IMPROVED PAIR TOGGLING DATA HIDING BY COOPERATING HUMAN VISUAL SYSTEM IN HALFTONE IMAGES

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ABSTRACT

An improved data hiding in halftone images with cooperating Pair Toggling Human Visual System (PTHVS) is presented in this paper. An objective halftone image quality evaluation method based on the human visual system obtained by Least-Mean-Square (LMS) is also introduced. By rigorously searching the optimum toggled pixels with the proposed human visual LMS-trained filter, the proposed method is proven to be superior to the Data Hiding Smart Pair Toggling (DHSPT), proposed by Fu and Au, in image quality under a number of tested halftone images. The tested halftone images include ordered dithering, Floyd error diffusion, Jarvis error diffusion, and Stucki error diffusion images. Moreover, the proposed method offers high embedded capacity, and it is flexible to deal with different capacity applications.

***Index Terms*—**halftone, error diffusion, least-squares, human visual system, data hiding.

1. INTRODUCTION

Digital halftoning [1] produces two-tone texture pattern that, through the human low-passed visual system, approximate the original multi-tone images, preserving a significant level of the original information content. The technique is widely used in computer printer-outs, printed books, newspapers, and magazines, because these printing processes are limited to the black-and-white format. There are many halftone methods, and the most popular ones are the ordered dithering [1], error diffusion [2]-[4], and least-squares [5]. Among these, error diffusion produces good visual quality and reasonable computational complexity.

Watermarking and data hiding have many usages, including: protecting ownership rights of an image, protecting against the use of an image without permission, and authenticating an image to prove that it has not been altered. Generally speaking, data hiding does not need to take the robustness issue into consideration. So the major applications for data hiding are tampering detection and authentication. Currently, numerous methods using halftones to embed secret data have been studied. These techniques can be used for printing security documents such as ID card, currency as well as confidential documents, and prevent from illegal duplication and forgery by further scanning these documents to digital forms. In general, these methods can be divided into two categories.

In techniques of the first category, the original host image is grayscale. The watermark embedding process cooperates with halftoning process, and the embedded image is halftone. This sort of method usually provides better image quality and higher capacity. These methods are as follows: Using a number of different dither cells to create a threshold pattern in the halftoning process [6]. In [6], the major advantage is the robustness against the print-and-scan attack. However, the major shortcoming is the inflexibility of embedded capacity. The halftone screens have to be redesigned as the capacity is changed. Using vector quantization (VQ) to embed watermarks into the most or least significant bit (MSB/LSB) of error diffusion images [7]. The benefits of this algorithm are that a low bit-depth halftone image can be directly obtained from a higher bit-depth halftone for printing or progressive transmission simply by masking one or more bits off of the higher bit-depth image. However, the technique proposed in [7] is just used to embed a watermark that is the error-diffused version of the original host image, and cannot be generalized to embed arbitrary binary or multi-scaled watermark images. One another special data hiding embeds hidden visual patterns into two or more halftone images. The hidden visual patterns can be perceived directly when the halftone images are overlaid each other. These techniques include using stochastic screen patterns [8], hybrid pixel-based data hiding and block-based watermarking [9]. The advantage of this category is the fast decoding even without the aid of computer. However, the major problem is that the decoded watermark is just an approximate version of the original watermark, which cannot fully convey the meaning of the original embedded data.

In methods of the second category, the original host image is already a halftone version. The works in this category are relatively fewer than in the first category, since the image quality is difficult to be maintained in high embedded capacity applications. The methods include the following: Directly force the pixel value according to the embedded data, named Data Hiding Self Toggling (DHST), or randomly choose a pair of pixels to be toggled in order to keep the local intensity unchanged, named Data Hiding Pair Toggling (DHPT) [10]. A modified technique, Data Hiding by Smart Pair Toggling (DHSPT), achieves the best quality by choosing the minimum connection toggled pixels after data embedding [11]. However, the parameters employed in [11] do not comply with the human visual system, which leads to limited image quality improvement.

Regarding the shortcomings in DHSPT [11], firstly, we proposed an objective halftone image quality evaluation method based on a human visual system obtained by Least-Mean-Square (LMS). Secondly, the optimum toggled pixel is determined by the proposed "Pair Toggling with Human Visual System (PTHVS)" method. As the experimental results demonstrated, this technique is superior to the previous DHSPT method in all kinds of halftone images, such as Floyd error diffusion [2], Jarvis error diffusion [3], Stucki error diffusion [4], and ordered dithering [1]. Moreover, the proposed method offers high embedded capacity, and it is flexible to deal with different capacity applications.

