Improved image watermarking scheme using nonnegative matrix factorization and wavelet transform

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Abstract—**Ouhsain et al [Expert Systems with Applications 36, 2123–2129(2009)] presented a technique using DWT and NMF, which apply NMF to the blocks of the wavelet decomposition sub-band, and then is followed by eigendecomposition distortion. Motivated by the approach of Ouhsain et al, we proposed an improved image watermarking scheme. Our technique do not apply NMF to the blocks of the wavelet decomposition sub-band, direct apply SVD to these blocks. Our proposed algorithm is simpler than algorithm of Ouhsain et al. Experimental results demonstrate that the proposed scheme not only provides good fidelity and robustness against intentional attacks and normal visual processes, but also achieves a low computational complexity.**

Keywords-component; watermarking; wavele ttransform; Nonnegative matrix factorization

I. INTRODUCTION

Importance of security and economic issues is increasing rapidly as digital imaging becomes dominant over analog modes. Digital presentation allows preservation of the quality of images after image processing operations, copying can be done quickly and easily, and the copy is identical to the original. Digital watermarking offers a possibility for controlling illegal copying or, more generally, access to the original digital information. As a complementary part to cryptography, the watermarking technique protects the data by embedding a watermark in such a way that it does not disturb the image in normal image perception or processing conditions or in the system development. The embedded watermark can then be extracted for the identified, authorized clients [1-2].

A variety of watermarking methods have been proposed for grey level images and RGB-color images. The watermarking techniques can be divided into two different categories according to the embedding domain of the cover image; one is applied in the spatial domain and the other is applied in the transform domain. The spatial domain methods are the earliest and simplest watermarking techniques but the spatial domain methods have a low information hiding capacity, and also the watermark can be easily distorted or erased. On the other hand, the transform domain approaches insert the watermark into the transform coefficients of the image cover, yielding a larger number of information embedding and more robustness against watermarking attacks. For RGB color image different color spaces also are considered for watermarking [3-9,11-13].

In terms of the visibility, digital watermarks can be classified into two different groups: Visible and invisible watermarks[10]. Visible watermarks can easily be perceived for example company logos that inserted into or overlaid on some TV channels. Although the owner of the multimedia content can be recognized without any calculation, embedded watermarks can be removed or destroyed easily. On the other hand, invisible watermarks are imperceptible and are embedded on the unknown places in the host data. The watermarked data should look similar to the original one, and should not cause suspicion by others. If it is used illegally, the embedded watermark will be used for showing the ownership.

With respect to permanency, invisible watermarks can be classified as semi-fragile, fragile and robust. Semi-fragile watermarks are capable of tolerating some degree of change of a watermarked image, such as the addition of quantization noise from lossy compression. Fragile watermarks are embedded in such a way that any modification or manipulation of the host image would corrupt the watermark. Therefore, fragile watermarks are mainly used for authentication purposes. Robust watermarks are designed to resist intentional or unintentional image modifications for instance filtering, geometric transformations, noise addition, etc. For copyrights protection, this kind of watermarks has to be utilized [11].

Ouhsain et al [Expert Systems with Applications 36, 2123–2129(2009)] presented a technique using DWT and NMF, which apply NMF to the blocks of the wavelet decomposition LL sub-band, and then is followed by eigendecomposition distortion [13]. Motivated by the approach of Ouhsain et al, we proposed an improved image watermarking scheme. Our

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technique do not apply NMF to the blocks of the wavelet decomposition sub-band, direct apply SVD to these blocks.

The organization of this paper is as follows. In Section II, we provide a brief background material about DWT, SVD and NMF. In Section III, we introduce the proposed watermark embedding and extraction algorithms. In Section IV, we present some experimental results to demonstrate the improved performance of the proposed method in comparison with technique given by Ouhsain et al. Finally, we conclude in Section V.

II. BACKGROUND

In order to describe the new proposed method, the discrete wavelet transform, Singular Value Decomposition (SVD) and nonnegative matrix factorization are briefly discussed here.

2.1 Discrete wavelet transform[14]

The discrete wavelet transform is a technique for multiresolution decomposition of images. The DWT is computed by successive low-pass and high-pass filtering of the discrete time domain signal. Its significance is in the manner it connects the continuous-time mutiresolution to discrete-time filters. The DWT can be implemented as a multi-stage transform. In the first stage, an image is decomposed into four subbands LL1, HL1, LH1, and HH1, where HL1, LH1, and HH1 Represent the finest scale wavelet coefficients, i.e., the detailed image, While LL1 stands for the coarse level coefficients, i.e., the approximation image. Fig.1 shows the two level wavelet decomposition of an image.

