Error Diffusion Halftone Image Watermarking Based on SVD-DWT Technique

Marzieh Amini*, Khashayar Yaghmaie**, Hamidreza Sadreazami***
* Department of Electrical Engineering, University of Semnan, Semnan, Iran, m_amini@semnan.ac.ir
** Department of Electrical Engineering, University of Semnan, Semnan, Iran, khyaghmaie@semnan.ac.ir
*** Department of Electrical Engineering, Shahid Beheshti University, Tehran, Iran, ha.sadreazami@mail.sbu.ac.ir

Abstract: *In this paper, a new halftone image watermarking is presented based on digital wavelet transform combined with singular value decomposition technique. Halftoning is the process of representing grayscale images using just black and white i.e. binary levels. The original image is an error diffusion halftone image which is decomposed into 2-level wavelet transform. In the second level of wavelet transform, the subband with the midst variance intensity is selected as a place for inserting the watermark. The singular value decomposing is applied to this selected subband and watermark image. The embedding modification is done by combining singular value of selected subband with singular value of watermark image. In extraction process, detector response is computed to obtain the original watermark. Experimental results show good robustness against some common signal processing attacks.*

Keywords: Halftone Binary Image Watermarking, Singular Value Decomposition, Digital Wavelet transform.

1. Introduction

Digital halftoning is the process of representing multitone images as two-tone binary images. This technique is commonly used in digital printing. Since most printers are just able to put a black dot on a specific point or leave the place as blank, they are called binary devices [1].

Many digital halftoning methods exist including ordered dithering [2], error diffusion [3] and direct binary search [4]. Among these techniques, error diffusion based methods achieve good visual quality and reasonable computational complexity.

Digital image watermarking as a significant tool for digital images copyright protection has attracted many research works in recent years. Most of earlier works are based on grayscale and color images which present moderate to high capacity for data hiding. Due to low capacity and sensitivity of the human visual system to even little distortion in binary images, data embedding in binary image is very challenging task. On the other hand, many grayscale images are basically binary images in which halftoning is used in order to simulate gray levels. Therefore, employing halftone technique specifications in watermarking may be observed as a special way of hiding data in gray scale images.

There are some challenges in embedding data in halftone images. Firstly, since each pixel value in halftone image is black or white, capability of information redundancy for each pixel is very limited. So, many data hiding approaches such as transform domain based techniques cannot be directly applied to halftone images. In other words, binarization process is needed after watermarked image to ensure that it remains a binary image. Secondly, human visual system is sensitive to abrupt changes caused by data embedding and therefore, pixel values need be carefully selected to change. Finally, since high capacity is one of the key factors in evaluating the performance of data hiding techniques, the capacity of data hiding in halftone images is expected to be limited, because of the visual quality degradation [5].

In digital image watermarking study, a variety of algorithms have been proposed in which watermarking schemes in transform domain have shown to be more advantageous over those in spatial domain. Discrete wavelet transform (DWT) has some unique characteristics because of its compatibility with human visual system. Several works have been proposed to combine DWT with other techniques to increase robustness and imperceptibility [6, 7].

Singular value decomposition (SVD) is one of the most useful tools of linear algebra with several applications in image compression, watermarking, and other signal processing applications. In SVD domain, a common approach is to modify the singular values of host image by the singular values of a visual watermark [8-11].

This paper presents a new watermarking method for error diffused halftone images in SVD-DWT domain. Applying 2-level DWT to the host image, we select the most significant sub band based on its variance intensity, for inserting the watermark. Then SVD is applied to the selected sub band. Singular value of watermarked image is modified by combining the singular value of selected

978-1-4244-9708-9/10/$26.00 ©2010 IEEE

subband with singular value of watermark image. In the extraction process, a correlation based algorithm is used to detect the watermark.

The rest of the paper is organized as follows: Section 2 provides a quick review on Singular Value Decomposition. In Section 3, proposed embedding and extracting algorithms are explained. Experimental results are presented in section 4.

