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A Robust Quantization-based Image Watermarking Scheme in the Wavelet-based Contourlet Domain

H. Sadreazami, *Student Member, IEEE*, M. Omair Ahmad, *Fellow, IEEE,* and M. N. S. Swamy, *Fellow, IEEE*

Department of Electrical and Computer Engineering
Concordia University, Montreal, Quebec, Canada, H3G 1M8
E-mail: {h_sadrea, omair, swamy}@ece.concordia.ca

Abstract—**Watermarking has attracted much attention in last decade due to its application in copyright protection of digital multimedia. In this paper, a blind watermarking scheme in the wavelet-based contourlet domain using the singular value decomposition technique is proposed. To realize a blind watermarking scheme, quantization-based embedding and extraction procedures are employed. Experiments are conducted to evaluate the performance of the proposed watermarking scheme. Simulation results show that the proposed scheme outperforms some of the existing schemes in terms of imperceptibility of the embedded watermark and providing lower bit error rate values. It is also shown that the proposed watermarking scheme is more robust against various kinds of attacks such as compression, median filtering, scaling and Gaussian noise, than other existing methods.**

Keywords—Digital image watermarking; wavelet-based contourlet transform; quantization; singular value decomposition; directional filter bank.

I. INTRODUCTION

Image watermarking is a technique to hide a piece of information in the host image for digital data security and copyright protection purposes. The information can be extracted in receiver to verify the ownership or intellectual property rights. It is known that embedding the watermark bits in the transform domain leads to an improved performance in comparison to the traditional pixel-based methods [1]. In transform domain techniques of digital image watermarking, the contourlet transform has been shown to provide superior performance, in terms of invisibility of the watermark and robustness, to other transforms [2]. This is mostly due to the directional selectability and anisotropy of the contourlet transform [3].

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There exist many watermarking schemes in the contourlet domain such as non-blind [4], [5], and blind [2] schemes. A watermarking scheme is called blind if its detector has no access to the original image. In [5], a non-blind scheme in the contourlet domain has been proposed by using the singular value decomposition technique. In [6], an adaptive watermarking method has been proposed by embedding the watermark into the largest detail subbands in the contourlet domain. In [7], a dual adaptive watermarking scheme has been proposed in the contourlet domain for medical images. In [2], a blind watermark detector using the statistical properties of the contourlet coefficients has been designed. In [8], a watermark extraction process has been proposed by modeling the noisy watermarked dihedral angles using the Beta distribution.

A watermarking scheme should be robust against any distortions and only the authorized user should be able to detect the watermark. The robustness may significantly increase by utilizing the singular value decomposition technique in which the watermark is embedded in the singular values [5].

In this work, we propose a blind image watermarking scheme in the wavelet-based contourlet domain using the singular value decomposition. The wavelet-based contourlet transform is realized by replacing the Laplacian pyramid stage of the conventional contourlet transform by the wavelet transform to achieve a non-redundant transform. The subband with the highest entropy in the finest scale is selected to be further decomposed into a number of directional subbands by using the directional filter bank. The watermark bits are inserted into the singular values of the directional subband coefficients by employing an efficient quantization technique. Several experiments are performed to evaluate the performance of the proposed watermarking scheme and to compare it with that of some of the existing schemes with or without presence of any attacks.

The paper is organized as follows: in Section II, embedding and extraction steps of the proposed watermarking scheme are presented. Experimental results are presented in Section III. Section IV concludes the paper.

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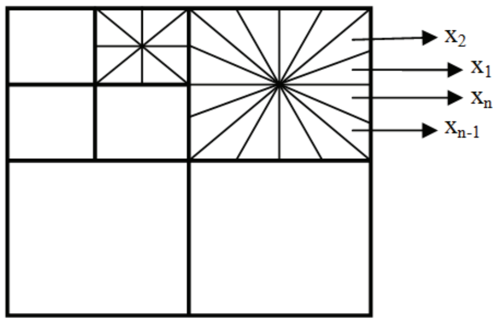

Fig. 1. Block diagram of the wavelet-based contourlet transform.

II. PROPOSED WATERMARKING SCHEME

The proposed watermarking scheme consists of two stages; embedding and extraction. In the embedding part, the watermark signal is inserted into the host image whereas in the decoder part, the watermark bits are blindly extracted from the watermarked image.

A. Watermark Embedding

The contourlet transform consists of two stages: a Laplacian pyramid as the first stage and a directional filter bank as the second stage. In the wavelet-based contourlet transform the first stage is replaced by the wavelet transform to generate a lowpass subband and three highpass subbands [9]. The second stage is a directional filter bank, which provides angular decomposition as shown in Fig. 1. To embed the watermark, the original image is first decomposed by the wavelet transform into two scales.