2. QUALITY EVALUATION

Following we define the quality evaluation employed in this paper. For an image with size $P \times Q$, the quality evaluation of halftone images is defined as,

$$PSNR = 10 \log_{10} \frac{P \times Q}{\sum_{i=1}^{P} \sum_{j=1}^{Q} [x_{i,j} - \sum_{m,n \in R} \sum w_{m,n} b_{i+m,j+n}]^2} \quad (1)$$

where $x_{i,j}$ is the original grayscale image, $b_{i,j}$ is the halftone image, $w_{m,n}$ is the human visual system coefficient at position (m,n), and R is the support region of the human visual system coefficients. In this paper we fixed R at size 7×7. The human visual system w can be obtained by psychophysical experiments [12]. The other way to derive w can use a training set of both pairs of gray level images and good halftone results of them, such as using error diffusion or ordered dithering to produce the set [13]. Here we use Least-Mean-Square (LMS) to derive w as described as follows.

$$\hat{x}_{i,j} = \sum_{m,n\in R}\sum w_{m,n} b_{i+m,j+n}, \tag{2}$$

$$e_{i,j}^2 = (x_{i,j} - \hat{x}_{i,j})^2, \tag{3}$$

$$\frac{\partial e_{i,j}^2}{\partial w_{m,n}} = -2 e_{i,j} b_{i+m,j+n}, \tag{4}$$

$$\begin{cases} \textit{if } w_{m,n} > w_{m,n,opt}, \textit{ slope} > 0, w_{m,n} \textit{ should be decreased} \\ \textit{if } w_{m,n} < w_{m,n,opt}, \textit{ slope} < 0, w_{m,n} \textit{ should be increased}, \end{cases} \tag{5}$$

$$w_{m,n}^{(k+1)} = w_{m,n}^{k} + \mu e_{i+m,j+n} b_{i+m,j+n}, \tag{6}$$

where $w_{i,j,opt}$ is the optimum LMS coefficient; $e_{i,j}^2$ is the MSE between $x_{i,j}$ and $\hat{x}_{i,j}$; μ is the adjusting parameter used to control the convergent speed of the LMS optimum procedure, which is set to be 10^{-5} in our experiments.

There are 8 images used in our training process: Lena, Mandrill, Yosemite, Paris, Airplane, Peppers, Milk, and Lake images. The Floyd error diffusion [2] and Bayer-5 dispersed-dot halftone screen [1] are used to produce the corresponding halftone training results. Notice that this filter has several basic human visual system characteristics, which includes (1) the diagonal has less sensitivity than the vertical and horizontal directions and (2) the center portion has the highest sensitivity and it decreases while moving away from the center.

3. DATA HIDING BY SMART PAIR TOGGLING (DHSPT)

In this section, we briefly describe the previous DHSPT technique [11]. Firstly, the N pseudo random locations in the original host image are determined to be embedded with secret data of size N. The N selected pixel values of the host image are forced to be the same as the secret data. As one pixel (called master pixel) is toggled, one of the eight pixels (called slave pixel) in the neighborhood with opposite value is toggled to keep the local average intensity unchanged. The method used to determine the best toggled slave pixel is described as follows.

The connection $con(m,n)$ of a slave pixel x_0 at location (m,n) is defined as

$$con(m,n) = \sum_{i=1}^{8} w(i) f(x_0, x_i),$$
$$f(x,y) = \begin{cases} 1, & x = y \\ 0, & x \neq y \end{cases} \tag{7}$$

where x_i represent the eight neighborhood of the pixel x_0, and are expressed in Matlab notation as $[x_1, x_2, x_3; x_4, x_0, x_5; x_6, x_7, x_8]$. The variable $w(i)=1$ for i=1, 3, 6, 8 and $w(i)=2$ for i=2, 4, 5, 7. Since the master and slave pixels are toggled in the same time, the contribution of the master to the connection of the slave will be zero whether before or after the toggling. If the master is horizontal or vertical to the slave, the weight of the master is 2, and $con_{before}(m,n) + con_{after}(m,n) = 10$ (where $con_{before}(m,n)$ and $con_{after}(m,n)$ indicate the connection of a slave pixel before and after the toggling). Otherwise, $con_{before}(m,n) + con_{after}(m,n) = 11$. Hence

$$con_{after}^{DHSPT}(m,n) = \begin{cases} 10 - con_{before}^{DHSPT}(m,n), & \textit{If master slave are vertical or horizontal neighbors} \\ 11 - con_{before}^{DHSPT}(m,n), & \textit{Otherwise}, \end{cases} \tag{8}$$

is used to determine the best toggled slave pixel, and the one with the minimum con_{after}^{DHSPT} is the winner.