2. Singular Value Decomposition

Singular value decomposition is one of the most efficient linear algebra tools, widely used in image compression, digital watermark and other signal processing fields [8]. Every real matrix A can be decomposed into a product of three matrices as $A = U S V^T$, where U and V are orthogonal matrices i.e. $U^T U = I$, $V^T V = I$ and S matrix is a diagonal matrix as $S = diag(\lambda_1, \lambda_2, ...)$. Diagonal entries of S are called the singular values of A. The columns of U and V are called the left and right singular vectors of A, respectively. This decomposition is known as the SVD of A, and can be written as:

$$A = \lambda_1 U_1 V_1^T + \lambda_2 U_2 V_2^T + ... + \lambda_r U_r V_r^T \qquad (1)$$

where r is the rank of matrix A:

The singular value decomposition of digital images demonstrates the following features [9]:

- The singular value of images is noticeably stable which means that the singular value of an image changes little when a small disturbance is applied.
- Each singular value specifies the luminance of an image layer while the corresponding pair of singular vectors specifies the geometry of the image layer.

3. Watermarking Algorithm

A binary error diffusion halftone image is selected as a host image I of size $N \times N$ and pseudo random matrix W is selected as watermark with size of $M \times M$.

3.1 Embedding

The embedding process employs the following steps:

- Decomposing the host image into four sub-bands LL, HL, LH and HH by using 1-level DWT.
- Applying 1-level wavelet transform on LL sub-band to achieve four sub-bands LL_1, HL_1, LH_1 and HH_1. The intensity variance of each sub-band is calculated, and sub-band A_S with the midst value is selected as an appropriate band for inserting the watermark [10].
- Applying SVD to the selected subband A_S.

$$A_S = U_S S_S V_S^T \qquad (2)$$

- Applying SVD to watermark matrix W.

$$W = U_W S_W V_W^T \qquad (3)$$

- Combining SVs of selected subband with the SVs of the watermark using the following equation:

$$S_S^W = S_S + a\, S_W \left| S_S \right| \qquad (4)$$

where a is the embedding intensity factor.

- The watermarked subband is obtained from the following equation:

$$A_S^W = U_S S_S^W V_S^T \qquad (5)$$

- Applying 2-level inverse wavelet transform to obtain the watermarked image. Binarization process is done to achieve binary watermarked image.

3.2 Extraction

The proposed algorithm is a correlation based watermarking method in which a set of sample marks are required in extraction process. If I^* is the corrupt watermarked image after facing with various types of attack, the detection process is as follows:

- Calculating 2-level wavelet transform of I^*.
- The most significant sub-band is calculated in the same way as in embedding. The SVs of selected sub-band is computed as

$$A_S^* = U_S^* S_S^* V_S^{*T} \qquad (6)$$

- Generating 1000 sample random marks denoted by $Y_k, k = 1:1000$ including the original watermark, and then applying SVD to each single mark as follow: $Y_k = U_k S_k V_k^T \;, for\, k = 1:1000$.
- Multiplying the SVs of selected sub-band S_S^*, belong to the corrupt watermarked image, by U_k and V_k^T obtained from each sample mark, the X_k is calculated as follow:

$$X_k = U_k S_S^* V_k^T \;, \quad k = 1:1000 \qquad (7)$$

- For extracting the watermark, the correlation method needs to be applied between X_k and Y_k to obtain the detector response as :

$$z(k) = \frac{1}{M} \sum_{j=1}^{M} \left(\frac{1}{M} \sum_{i=1}^{M} X_k(i,j) . Y_k(i,j) \right) \qquad (8)$$

In order to distinguish the original watermark among a set of known marks, detector response, denoted by z, is computed for each of marks and the one with the largest correlation is assumed to be the original watermark. More precisely, detector responses are compared with a threshold value obtained in (9) to show whether the watermark is present or not [12].

$$T = \frac{1}{M} \sum_{j=1}^{M} \left(\frac{a}{2M} \sum_{i=1}^{M} A_S^*(i,j) \right) \qquad (9)$$

(a)

(b)

Fig. 1: (a) Original error diffusion binary image.
(b) Watermarked image with BCR= 0.9999.

4. Experimental Results

In order to demonstrate the efficiency of the proposed algorithm, we tested the proposed algorithm on a binary error diffusion halftone image with size of 256×256.

Watermark image was a pseudo random matrix of size 64×64. In our experiments, the intensity coefficient a, was set to 0. 04.

To measure transparency of watermark algorithms, common distortion measurements such as PSNR is not efficient since the pixel values of binary images values are only 0 or 1. Therefore a more efficient measure called bit correct rate (BCR) is employed. BCR is the ratio of the number of unaltered pixels after watermarking process to the total number of pixels in the original image.

Fig. 1 shows original error diffusion halftone binary as well as the watermarked images. The comparison between these two images exhibits imperceptibility of the proposed algorithm.