It is known that the watermark should be inserted into the significant features of an image in order to increase the invisibility and robustness of the watermark [2]. In view of this, in the finest scale, the entropy of each subband is calculated and the one having the highest entropy is selected. The selected subband is further decomposed into a number of directional subbands $\{x_i\}_{i=1}^{n}$, using the directional filter bank structure [10]. The singular values of each directional subband $\{S_{x_i}\}_{i=1}^{n}$ are obtained by using the singular value decomposition (SVD) technique. SVD can decompose the subband x into product of three matrices as $x_i = U S_{x_i} V^T$, where U and V are the left and right singular vectors of x, respectively, and S is a diagonal matrix with singular values of x in its diagonal entries [5]. In order to realize the blind watermarking scheme, the obtained singular values are quantized by a quantization step Λ as

$$Q = \left\lfloor \frac{\|S_i\|_\infty}{\Lambda} \right\rfloor \tag{1}$$

where $\| \|_\infty$ denotes the infinity norm. The watermark bits for every odd and even values of Q are embedded as

$$Y = \begin{cases} Q+1 & Q \text{ is odd} \\ Q+0 & Q \text{ is even} \end{cases} \tag{2}$$

The watermarked singular values $\{S_{y_i}\}_{i=1}^{n}$ are obtained as

$$S_{y_i} = S_{x_i} \frac{Y\Lambda}{Q} \tag{3}$$

Each watermarked subband is found by $x_i^{'} = U S_{y_i} V^T$. The watermarked image is then obtained by applying the inverse directional filter bank followed by the inverse wavelet transform to the watermarked coefficients. It should be noted that to embed messages of different lengths, the selected subband is accordingly decomposed and each watermark bit is embedded in one of the directional subbands.

B. Watermark Extraction

In order to extract the watermark bits, the watermarked image is decomposed by the wavelet transform and the subband with the highest entropy in the finest scale is selected. It is assumed that embedding the watermark bits does not alter the selected subband position. Similar to the embedding procedure, the selected subband is decomposed into a number of directional subbands using the directional filter bank structure. The directional subbands x_w_i are decomposed using SVD technique to $x\_w_i = U S_{x\_w_i} V^T$. The singular values are then quantized by the same quantization step as in embedding

$$Q_w = \left\lfloor \frac{\|S_{x\_w_i}\|_\infty}{\Lambda} \right\rfloor \tag{4}$$

The watermark bits are then extracted as

$$w = \begin{cases} 1 & Q_w \text{ is even} \\ 0 & Q_w \text{ is odd} \end{cases} \tag{5}$$