4. DATA HIDING BY PAIR TOGGLING WITH HUMAN VISUAL SYSTEM (PTHVS)

In this section, we present the proposed data hiding by Pair Toggling with Human Visual System (PTHVS). In our observation, the DHSPT has the following shortcomings:

1. The weightings used to determine the connection of a slave pixel are set to 2 (for vertical and horizontal neighborhood) and 1 (for diagonal neighborhood), which is a good choice. However, the actual human visual sensitivity is not considered in the weightings' allocation. The weightings could be improved by cooperating with the human visual system.
2. As a slave pixel is toggled, only the eight neighborhoods are included in the connection evaluation. This assumption obeys the human visual characteristic as well, since an optimum toggled position has to take a larger region into account in normal viewing distance.

For these, we employ the LMS-trained filter discussed in section II cooperating with pair toggling for secret data embedding. Here we suppose the dimensions of the host halftone image and the LMS-trained filter are $P\times Q$ and $M\times N$ (7x7 in this paper as discussed in section 2), respectively.

Firstly, a temporary inverse halftone image is obtained by

$$\tilde{g}_{x,y} = \sum_{\substack{FIX(-\frac{M}{2})\le m\le FIX(-\frac{M}{2}) \\ FIX(-\frac{N}{2})\le n\le FIX(-\frac{N}{2})}}\sum w_{m,n} b_{x+m,y+n}, \tag{9}$$

where x, y $\in P\times Q$, and $FIX(x)$ rounds the elements of x to the nearest integers towards zero. The variable $w_{m,n}$ represents the coefficient of LMS filter at (m,n), and $b_{x,y}$ stands for halftone host image. As a slave pixel is toggled, the Visual Error (VE) is given as

$$VE = \sum_{\substack{FIX(-\frac{M}{2})\le i\le FIX(\frac{M}{2}) \\ FIX(-\frac{N}{2})\le j\le FIX(\frac{N}{2})}}\sum \Big[\sum_{\substack{FIX(-\frac{M}{2})\le m\le FIX(\frac{M}{2}) \\ FIX(-\frac{N}{2})\le n\le FIX(\frac{N}{2})}}\sum (\tilde{g}_{i,j} - w_{m,n} b_{i+m,j+n})^2\Big], \tag{10}$$

where the toggled slave pixel is centered at $(i=0, j=0)$. Generally speaking, the slave pixel with smallest VE is the optimum candidate for toggling.

5. EXPERIMENTAL RESULTS

In this section, we conduct a number of experiments to show the performance of the proposed PTHVS technique. The simulation results are compared between DHSPT and PTHVS by objective (Figs. 1, 2) and subjective (Figs. 3-6) quality evaluation.

In Fig. 1, we show the quality comparison by embedding 1024 and 65536 bits into 8 tested 512x512 Floyd error-diffused images, which include Lena, Mandrill, Peppers, Milk, Airplane, Tiffany, Earth, and Lake. The result shows that in both embedded capacities situations, the proposed method achieves better quality than DHSPT.

We also perform an average PSNR (using the 8 tested images as described above) comparison with four different halftone techniques, which include Floyd error diffusion, Bayer-5 ordered dithering, Jarvis error diffusion, and Stucki error diffusion with 5 different embedded capacities. The results also show that the proposed PTHVS is superior to the DHSPT in all cases.

Finally, we give the a series of images for subjective quality evaluation as in Figs. 3-6, where the images with (a) are original halftone images, images with (b) are processed by DHSPT, and the images with (c) are obtained by the proposed PTHVS. It is still clear that the proposed method achieves better image quality (sharper and less noisy) than DHSPT in all the cases by subjective evaluation.

6. Conclusions

In this paper, a data hiding in halftone image with the proposed “Pair Toggling Human Visual System” (PTHVS) is presented. The human visual system is established by Least-Mean-Square (LMS) with a number of good quality halftone images. As demonstrated in the experimental results, the PTHVS is superior to the previous DHSPT method in image quality under different capacities and halftone images. Moreover, the proposed method offers high embedded capacity, and it is flexible to deal with different capacity applications.

