the data can be extracted by overlaying images, at the same time it leads to some visually detectable changes in image Y_1.

If image Y_1 in figure 7 is investigated, we see that the boundary of character 'T' in the upper part of the halftoned image is darker than the background and the boundary in the lower part is brighter than the background. Now to bring the brightness of the boundaries to the natural brightness of each part, we choose the threshold to halftone the boundaries adapted to the brightness of that part. For the upper dark part of the image the threshold is chosen lower than 128, while for the brighter lower part the threshold is chosen higher than 128.

So we need a measure of the average grey-level at every pixel of image *X* to adjust the halftoning threshold *T*. This measure may simply be the pixel values of the low-pass filtered version of the original image *X*. Suppose that *Z* is the low-pass filtered version of *X*, by the $(2L+1)\times(2L+1)$ averaging filter. If we choose *a* and *b* as lower and upper thresholds respectively, the adaptive threshold T_a is calculated using the following equation.

$$T_a = \begin{cases} a & z(i,j) < l \\ b & z(i,j) \geq u \\ 128 & otherwise \end{cases} \qquad (6)$$

In (6) l<128 and u>128, l is a criterion of being dark while u is a criterion of being bright. It is clear that in dark areas $T_a = a < 128$, while in bright areas $T_a = b > 128$. In the results shown in this paper we have chosen the following values for *a*, *b*, *u* and *l*.

$$a = 70 \quad b = 155 \quad u = 130 \quad l = 90 \qquad (7)$$

Figure 8 shows the result of applying DHSED with the adaptive threshold T_a in (6) to the synthetic image used in the previous section. Note that the edge effects in figure 7 are reduced when using Adaptive Thresholded DHSED instead of the simple DHSED. However in real pictures there aren't such large areas of the same grey-level as shown in figures 7 and 8, therefore using Adaptive Thresholded DHSED can blur the visual edges of the hidden text in areas of the same grey-level.

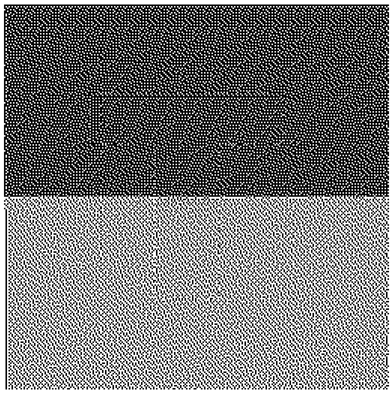

Figure 8: Image Y_1 using Adaptive Thresholded DHSED

4 Simulation Results

The proposed Adaptive Thresholded DHSED is simulated using the 256×256 Peppers image in figure 3. The error diffused halftone image using Floyd-Steinberg kernel with no hidden data Y_0, is shown in figure 4. The error diffused halftone image using Adaptive Thresholded DHSED with figure 2 as the watermark image is shown in figure 9. Note the visual edges of the first 'E' character of the hidden text in figure 5, which has been improved using the Adaptive Thresholding scheme as shown in figure 9. Figure 10 shows the overlaid version of Y_0 and the watermarked image in figure 9. The hidden pattern can be visualized also by a simple XNOR boolean operation. The result of XNORing Y_0 and Y_1 is shown in figure 11.

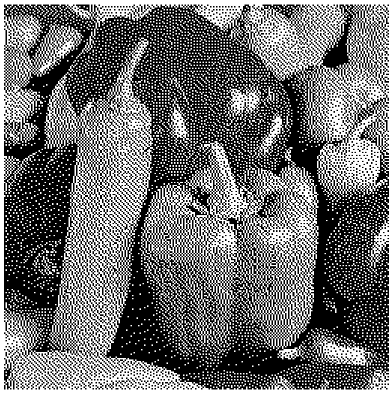

Figure 9: Watermarked image using Adaptive Thresholded DHSED

Figure 10: Result of overlaying Y_0 and the image in figure 9

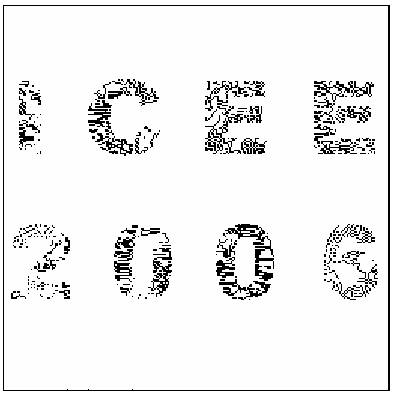

Figure 11: Visualizing the hidden pattern by the XNOR boolean operation

5 Conclusion

DHSED can embed hidden pattern in two visually halftone images. The pattern is visible through overlaying or XNOR boolean operation. This method shows edge effects when applying to synthetic images. In this paper we propose the Adaptive Thresholding method to reduce the edge effects of DHSED. In the experiments, Adaptive Thresholding found to be very effective in reducing the edge effects of DHSED without affecting the visual quality of the watermarked image.

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