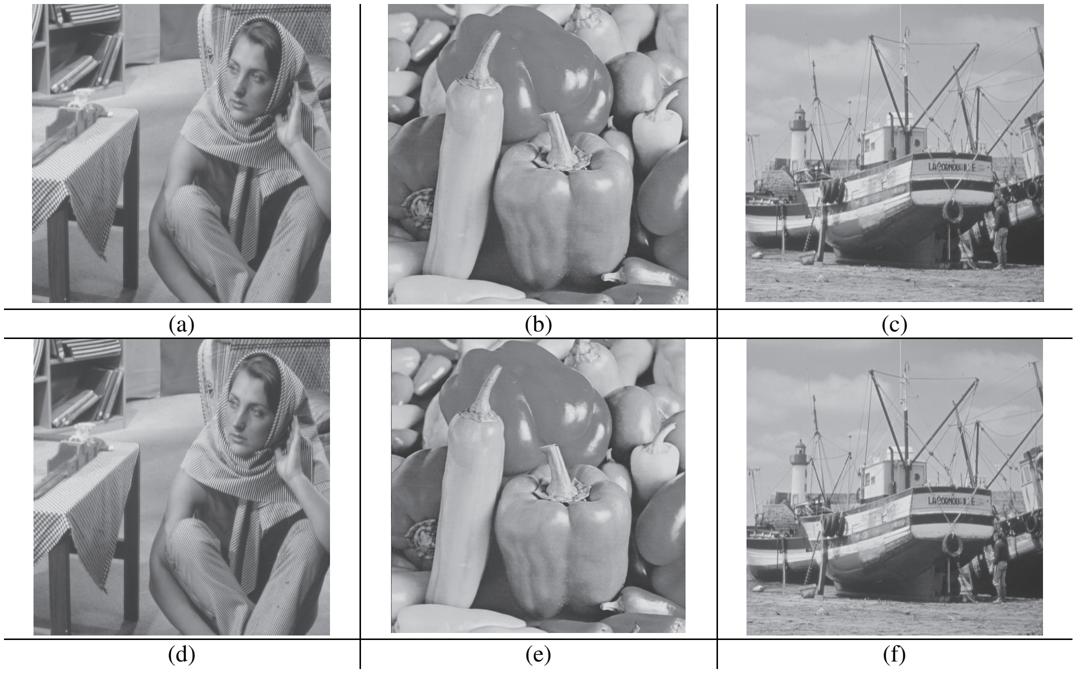

Fig. 2. Original (a)-(c) and watermarked (d)-(f) images of *Barbara* with PSNR=61.23, *Pepper*s with PSNR= 58.09, and *Boat* with PSNR= 56.31, respectively.

III. SIMULATION RESULTS

We have performed experiments on a set of 512×512 test images to evaluate the imperceptibility of the embedded watermark in the wavelet-based contourlet domain as well as the robustness of the proposed scheme against attacks. In order to assess the imperceptibility of the watermarked image, the peak signal-to-noise-ratio (PSNR) between the original and watermarked images is computed. Fig. 2 illustrates the original and watermarked images obtained using the proposed scheme for three of the test images, namely, *Barbara*, *Peppers* and *Boat*, with PSNR values equal to 61.23, 58.09, and 56.31 dB, respectively. The high PSNR values indicate that the watermark invisibility is fulfilled. In order to investigate the effect of the quantization step on the performance of the proposed watermarking scheme, PSNR values are obtained by varying the quantization step value from 1 to 100. Fig. 3 shows PSNR values as a function of the quantization step for a directional subband of the *Lena* image. It is seen from this figure that by increasing the quantization step, PSNR values decrease. It is also seen that the best value of the quantization step is less than 10. In a similar manner, we obtain the quantization step values for other test images.

The performance of the proposed watermarking scheme is compared to that of the schemes in [8], [11] and [12] in terms of bit error rate (BER) values when the watermarked images undergo different kinds of attacks.

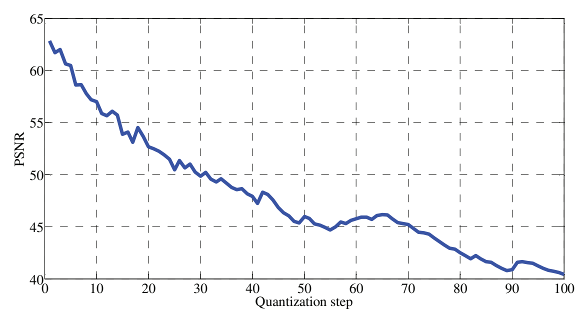

Fig. 3. PSNR vs. quantization step for a directional subband of *Lena* image.

TABLE I
BER (%) RESULTS OBTAINED USING THE PROPOSED WATERMARKING SCHEME AND THAT OF [11] AGAINST GAUSSIAN NOISE WITH VARIOUS NOISE LEVELS FOR A FEW OF THE TEST IMAGES. (MESSAGE LENGTH = 128 BITS)

	Proposed		[11]	
	$\sigma_n = 20$	$\sigma_n = 30$	$\sigma_n = 20$	$\sigma_n = 30$
Barbara	9.31	18.29	12.87	26.59
Baboon	8.69	15.73	12.48	26.28
Peppers	10.37	18.91	13.47	25.92
Lena	10.98	17.41	13.52	26.39

TABLE II
BER (%) RESULTS OBTAINED USING THE PROPOSED WATERMARKING SCHEME AND THAT OF [8] UNDER VARIOUS ATTACKS FOR A FEW OF THE TEST IMAGES. (MESSAGE LENGTH = 256 BITS)

	Median filter 3×3		JPEG, QF=11		AWGN, σ_n = 10	
	Prop.	[8]	Prop.	[8]	Prop.	[8]
Barbara	9.26	19.52	14.61	20.11	6.19	11.47
Baboon	8.46	17.38	12.19	15.23	4.15	6.13
Peppers	5.11	8.30	9.78	11.65	4.01	3.62
Lena	4.35	6.24	11.94	15.81	4.47	5.01

TABLE III
BER (%) RESULTS OF THE PROPOSED SCHEME AND THAT OF [12] AGAINST JPEG COMPRESSION (QF = 20) COMBINED WITH SCALING AND MEDIAN FILTER ATTACKS FOR A FEW OF THE TEST IMAGES. (MESSAGE LENGTH = 128 BITS)