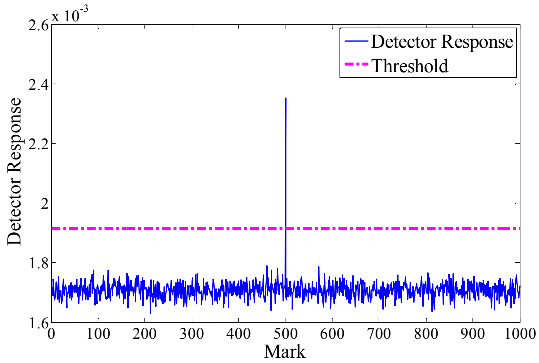

Fig. 2: Detector response of detected watermark.

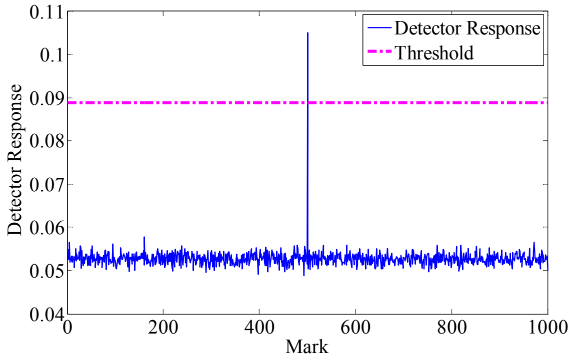

Fig. 3: Detector response of detected watermark in presence of Median filtering of 7×7 window mask and BCR= 0.6551.

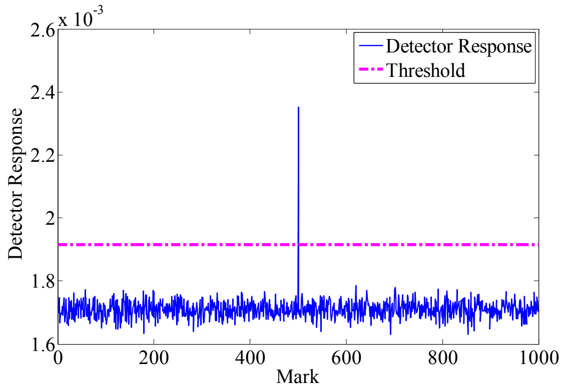

Fig. 4: Detector response of detected watermark against Gaussian filtering with mask size 7×7 and BCR= 0.9918.

Fig. 2 shows the detector response to 1000 randomly generated marks including the original watermark. Results show that the original watermark distinctively gives the highest detector response and threshold value can obviously select the correct mark.

Several common signal processing attacks were applied to the watermark image. In order to evaluate the robustness of the proposed algorithm, BCR between corrupt watermarked image and the original image was computed. The more the value of BCR, the less the amount of distortion caused by each attack.

In the first experiment, the watermarked image was filtered with a median filter and Gaussian filter with window mask sizes of 7×7. The obtained results demonstrated that watermarking method is robust against filtering as shown in Figs. 3 and 4.

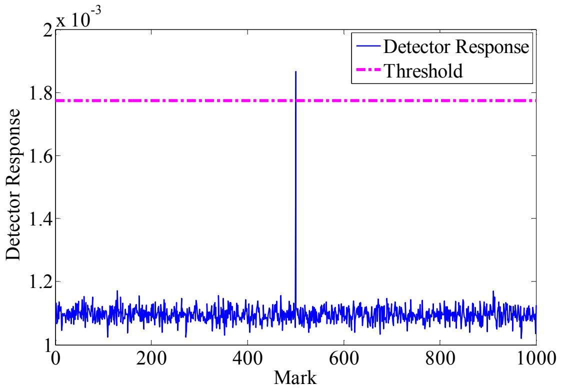

Fig. 5: Detector response of detected watermark against Gaussian noise with mean=0.5, variance=0.001 and BCR= 0.5016.

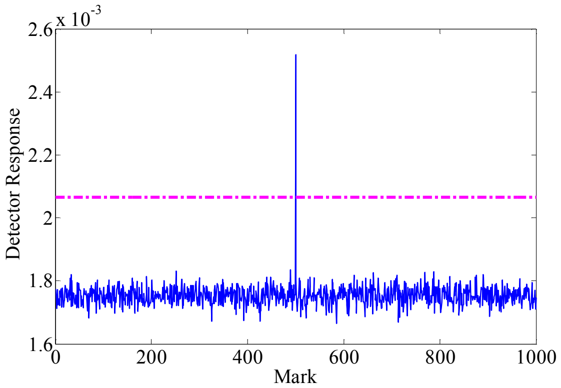

Fig. 6: Detector response of detected watermark against Salt & Pepper noise with variance=0.001 and BCR= 0.9997.