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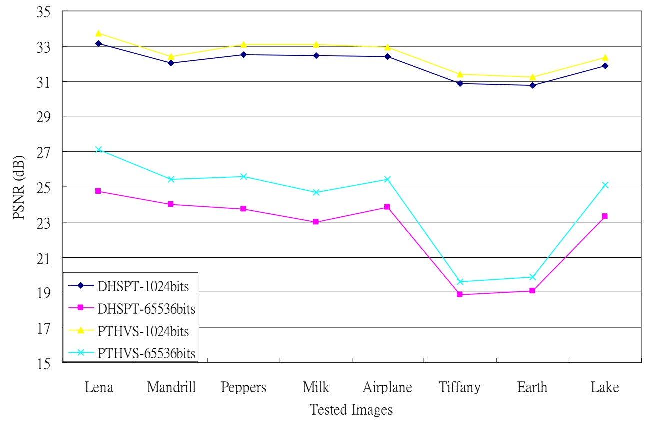
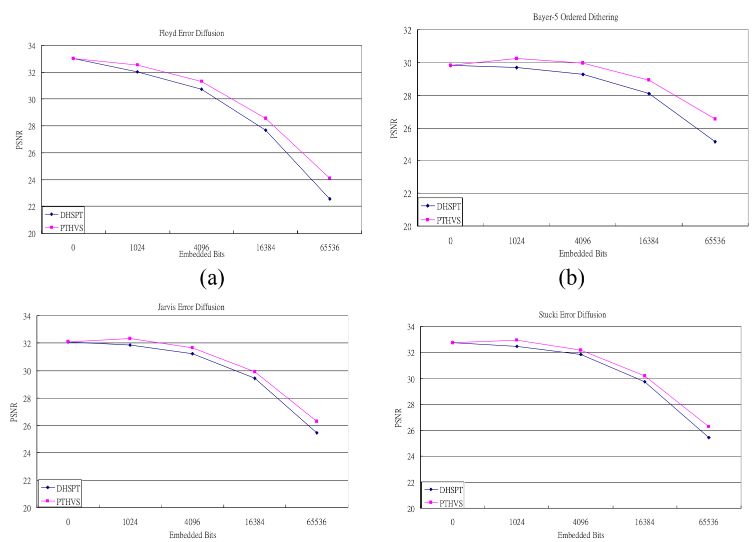


Fig. 1. Performance comparison between DHSPT [11] and the proposed PTHVS method when 1024 and 65536 bits are embedded with 8 tested Floyd error-diffused images.



(a) (b) (c) (d)

Fig. 2. Average PSNR (using 8 tested images) comparison between the DHSPT [11] and the proposed PTHVS method with four different halftone techniques, which include Floyd error diffusion, Bayer-5 ordered dithering, Jarvis error diffusion, and Stucki error diffusion.

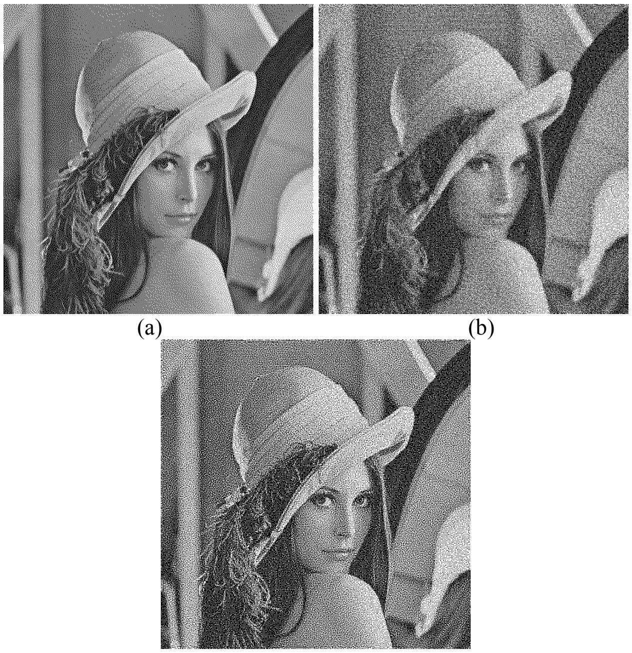


Fig. 3. Performance comparison with Floyd error diffusion (65536 embedded bits). (a) Original Floyd error-diffused Lena image (PSNR=34.29dB). (b) DHSPT embedded result (PSNR=24.72dB). (c) PTHVS embedded result (PSNR=27.11dB).