	Proposed		[12]	
	Scaling (0.75)	Median filter 5×5	Scaling (0.75)	Median filter 5×5
Barbara	10.2	11.5	14.99	15.64
Baboon	4.92	8.19	4.62	10.70
Peppers	5.15	5.23	7.49	3.57
Boat	8.60	9.67	11.38	12.11

Table I gives BER values obtained using the proposed scheme and that of the scheme in [11] when the watermarked images are contaminated by the additive white Gaussian noise with σ_n = 20 and 30. From this table, it is seen that the proposed scheme in the wavelet-based contourlet domain is more robust than that in [11] against Gaussian noise attack. Table II gives BER values obtained using the proposed scheme and that of the scheme in [8] when the watermarked images contain a 256-bit message and undergo median filtering with a mask of size 3×3, JPEG compression with quality factor (QF) = 11 and Gaussian noise with σ_n =10. It can be seen from this table that compared to the scheme in [8], the proposed scheme is more robust against various attacks. Table III gives BERs obtained using the proposed watermarking scheme and that provided by the scheme in [12] when the watermarked images are JPEG-compressed by QF = 20 combined with median filtering with a window of size 5×5 or scaling attack with scaling factor of 0.75. It is seen from this table that the proposed scheme is more robust than the scheme in [12] against combinational attacks.

IV. CONCLUSION

A blind watermarking scheme in the wavelet-based contourlet domain has been proposed. The original image has been first decomposed by the wavelet transform and the subband with the highest entropy has been selected to be further decomposed by the directional filter bank structure. To embed the watermark, the singular values of the directional subband coefficients are quantized. The performance of the proposed watermarking scheme has been studied and compared to that of some of the existing schemes against various attacks such as JPEG compression, median filtering, scaling and Gaussian noise. It has been shown that the proposed scheme provides lower bit error rate values than other schemes do, indicating its more robustness.

REFERENCES

[1] H. Sadreazami, and M. Amini, “A robust spread spectrum based image watermarking in ridgelet domain,” *International Journal of Electronics and Communications,* vol. 66, no. 5, pp. 364-371, 2012.

[2] H. Sadreazami, M. O. Ahmad and M. N. S. Swamy, “A study of multiplicative watermark detection in the contourlet domain using alpha-stable distributions,” *IEEE Transactions on Image Processing,* vol. 23, no.10, pp. 4348-4360, 2014.

[3] M. N. Do and M. Vetterli, “The contourlet transform: an efficient directional multiresolution image representation,” *IEEE Transactions on Image Processing*, vol. 14, no. 12, pp. 2091-2106, 2005.

[4] P. Mitra, R. Gunjan and M. Gaur, “A multi-resolution watermarking based on contourlet transform using SVD and QR decomposition,” in *Proc. IEEE International Conference on Recent Advances in Computing and Software Systems,* pp. 135-140, 2012.

[5] H. Sadreazami, and M. Amini, “Highly robust image watermarking in contourlet domain using singular value decomposition,” in *Proc. International Conference on Signal Processing (ICSP),* pp. 628-631, 2012.

[6] H. Song, S. Yu, and C. Wang, “Contourlet-based image adaptive watermarking,” *Signal Processing, Image Communication*, vol. 23, pp. 162-178, 2008.

[7] F. Rahimi and H. Rabbani, “A dual adaptive watermarking scheme in contourlet domain for DICOM images”, *BioMedical Engineering OnLine*, vol. 10, no. 53, pp. 1-18, 2011.

[8] M. Hamghalam, S. Mirzakuchaki and M. Akhaee, “Robust image watermarking using dihedral angle based maximum-likelihood detector,” *IET Image Processing*, vol. 7, no. 5, pp. 451-463, 2013.

[9] R. Eslami and H. Radha, “Wavelet based contourlet transform and its application to image coding,” in *Proc. International Conference on Computer Vision,* pp. 1208-1213, 2005.

[10] R. H. Bamberger and M. J. T. Smith, “A filter bank for the directional decomposition of images: Theory and design,” *IEEE Transactions on Signal Processing*, vol. 40, no. 4, pp. 882-893, 1992.

[11] A. Akhaee, S. Sahraeian, B. Sankur and F. Marvasti, “Robust scaling-based image watermarking using maximum-likelihood decoder with optimum strength factor,” *IEEE Transactions on Multimedia*, vol. 11, no. 5, pp. 822-833, 2009.

[12] E. Nezhadarya, Z. J. Wang and R. K. Ward, “Robust image watermarking based on multiscale gradient direction quantization,” *IEEE Transactions on Information Forensics and Security*, vol. 6, no. 4, pp. 1200-1213, 2011.