Hiding Data in Halftone Image using Modified Data Hiding Error Diffusion

Ming Sun Fu, Oscar C. Au

Department of Electrical and Electronic Engineering,
Hong Kong University of Science and Technology,
Clear Water Bay, Hong Kong, China.
Email: fmsun@ust.hk, eeau@ust.hk

Abstract

With the ease of distribution of digital images, there is a growing concern for copyright control and authentication. While there are many existing watermarking and data hiding methods for natural images, almost none can be applied to halftone images. In this paper, we proposed a novel data hiding method, Modified Data Hiding Ordered Dithering (MDHED) for halftone images. MDHED is an effective method to hide a relative amount of data while yielding halftone images with good visual quality. Besides, the amount of hidden data is easy to control and the security depends on the key not the system itself.

Keywords: data hiding, halftone image, watermarking, error diffusion

1. Introduction

Nowadays, digital images can be distributed easily through the Internet and the Web. As a side effect, the problems of copyright infringement and authentication grow rapidly with the ease of distribution. One of the possible solutions is to embed some hidden or invisible watermarking data into these images. There have been quite a number of watermarking methods [1,2,3] designed for natural gray scale images. They mainly use the inherent redundancy of gray scale images to embed data such as using the least significant bit to embed data in the spatial domain or modifying the images within the perceptual thresholds in the frequency domain. However, few, if not none, of the algorithms can be applied to halftone images [4]. This is because halftone images have only 2 tones and have large amount of high frequency noise resulting in little intensity redundancy.

Halftoning [5] is a process to change multi-tone images into 2 tone images, which look like the original multi-tone images when viewed from a distance. Halftone images are widely used in the printing of books, magazines, newspapers and in computer printers, which are very common in our daily lives. It is often desirable to hide certain data within the halftone images such as company identity, owner information, creation date and time and other information for copyright protection and authentication purposes. In this paper, a improved method called Modified Data Hiding Error Diffusion (MDHED) to a hide a fairly large amount of data in the halftone images with minimal degradation of the visual quality is developed.

There are two main kinds of halftoning techniques, namely, ordered dithering [6] and error diffusion [7]. Ordered Dithering is a computationally simple and effective halftoning method. It compares the pixel intensities with some pseudo random threshold screens in order to determinate its 2-tone output. Error diffusion is an advanced technique, which can generate halftone image with higher visual quality. The essential parameter of error diffusion is its error kernel. Figure 1a is the Jarvis kernel and Figure 1b is the Steinberg kernel. Different kernels generate halftone images with significant different characteristics. For simplicity, the Steinberg kernel will be used in the rest of paper.

Figure 3a Impulse response of halftone error at location(3,2)

Figure 3b Convolution kernel of pixel at location (3,3)

Let $x(i, j)$ be the multi tone pixel, $h(i,j)$ be the halftone pixel and $e(i,j)$ be the halftone error of image pixel at location (i,j) . They are related as follows.

$u(i,j) = x(i,j) + \text{weighted sum of past halftone errors}$

$h(i,j) = 255$ if $u(i,j) \geq T$; where T is the threshold, 128 is often used
 $h(i,j) = 0$ if $u(i,j) < T$

$e(i,j) = u(i,j) - h(i,j)$; halftone error

When the above equations are applied sequentially, the whole halftone image can be generated. The error feed forward mechanism helps to maintain the local average of the halftone image, which is essential for visual perceiving.

3. Data Hiding Error Diffusion (DHED)

Data Hiding Error Diffusion (DHED) [8] is a simple method to embed data during the error diffusion halftoning. Figure 4 is the block diagram of the DHED. It is a symmetric key cryptography. In DHED, N pseudo-random locations are generated by a key to embed data. Data can be any kinds of data such as raw data, data after DES [9] or RSA [10] and any data after error correction codes. One bit of data is hidden at each of the N pseudo-random locations by forcing the pixels at those locations to be zero or one if necessary according to the embedded data.

Figure 4 Block Diagram of DHED

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

Figure 1a Jarvis kernel

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

Figure 1b Steinberg kernel

For data hiding in halftone images, there are two different situations. The first situation is the one in which a halftone image is available without the original multi-tone image and the method of halftoning is not known. In this case, any data-hiding algorithm can only operate on the available halftone image. Data Hiding Pair Toggling (DHPT) [8] is a method to handle this situation.

The second situation is the one in which the original multi-tone image is known as well as the method of halftoning. In this situation, the data-hiding algorithms can be integrated into the halftoning procedure to yield higher visual quality than the first situation. In this paper, we are concern about the case when the halftoning procedure is error diffusion. Data Hiding Error Diffusion (DHED) [8] was previously report to integrate the data hiding procedure into the error diffusion process. In this paper, we propose an improved method which we call the Modified Data Hiding Error Diffusion (MDHED) to achieve improved visual quality.