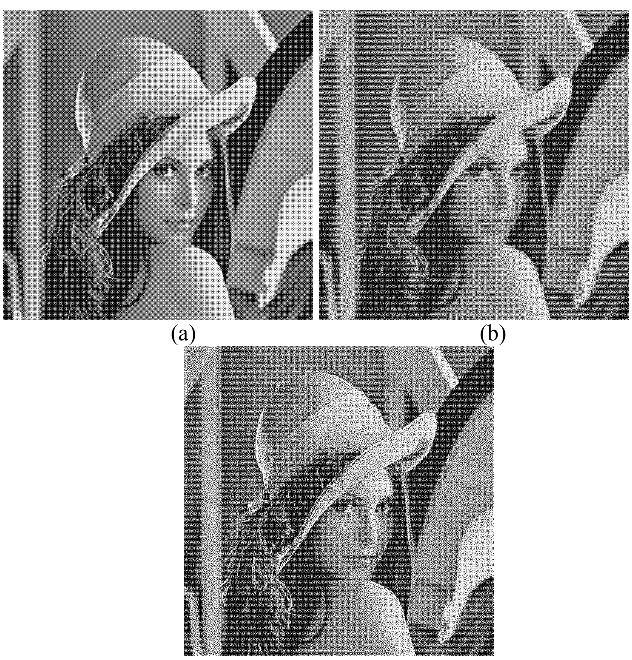


Fig. 4. Performance comparison with ordered dithering (65536 embedded bits). (a) Original ordered dithering Lena image (PSNR=30.43dB). (b) DHSPT embedded result (PSNR=27.31dB). (c) PTHVS embedded result (PSNR=29.36dB).

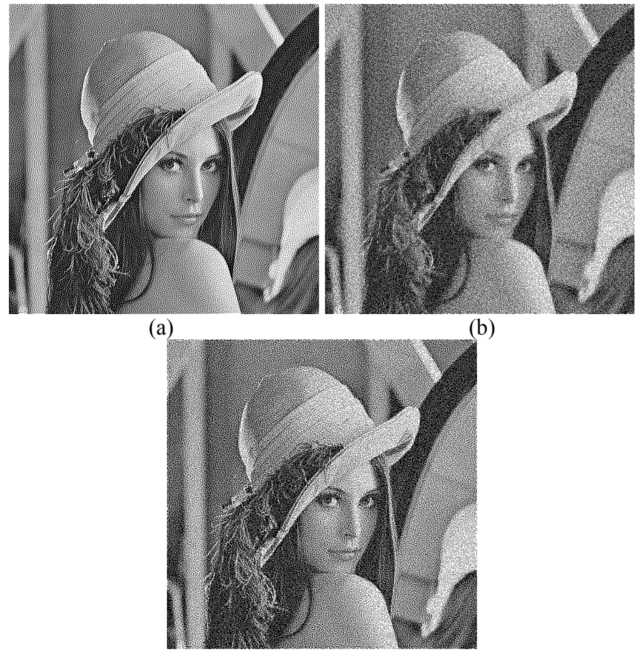


Fig. 5. Performance comparison with Jarvis error diffusion (65536 embedded bits). (a) Original Jarvis error-diffused Lena image (PSNR=32.47dB). (b) DHSPT embedded result (PSNR=27.6dB). (c) PTHVS embedded result (PSNR=29.09dB).

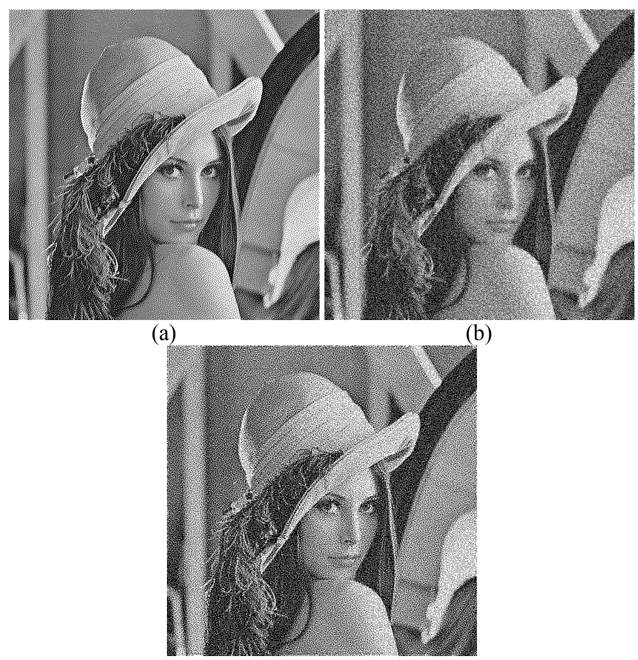


Fig. 6. Performance comparison with Stucki error diffusion (65536 embedded bits). (a) Original Stucki error-diffused Lena image (PSNR=33.3dB). (b) DHSPT embedded result (PSNR=27.62dB). (c) PTHVS embedded result (PSNR=29.13dB).