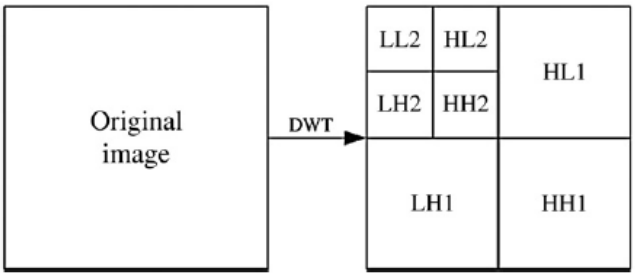


Fig.1 two level wavelet decomposition of an image

2.2 SVD

Every $m \times m$ real matrix A has the following decomposition:

$$A = U\Sigma V^T \tag{1}$$

Where U and V are $m \times m$ orthogonal matrices, respectively, and Σ is a diagonal matrix having the following form:

$$\Sigma = \begin{pmatrix} \sigma_1 & & 0 \\ & \ddots & \\ 0 & & \sigma_m \end{pmatrix} = diag(\sigma_1, \ldots, \sigma_m) \tag{2}$$

Here σ_i are the singular values, and they satisfy

$$\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_m \geq 0 \tag{3}$$

The above decomposition is called the singular value decomposition (SVD) of the matrix A. If we let u_i and v_i be the column vectors of the orthogonal matrices U and V, then

$$A = \sum_{i=1}^{m} \sigma_i u_i v_i^T \tag{4}$$

2.3 NMF[15]

Nonnegative matrix factorization (NMF) is developed as a matrix factorization technique that decomposes nonnegative matrices in physically meaningful data in two-dimensional signal analysis. A formal description of nonnegative matrix factorization can be described as follows. Give an image C of size $m \times m$, we can approximately factorize C into the product of two nonnegative matrices B and H,

$$C \approx BH \tag{5}$$

Where matrix B contains the basis vectors and matrix H cont ain their multiplers.

III. PROPOSED WATERMARKING METHOD

In this section, we provide the main steps of the proposed watermark embedding and extraction method.

Watermark embedding algorithm

(1) Apply DWT to the cover image C of size $m \times m$ to obtain 4 sub-bands(LL, LH, HL, HH).

(2) Divide the LL and HH sub-bands into blocks of size $l \times l$.

(3) Apply the SVD to the each block of the LL sub-band $L = U_l \Sigma_l V_l^{'}$.

(4) Apply the SVD to the each block of the HH sub-band $G = U_g \Sigma_g V_g^{'}$.

(5) Apply the NMF to the watermark $W = B_w H_w$, followed by applying SVD to the weight matrix $H_w = U_w \Sigma_w V_w^{'}$,where $\Sigma_w = diag(\lambda_{wi})$.

(6) Modify $\lambda_{\max}$ according to $\lambda_i^d = \lambda_{\max} + \alpha\lambda_{wi}$, where $\lambda_{\max}$ denotes the largest SV of L; λ_i^d denotes the distorted SV of L, and α is a constant scaling factor.

(7) Modify $\delta_{\max}$ according to $\delta_i^d = \delta_{\max} + \beta\lambda_{wi}$, where $\delta_{\max}$ denotes the largest SV of G; δ_i^d denotes the distorted SV of G, and β is a constant scaling factor.

(8) Use all the distorted blocks $L^d = U_l \Sigma_l^d V_l^{'}$ and $\Sigma_l^d = diag(\lambda_i^d)$.

(9) Use all the distorted blocks $G^d = U_g \Sigma_g^d V_g^{'}$ and $\Sigma_g^d = diag(\delta_i^d)$.

(10) Apply the inverse DWT to the produce the watermarked image.

Watermark extraction algorithm

Watermark detection could be either blind or non-blind depending on the absence or the presence of the original image. The latter type is used in this paper.

(1) Apply the first four steps of the embedding algorithm to the watermarked image.

(2) Extract the SVs from each LL sub-band block using $\hat{\lambda}_{wi} = (\lambda_i^d - \lambda_{\max})/\alpha$, where λ_i^d are the SVs of L

(3) Extract the SVs from each HH sub-band block using $\hat{\delta}_{wi} = (\delta_i^d - \delta_{\max})/\beta$,where

(4) Construct the first watermark image $\hat{W}_l = B_w \hat{H}_w$, where $\hat{H}_w = U_w \hat{\Sigma}_w^l V_w'$ and $\hat{\Sigma}_w^l = diag(\hat{\lambda}_{wi})$.

(5) Construct the second watermark image $\hat{W}_h = B_w \hat{H}_w$,where $\hat{H}_w = U_w \hat{\Sigma}_w^h V_w'$ and $\hat{\Sigma}_w^h = diag(\hat{\delta}_{wi})$.

Note that the watermark algorithm given above is simpler than the one given by Mohamed Ouhsain et al. The proposed algorithm does not need the NMF of blocks of the each block of the LL sub-band.