2. Error Diffusion

Error Diffusion is an advanced halftoning technique, which can generate higher quality halftone image. Although it is more complicated than ordered dithering, overall it is still a simple process. Figure 2 is the block diagram of error diffusion. Error Diffusion is a causal single-pass sequential algorithm. The 2-D multi tone image is halftoned line by line sequentially. In this paper, horizontal line process is chosen for illustration.

Figure 2 Block diagram of Error Diffusion

Error kernel can be considered as the impulse response of a filter operating on the halftone error. Each halftone error is fed forward to its adjacent location. Since error diffusion is a single pass algorithm, it is useless to feed the error backward. Figure 3a is the impulse response of the halftone error at location (3,2) according to the Steinberg kernel. Shaded pixel represents the halftone error of halftoned pixel. In terms of convolution, each pixel is added to the weighted sum of its past adjacent halftone errors before thresholding. It is illustrated in Figure 3b.

From another point of view, error diffusion compares the multi tone pixel with a threshold that adapts to the local (past) image characteristics (halftone error). This is superior to ordered dithering in which the multi tone pixel is compared with fixed pseudo-random threshold independent of the local image characteristics. Therefore, error diffused halftone image can achieve higher visual quality.

DHED is the same as normal error diffusion outside the N locations. At the N locations, the $h(i,j)$ is set according to the embedded data, not by usual thresholding as in error diffusion. Assume that the embedded data are uniformly distributed and independent of the image characteristics, then, with a probability of 0.5, $h(i,j)$ is equal to the output of the normal thresholding. In these cases, the data are embedded naturally and thus no change is needed.

However, with a probability of 0.5, $h(i,j)$ is different from the natural output of the error diffusion thresholding. For the regular error diffusion, the magnitude of $e(i,j)$ is less than or equal to 128. However, when the original halftone value differs from the natural halftone output in DHED, the magnitude of $e(i,j)$ will always be greater than 128. Such larger error will create artifact if it is not well compensated. Fortunately, such error can be fed forward to its adjacent pixels as usual. In the error diffusion mechanism, the local average of the halftone image can be maintained.

In order to extract data, it is simple. Assume the same key is known. The embedded data in the N locations can be extracted by reading the halftone values at the N pseudo-random locations. Figure 5 is the block diagram of data extraction

Figure 5 Block Diagram of Data Extraction

Although DHED can achieve satisfactory performance, there are still two weaknesses. The first weakness is that both the relatively small normal halftone error and the relatively large data hiding error are spread by the same error kernel. The large halftone error tends to dominate over the small normal error diffusion halftone errors. The second weakness is that the halftone error by embedded data is only compensated by the future pixels. It may distort the structure of error diffused halftone image and forms clusters.

For an area with normalized intensity $2/3$, roughly a fraction $2/3$ of the pixels are white pixels and $1/3$ of the pixels are black. Usually, due to the nature of error diffusion, those minority pixels are scattered like Figure 6a. However, for DHED, if the pixel at location $(2,2)$ is required to be embed bit 0 (black pixel), it abnormally connects the adjacent black pixels together to form a cluster which is a visual artifact for halftone image. Although such error may feed to its coming pixels, for example pixel at location $(3,3)$ is changed to be a white pixel in order to maintain the local average of this area by error diffusion. However, DHED cannot avoid the formation of the clusters before the embedding location.

Figure 6a Area before DHED

Figure 6b Area after DHED

4. Modified Data Hiding Error Diffusion (MDHED)

Modified Data Hiding Error Diffusion (MDHED) is proposed to solve the weakness of DHED. The major difference between it and DHED is that the kernel of MDHED is non-causal. Figure 7 is the detailed block diagram of MDHED. It consists of two stages, the pre-halftoning and error estimation stage and the non-causal error diffusion stage.

Figure 7 Block Diagram of MDHED

The pre-halftoning and error estimation stage

The error estimation stage is very simple. It uses the same N pseudo-random locations and hide one bit of embedded data in each of those locations as in DHED. Then the $h(i,j)$ is known for these N locations. However, $e(i,j)$ is still unknown, since

$$e(i,j) = u(i,j) - h(i,j) = x(i,j) + \text{weighted sum of past half errors} - h(i,j)$$

and the past errors are not known yet until error diffusion is applied to them. However, the weighted sum of past half errors can be assumed to be a zero mean random variable. Therefore, the unbiased estimation of the $e(i,j)$ is

$$e(i,j) = [x(i,j) - h(i,j)] / \text{normalization factor } M$$

The non-causal error diffusion stage

Since these N halftone errors are pre-estimated. Their errors can be fed both backward and forward to its adjacent pixels. Their impulse response can be model as the kernel in Figure 8. It is a symmetric kernel. Notices that the sum of the kernel is equal to 2, not equal to one. In order to normalize it, the normalization factor $M=2$ is used in the error estimation stage.