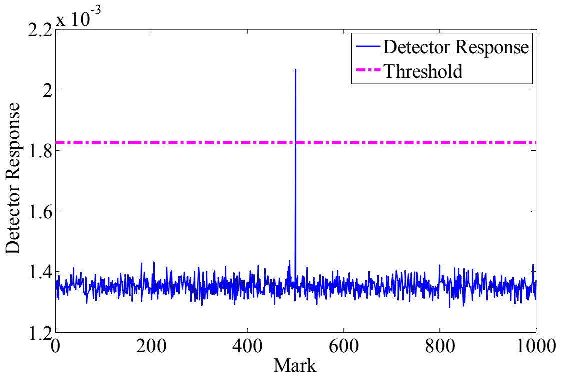

Fig. 7: Detector response of detected watermark against Speckle noise with variance=0.001 and BCR= 0.7581.

In another test, the watermarked image was corrupted by adding a Gaussian noise with mean=0.5 and variance=0.001. Corresponding detector response is shown in Fig. 5.

In Figs. 6 and 7, the detector responses after corrupting the watermarked image by Salt & Pepper noise and Speckle noise with variance=0.001 are shown. As can be seen, even in presence of noise which makes the watermarks image randomly distorted, the proposed algorithm can detect the original watermark with noticeable accuracy.

5. Conclusion

In this paper, digital wavelet transform and singular value decomposition were combined to introduce a new watermarking algorithm for error diffused halftone images. The good characteristics of SVD transform was employed to insert the watermark in a way that the watermarked image remains highly imperceptible and robust. In extraction process, the detector is able to retrieve original watermark from randomly selected sample marks. The proposed method demonstrates significant perceptual invisibility and good robustness against common signal processing attacks such as Gaussian filtering, median filtering and even against noises such as Gaussian, Salt and pepper and Speckle.

References

[1] N. Damera-Venkata, "Analysis and Design of Vector Error Diffusion Systems for Image Halftoning " Ph.D. thesis, Dept. ECE, Univ. Texas,. Austin, Dec. 2000.

[2] R. A. Ulichney, "Digital Halftoning " Cambridge, MA:MIT Press, 1987.

[3] R. W. Floyd and L. Steinberg, "An Adaptive Algorithm for Spatial Grayscale, " Proc. SID 75 Digest. Society for information Display, pp: 36-37, 1975.

[4] D. Lieberman and J. Allebach, "Digital Halftoning Using Direct Binary Search, " Proc. of 1996 1st IEEE Int. Conf. On High technology, pp: 114-124, 1996.

[5] H. Luo, Z. Zhao, J. Huang and Z. Lu, "Halftone Image Watermarking Based on the Binary Pseudo-Wavelet Transform, " Third International Conference on International Information Hiding and Multimedia Signal Processing (IIH-MSP 2007), iih-msp, vol. 1, pp: 299-302, 2007.

[6] H. Lu and W. Xia, "A Robust Binary Image Watermarking Based on Wavelet Domain and Krawtchouk Moments," International Conference on Research Challenges in Computer Science, 2009.

[7] M. Amini, H. R. Sadreazami, K. Yaghmaie, "A New Scheme for Dual Watermarking Using DWT-PCA Technique," IMAGAPP - International Conference on Imaging Theory and Applications, pp: 43-46, May 2010.

[8] E. Ganic and A. M. Eskicioglu, "Robust Embedding of Visual Watermarks Using DWT-SVD," Journal of Electronic Imaging, vol. 14, no. 4, 2005.

[9] H. Zhihua, "Binary Image Watermarking Algorithm Based on SVD," International Conference on Intelligent Human-Machine Systems and Cybernetics, pp: 400-403, 2009.

[10] R. Liu and T. Tan, "An SVD-Based Watermarking Scheme for Protecting Rightful Ownership," IEEE Transactions on Multimedia, vol. 4, no. 1, pp: 121-128, 2002.

[11] A. Mansouri, A. A. Aznaveh and F. Torkamani Azar, "SVD-based Digital Image Watermarking Using Complex Wavelet Transform," Sadhana, vol. 34(3), pp: 393–406, June 2009.

[12] M. Barni, F. Bartolini , V. Cappellini and A. Piva, "A DCT Domain System for Robust Image Watermarking," Signal Processing 1998 Elsevier Science, vol. 66, pp: 357–72, 1998.