IV. Quality Measurement of The Embedding and Extraction

The following measures were used to evaluate the quality of the reconstruction. The quality in embedding was measured by peak signal to-noise ratio (PSNR), which is defined as

$$PSNR = 10\log_{10}\frac{255^2}{\frac{1}{N\times N}\sum_{i=1}^{N}\sum_{j=1}^{N}(I_{wm}(i,j)-I(i,j))^2} \quad (20)$$

Where $I_{wm}(i,j)$ is the value of a pixel with spatial coordinates (i,j) of the watermarked image, and $I(i,j)$ is the value of a pixel with the same coordinates of the original image.

In this paper, the correlation coefficient (cc) is used as a measure of the quality of the extracted watermark image and is defined as

$$cc = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m}[(W)_{ij}-\bar{\mu}][(W^{(r)})_{ij}-\bar{\mu}^{(r)}]}{\sqrt{\left\{\sum_{i=1}^{m}\sum_{j=1}^{m}[(W)_{ij}-\bar{\mu}]^2\right\}\left\{\sum_{i=1}^{m}\sum_{j=1}^{m}[(W^{(r)})_{ij}-\bar{\mu}^{(r)}]^2\right\}}} \quad (21)$$

where W and $W^{(r)}$ are the original and extracted watermark images, respectively, and where $\bar{\mu}$ and $\bar{\mu}^{(r)}$ are the mean values of the gray level values of the original and extracted watermark images, respectively. Note that the measure cc is equal to unity if the two images W and $W^{(r)}$ are the same. Hence, the closer to 1 the measure cc is, the closer to the original watermark image W the extracted watermark image $W^{(r)}$ will be.

In this study, the watermark is a visual image, not a sequence of numbers. Single mathematical function values only objectively reflect the similarity degree of images in the mass and do not reflect a concrete distribution. Human visual detection is sensitive, but has subjective restrictions. Therefore, human vision and mathematical function values together are used to determine the degree of similarity of the extracted watermark to the original watermark.

V. Experimental Results

In this section, we perform a number of experiments using a variety of gray-scale images to show the effectiveness of the proposed scheme. The images used in the experiments are of size 512×512 for cover images and of size 64×64 for the watermark image as showed in Fig. 2. In all the experiments, the scaling factors α and β are fixed to 0.02 and 0.01 for the LL and HH sub-band, respectively.

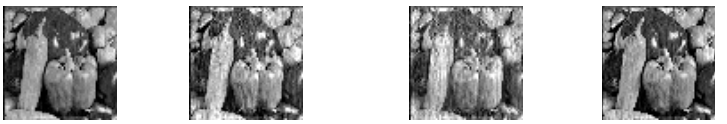
Fig. 2 left column (cover images); right column (watermark images)

JPEG compression Gaussian noise 0.06 multiplicative uniform 0.05 additive uniform 0.005

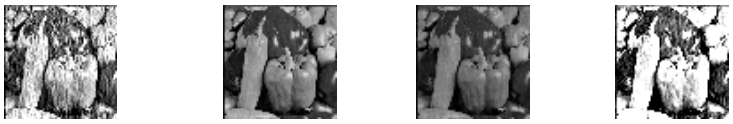
Salt & pepper noise 0.04 mean filter 3 gamma correction histogram eq

Sharpen rescaling 512-256-512 cropping bright-128

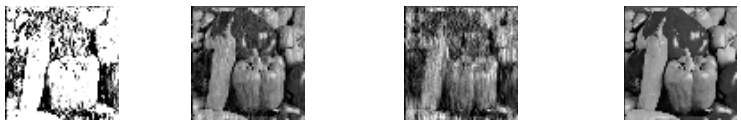
Fig 3. The watermarked image under different attacks



0.9810 0.9264 0.8881 0.9679



0.8686 0.9960 0.9874 0.9216



0.7505 0.9603 0.7870 0.9988

Fig 4 The best extracted watermark under different attacks and their corresponding correlation coefficients.

Robustness

To verity the robustness of our proposed algorithm, we applied different attacks to the watermarked image. The attacks include JPEG compression, Gaussian noise, multiplicative uniform noise, additive uniform noise, salt and pepper noise, mean filter, gamma correction, histogram equalization, sharpening, rescaling, cropping, and brightness change. In Fig 3, we show an example of a watermarked image with different kinds of attacks. The corresponding best extracted watermarks are shown in Fig 4.

Comparison

The robustness of the proposed watermark scheme and scheme has been tested against different kind of attacks. Table 1 list the PSNRs of the proposed method and method given by Ouhsain et al for the same test images.

Table 1 PSNR comparison results

Image	Proposed scheme	Scheme in [13]
Goldhill	39.72	39.83
Lena	38.56	38.66
Zelda	40.02	40.09

The PSNR of watermarked image with the proposed method is a little lower than for one with method given by Ouhsain et al. Simulation results for common image processing are shown in Table 1, 2 and 3, respectively. The results obtained indicate that the proposed method performs better in terms of robustness against the attacks.