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

Figure 8 New kernel

Although the kernel is non-causal, the error diffusion is a single-pass sequential process. It is actually the same as usual for area without embedded data. Figure 7a show the convolution kernel of the pixel at location (3,3), where there are no embedded data within the 3x3 neighborhood. Although its kernel elements are non-zero, the halftone error of its future unhalftoned pixels are chosen to be zero. Therefore, its result is the same as the causal kernel.

Figure 9a

Figure 9b

For the adjacent pixel near embedded data, the situation is different. Suppose there is an embedded data at location (4,4). Figure 10a shows the impulse response of halftone error in (3,2). Because of this impulse response, the contribution of the error at (3,2) to the pixel at (3,3) is 7/16 in Figure 10c. With data embedded at (4,4), the halftone error at location (4,4) is estimated by assuming past pixel errors are zero. Figure 10b shows the normalized impulse response of the estimated halftone error at location (4,4) by normalization factor $M=2$. Because of this impulse response, the contribution of the error at (4,4) to the pixel at (3,2) is 1/32 in Figure 10c. Figure 10c shows the resulting convolution kernel of (3,3). As the unhalftoned future pixels are assumed to have zero error, the effective convolution kernel of (3,3) is shown in Figure 10d.

Figure 10a Impulse response at (3,2)

Figure 10b Impulse response at (4,4)

Figure 10c Convolution kernel at (3,3)

Figure 10d Effective kernel at (3,3)

After the pixel (4,4) is halftoned, the exact halftone error can be obtained.

$$e(i,j) = x(i,j) + \text{weighted sum of halftone error} - h(i,j)$$

However, it is better not to replace the estimated error by the exactly halftone error. In this case, keeping the estimated halftone error helps to maintain consistency for both the past and the future pixel adjacent to the pixel location at (4,4). Updating the error will distort the impulse response at location (4,4).

MDHED can solve the two weakness of DHED. The abnormal large error due to the embed data is now diffused into a larger area in all directions. It also helps to avoid clustered pixels. The pixels can foresee the embedded data by the feedback of halftone error of embedded data. Therefore, error is unlikely to accumulate in both past and future pixels.

In general, the non-causal kernel is not necessary to be symmetric. The causal portion itself is required to be normalized to one like normal error diffusion. The rest of kernel can be anything. The normalization factor M is the sum of the whole non-causal kernel.

4. Simulation results

In order to illustrate the performance of MDHED, a 512x512 8-bit gray scale image Lena shown in Figure 11a is used as a testing image. Figure 11b is the enlargement of the center portion of Lena. Figure 12a is the halftone image generated by error diffusion using the Steinberg Kernel. Figure 12b is the enlargement of Figure 12a. In Figure 12b, it can be observed that the white pixels are seldom grouped together in dark regions, and dark pixels are seldom group together in bright regions.

Figure 13a is the halftone image generated by DHED. Figure 13b is its enlargement. In this image, one random pixel within each 8x8 block is chosen to embed data. Therefore, there are a total of $N = 4096$ bits embedded. The percentage is 1.5625% of the total image size. This high percentage is used for illustration of the proposed algorithm under stress. In real applications, N can be smaller. From Figure 13a, the image is very similar to Figure 12a at first glance. Under detailed observation, some abnormal black and white artifacts are found. From the enlargement in Figure 13b, these black and white artifacts are formed by abnormal clustering of white and black pixels in the bright and dark regions respectively. For each cluster, one of pixel belongs to the N locations and the black and white noise is the embedded data itself.

Figure 14a is the halftone image by MDHED. The same key is used and the same data is embedded. Figure 14b is its enlargement. Figure 14a looks the same as Figure 12a which has no embedded data. Even under detailed examination, it is hard to find out any abnormal artifact. From Figure 14b, it is hard to spot out which pixel embedded data. MDHED can achieve higher visual quality than DHED, while maintaining the same data hiding capacity.

5. Conclusion

Modified Data Hiding Error Diffusion (MDHED) is a algorithm proposed for embed data during the halftoning. The halftone errors due to embedded data are estimated first and non-causal error diffusion is applied to spread these errors to its adjacent pixels in all direction, which is significantly different from normal error diffusion. It can generate halftone image with better visual quality than DHED.

6. Reference

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Figure 11a Original multi-tone image

Figure 11b Enlargement of Figure 11a

Figure 12a Halftone image by error diffusion (Steinberg kernel)

Figure 12b Enlargement of Figure 12a

Figure 13a Halftone image by DHED

Figure 13b Enlargement of Figure 13b

Figure 14a Halftone image by MDHED

Figure 14b Enlargement of Figure 14a