Table 2 The results for Goldhill image

	Proposed scheme	Scheme in [13]
JPEG compression	0.9899	0.9873
Gaussian noise 0.006	0.9565	0.9385
multiplicative uniform noise 0:05	0.9316	0.9249
additive uniform noise r _ 0.005	0.9679	0.9618
Gamma correction 0.6	0.9874	0.9825
histogram equalization	0.9216	0.9215
rescaling	0.9603	0.9598
Median filter	0.9938	0.9941
Mean filter	0.9960	0.9974

Table 3 The results for Lena image

	Proposed scheme	Scheme in [13]
JPEG compression	0.9919	0.9876
Gaussian noise 0.006	0.9606	0.9459
multiplicative uniform noise 0:05	0.8638	0.8330
additive uniform noise r _ 0.005	0.8840	0.8828
Gamma correction 0.6	0.9948	0.9868
histogram equalization	0.9679	0.9635
rescaling	0.9468	0.9284
Median filter	0.9944	0.9966
Mean filter	0.9990	0.9981

Table 4 The results for Zelda image

	Proposed scheme	Scheme in [13]
JPEG compression	0.9899	0.9873
Gaussian noise 0.006	0.9565	0.9385
multiplicative uniform noise 0:05	0.9316	0.9249
additive uniform noise r _ 0.005	0.9791	0.9719
Gamma correction 0.6	0.9914	0.9916
histogram equalization	0.9590	0.9581
rescaling	0.9466	0.9447
Median filter	0.9983	0.9974
Mean filter	0.9994	0.9976

VI. CONCLUSION

In this paper, we proposed a n improved image watermarking scheme using wavelet transform and nonnegative matrix factorization. The key feature is that our technique does not apply NMF to the blocks of the wavelet decomposition sub-band, direct apply SVD to these blocks. Experimental results demonstrate that the proposed scheme not only provides good fidelity and robustness against intentional attacks and normal visual processes, but also achieves a low computational complexity.

REFERENCES

[1] I. J. Cox, Matthew L. Miller, and J. A. Bloom, Digital Watermarking (Academic, SanDiego, 2002).

[2] D. Artz, Digital Steganography: Hiding data within data, IEEE Internet Computing, May/June 2001, pp. 75–80.

[3] Podilchuk, C.I., Delp, E.J., Digital watermarking: algorithms and applications, IEEE Signal Processing Magazine, July 2001, pp. 33–46.

[4] M. Barni and F. Bartolini, "Watermarking systems engineering enabling digital assets security and other applications", in Signal Processing and Communications Series (Marcel-Decker, New York, 2004).

[5] F. Cayre, C. Fontaine, and T. Furon, "Watermarking security: Theory and practice", IEEE Trans. Signal Process. 53, 3976–3987 (2005).

[6] B. Macq, J. Dittmann, and E. J. Delp, "Benchmarking of image watermarking algorithms for digital rights management", Proc. IEEE 92, 971–984 (2004).

[7] P. Bao and M. Xiaohu, "Image adaptive watermarking using wavelet domain singular value decomposition", IEEE Trans. Circuits Syst. Video Technol. 15, 96–102 (2005).

[8] Kundur, D., Hatzinakos, D., A Robust Digital Image Watermarking Method using Wavelet-Based Fusion, Proceedings of the IEEE Intl. Conference on Image processing, Santa Barbara, California, vol. 1., 1997, pp. 544–547.

[9] A. Parisis, P. Carre, and C. Fernandez-Maloigne, "Colour watermarking: study of different representation spaces", Proc. CGIV (IS&T, Springfield, VA, 2002), pp. 390–393.

[10] J.S. Pan, H.C. Huang, L.C. Jain, Intelligent Watermarking Techniques, World Scientific Publishing Company, Singapore, 2004.

[11] Veysel Aslantas, "An optimal robust digital image watermarking based on SVD using differential evolution algorithm", Optics Communications, Volume 282, Issue 5, Pages 769-777

[12] Abdallah, E. E., Hamza, A. B., & Bhattacharya, P. "An improved image watermarking scheme using fast Hadamard and discrete wavelet transforms". Journal of Electronic Imaging, 16(3), 033020.1–033020.9.(2007).

[13] Abdallah, E. E., Hamza, A. B. "Image watermarking scheme using nonnegative matrix factorization and wavelet transform", Expert Systems with Applications,36(2), 2123-2129(2009).

[14] M. R. Raghuveer and S. B. Ajit, Wavelet Transforms—Introduction to Theory and Applications, Addison-Wesley, Reading, MA 2000.

[15] Lee, D., & Seung, H. (1999). Learning the parts of objects by nonnegative matrix factorization. Nature, 401, 788–791.